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Vol. 13, No. 1, pp. 1-7 December, 20, 1921

LOWER AND MIDDLE CAMBRIAN FORMATIONS OF THE MOHAVE DESERT

BY
CLIFTON W. CLARK

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INTRODUCTION

Paleozoic sedimentary rocks are exposed in Bristol Mountain[1] in Mojave Desert near the town of Cadiz on the Santa Fé railroad, about 100 miles east of Barstow, California. Darton[2] first described these rocks in 1907 and again in the Santa Fé Railroad Guide in 1915.[3]

In 1915, Mr. O. A. Cavins, a student in the University of California, while studying the geology of this region, discovered a shale bed containing Lower Cambrian fossils. From the study of a small collection made by Mr. Cavins the writer became interested in the region and spent about two weeks visiting various exposures and obtaining a collection representing the fauna.

[1] The Iron Mountains referred to by Darton in the Santa Fé Railroad Guide for 1915, will be called in this paper Bristol Mountain, the name given to the range on the official map of San Bernardino County. This map also gives to the lake at Amboy, 14 miles west of Cadiz, California, the name, Bristol Lake.

[2] Jour. of Geol. vol. 15, p. 470, 1907.

[3] U. S. Geol. Surv. Bull. No. 613, Part C, Santa Fé Route, 1915.

Bristol Mountain is a long, low range of hills or ridges composed of igneous and sedimentary rocks representing various geologic ages. The sediments range in age from Lower Cambrian to Carboniferous. The mountain is about 20 miles long and from 1 to 3 miles wide, the highest peaks reaching an elevation of 1000 to 1300 feet above the desert plain. It is situated on the north side of a great dry lake basin, the lowest point of which is near the town of Amboy. Just south of this town there are extensive beds of salt and gypsum which were left as a deposit when the lake became dry. How large this lake was is not known, but the country slopes toward the saline deposit for many miles on all sides except the southeast.

Sedimentary rocks very similar to those in Bristol Mountain are present in a number of other ranges in this region, but most of them have suffered more intense metamorphism. The character of the sediments and the fauna contained in them indicate that these formations may be correlated with those described by Darton in the Providence Range to the north and also with those of the Highland Range in Nevada. The Providence Range was not visited owing to the limited time allotted to the work. The study of the section in Bristol Mountain, together with more detailed collecting in other exposures of sedimentary rocks in this region, should add many facts to our knowledge of the Paleozoic of the Great Basin.

OCCURRENCE OF FORMATIONS

The writer has visited localities in the Ship Mountains, the Marble Mountains, and the Clipper Mountains, but no fossils were found in these ranges. All the fossils referred to in this paper were obtained in Bristol Mountain. Paleozoic strata occur at two localities in this range. At the southern end their exposure extends to the northwest for about two miles to a point where they have been entirely stripped from the underlying granite by erosion. From this point granite and Tertiary lavas make up the range, forming low rounded hills for three or four miles toward the northwest to a point where the granite is again overlain by Cambrian strata. Here the exposure of Paleozoic rocks begins just north of a deep cañon which transects the range. The rocks extend toward the northwest overlying the pre-Cambrian granite for a distance of about three miles, beyond which they have been cut off abruptly by a large post-Carboniferous granitic mass. Although the range was not visited farther north, the writer was informed by a resident of the district that the whole of the northern end is composed of igneous rock.

GEOLOGICAL RELATIONS

The sedimentary formations in Bristol Mountain rest on pre-Cambrian granite and dip at a high angle to the east, passing under Tertiary eruptive rocks. They comprise quartzite, sandstone, shale, conglomerate, and limestone in a conformable series. A repetition of this series across the strike of the formations has resulted from local faulting, which is very common; and step faulting is well exemplified at various localities. A good example of the effect of step faulting is shown in the western end of the exposure of sedimentary rocks in the Ship Mountains and also in the southern end of Bristol Mountain.

The Invasion of Marine Waters.—The invasion of marine waters in early Cambrian time is well known in the Cordilleran geosyncline. It began early in the period, entering the continent at about the latitude of the present Gulf of California, passing inward across southern California and across Nevada toward the north for several hundred miles. This sea probably connected with the Arctic Ocean. This portion of the continent transgressed by the early Cambrian sea was far advanced in the geomorphic cycle, the country being a peneplain. The surface of the basal complex, which is granite in the area studied, is fresh and is entirely devoid of any regolith. The sea probably advanced slowly over southern California and the wave action removed the regolith, depositing the quartz as sandstone near the strand line on the smooth wave cut surface of the fresh granite complex; while the remaining granite materials were pulverized to fine sediments, carried farther out to sea and deposited as mud overlying the sands.

Pre-Cambrian Granite.—The pre-Cambrian granite is the oldest rock in the region and underlies the sedimentary formations. It outcrops along the western border of Bristol Mountain where overlain by Paleozoic strata, but at other places where not covered by Tertiary lavas it forms a considerable part of the range.

According to Cavins,[4] the principal minerals of the granite are crystals of orthoclase which are an inch or more in length, quartz, and brown biotite. The quartz and feldspar constitute about 90 per cent of the rock, being present in the proportion of about one to two.

Lower Cambrian.—The lower Cambrian is composed of a thick bed of quartzite at the base, resting on a worn surface of the pre-Cambrian

[4] Bachelor's thesis, University of California, 1915.

granite. Although no fossils were found in this quartzite it is probably Cambrian in age. About 10 feet above the base of the quartzite there is a 10-foot bed of conglomerate, composed of quartz pebbles in a quartzite matrix. The lowest 2 or 3 feet of quartzite are usually cross-bedded and often contain feldspar fragments, but the greater part of the stratum is made up of well sorted and rounded quartz grains firmly cemented together. An arenaceous shale having an average thickness of 22 feet rests conformably on the surface of the quartzite. It contains numerous beds of quartzite from 1 to 3 inches thick and is highly fossiliferous. A bed of very hard, dark blue to black, nodular limestone or marble lies conformably above the shale and is quarried for marble in several places. Although no fossils were found in this limestone it is considered to be the upper limit of the Lower Cambrian.

Middle Cambrian.—The Middle Cambrian, as determined by a few fossils, consists of a massive arenaceous shale resting conformably on the nodular blue limestone. The shale is light gray to brown or black, and contains numerous beds of quartzite and calcareous sandstone. Although a careful search was made for fossils in this shale the writer was unable to find any; but Mr. Cavins, at the request of the writer, revisited the region and found a few specimens of the *trilobite Bathyuriscus* about 12 feet from the top of the shale bed.

Carboniferous.—The Carboniferous is represented by a thick bed of massive limestone or marble which rests apparently conformably on the Middle Cambrian shale. A few fragments of fossils consisting of very poorly preserved, rounded, crinoid stems and faint impressions of coral were found on the upper surface of the limestone. Mr. Darton[5] reports numerous fossils which he found in the upper part of this limestone that definitely place it in the Carboniferous. Owing to the massive character of the entire bed of limestone, notwithstanding the lack of fossils in the lower portion, it is all included in the Carboniferous.

[5] Personal communication.

BRISTOL MOUNTAIN SECTION

The Bristol Mountain section represents the section of Paleozoic sedimentary rocks present in Bristol Mountain northeast of Cadiz, California. The sediments range in age from Lower Cambrian to Carboniferous and are present in two localities in the range; one near the southern end, or about two and one-half miles northeast, and the other about five miles due north of Cadiz, San Bernardino County, California.

	Estimated thickness in feet
Carboniferous:	
White to gray or brown limestone which in many places is partially crystalline while in others, where metamorphism has been more intense, is altered to marble	635
Middle Cambrian:	
Light gray to brown or black arenaceous shale containing numerous thin beds of sandstone and quartzite	120
Lower Cambrian:	
Dark brown to blue, or black nodular limestone or marble, which is very hard and is largely made up of nodules that weather out and lie scattered over the surface	25
Fine arenaceous shale containing numerous thin beds of sandstone and quartzite, replete with Lower Cambrian fossils	22
Quartzite composed of well sorted quartz grains firmly cemented together	450
Conglomerate composed of rounded quartz pebbles imbedded in a quartzite matrix	10
Quartzite composed of well rounded quartz grains, cross-bedded near the base, where it contains numerous fragments of feldspar; lies unconformably on an erosional surface of the pre-Cambrian granite	10
Total section, feet	1,272

FAUNAS

The fauna obtained from Bristol Mountain consists of several species of trilobites and one species of brachiopod. All of the trilobites with the exception of the Middle Cambrian form, *Bathyuriscus,* were found in a thin bed of arenaceous shale in the Lower Cambrian and all the species were so intimately associated that fragments of thoracic segments could not definitely be differentiated. A similar confusion was encountered in attempting to distinguish between fragments of the hypostoma, consequently several of the species are based on the cephalon only.

Lower Cambrian.—The fauna of the Lower Cambrian consists of four species of trilobite and one brachiopod. These forms represent the upper part of the Lower Cambrian or the Olenellus zone.

FAUNA OF THE LOWER CAMBRIAN

Mesonacis gilberti, Meek.
Olenellus fremonti, Walcott.
Callavia = C.? nevadensis, Walcott.
Wanneria? cadizensis, n. sp.
Micromitra (Paternia) prospectensis, Walcott.

Middle Cambrian.—Only one species that could be definitely determined was found in the Middle Cambrian. Two or three specimens similar to *Bathyuriscus howelli* were found near the top of the massive shale of the Middle Cambrian. This species is probably new, but the cephalons of all the specimens were crushed so that the original characters could not be accurately determined. It is referred to *B. howelli* as it has eight thoracic segments and seems to correspond to this species excepting in the fifth segment, which is broader than any of the others and terminates in a long spine that curves well back toward the pygidium. It is therefore called *B. howelli* var. *lodensis.*

Carboniferous.—The carboniferous is represented by numerous fragments of rounded crinoid stems and faint outlines of corals together with indeterminable organic remains. According to Mr. Darton, the Carboniferous also contains *Spirifer rockymontanus, Michelina,* sp., *Cliothyridina?,* sp., etc.

CORRELATION

The Cambrian section of the Mojave Desert may possibly be correlated with the Cambrian of central and eastern Nevada. According to Wallcott,[6] *Olenellus* is found in a thin bed of shale lying just above a massive quartzite in several localities in Nevada, notably in the Eureka District, in the Highland Range, and also in the Big Cottonwood section of Utah. This shale is near the top of the Lower Cambrian in the localities just mentioned and in the Mojave region it appears to have a similar position.

The Lower Cambrian quartzite in Bristol Mountain rests on an erosional surface of pre-Cambrian granite. In many of the sections of the Great Basin containing Cambrian sediments, the bottom of the sedimentary series is not exposed, but, according to Hershey,[7] the Lower Cambrian just west of Clover Valley in eastern Nevada rests on pre-Cambrian granite and schists. Spurr[8] thinks that probably much of the Cambrian in northeastern Nevada is underlain by pre-Cambrian igneous rocks. However, he states that some granites which have been supposed to be pre-Cambrian have upon investigation been proved to be later intrusives. In the Mojave Desert region these later or post-Carboniferous granites are abundant and have been the principal cause of the metamorphism, but the pre-Cambrian granites and schists occur in large areas and are cut by the later granite.

The writer is indebted to Dr. C. D. Walcott for very kindly reviewing the manuscript of this paper.

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[6] U. S. Geol. Surv. Bull. No. 81, 1891.

[7] Am. Jour. Sci. Ser. 4, vol. 34, p. 267, 1912.

[8] U. S. Geol. Surv. Bull. No. 208, p. 27, 1903.

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December 22, 1921

NOTES ON PECCARY REMAINS FROM RANCHO LA BREA

BY
JOHN C. MERRIAM AND CHESTER STOCK

NOTE ON AN HIPPARION TOOTH FROM THE SIESTAN DEPOSITS OF THE BERKELEY HILLS, CALIFORNIA

BY
CHESTER STOCK

UNIVERSITY OF CALIFORNIA PRESS
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BY
JOHN C. MERRIAM AND CHESTER STOCK

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INTRODUCTION

Study of the collections of Pleistocene mammals obtained by the University of California from the asphalt deposits of Rancho La Brea has revealed a single astragalus belonging to a peccary. Later excavations at Rancho La Brea conducted by the Los Angeles Museum of History, Science and Art under the direction of the late Dr. Frank S. Daggett have brought to light additional remains of the dicotyline group of mammals, among which are a fairly preserved skull and some incomplete limb elements. These are now in the palaeontological collections of the Los Angeles Museum and afford a better opportunity than does the single astragalus to secure needed information concerning the group in the Pleistocene of California.

Infrequency of occurrence of peccaries in the asphalt beds lends special interest to the record of their presence, and may be of greater or less significance in an interpretation of problems relating to the Rancho La Brea fauna. The completeness of the record of Pleistocene mammalian life in western North America as offered by the collections from Rancho La Brea makes it desirable to ascertain the status of the more uncommon types occurring in the asphalt beds, particularly of forms closely related to species met with in other Pleistocene deposits.

PLATYGONUS, possibly n. sp. or n. subsp.

Skull

The skull, no. 4400, L. A. M. H. S. A.,[1] from Rancho La Brea possesses the facial region including the palate and superior dentition. The posterior portion of the specimen has suffered much loss, but on the left side there remain structures around the orbit and posterior to the glenoid fossa that furnish some information of this region of the cranium. At the anterior end of the snout the nasals are broken away. The teeth, with exception of M^1 and M^2, show a moderate degree of wear. M^2 and particularly M^1 are well worn, as is also the anterior edge of the superior canine.

Specimen 4400 is definitely referable to the genus *Platygonus.* The diastema between superior canine and P^2 is not characterized by great length as in *Mylohyus,* but is slightly longer than in *Tayassu.* It reaches a length slightly greater than that of the premolar series. Two incisors are present in each premaxillary, their alveoli indicating that the forward or medial incisor was very large while the posterior or lateral tooth, situated immediately behind the former, was much smaller. P^4 is not molariform. Although the cheek-tooth series has been subjected to attrition, the cusps of the individual teeth seem to be characterized by a more prominent development than in teeth of *Tayassu.*

The specimen available from Rancho La Brea agrees fairly closely in size with peccary skulls from the Pleistocene of Kansas described by Williston[2] under the species *Platygonus leptorhinus.* It likewise compares favorably in this character with skull specimens referred to *P. compressus.* In no. 4400 a shallow fossa is present above and behind the posterior margin of the exit of the infra-orbital canal, while a deeper fossa is located in front of the opening. Fossae comparable to these are noted by Williston in a female skull of *P. leptorhinus,* but are lacking, according to Wagner,[3] in the skull of *P. compressus* from the Pleistocene of Michigan. While the groove or sulcus that extends along the lateral side of the snout is present in the California skull, a continuation of the groove can not be traced to the top of the skull because of the destruction of the greater portion of the dorsal

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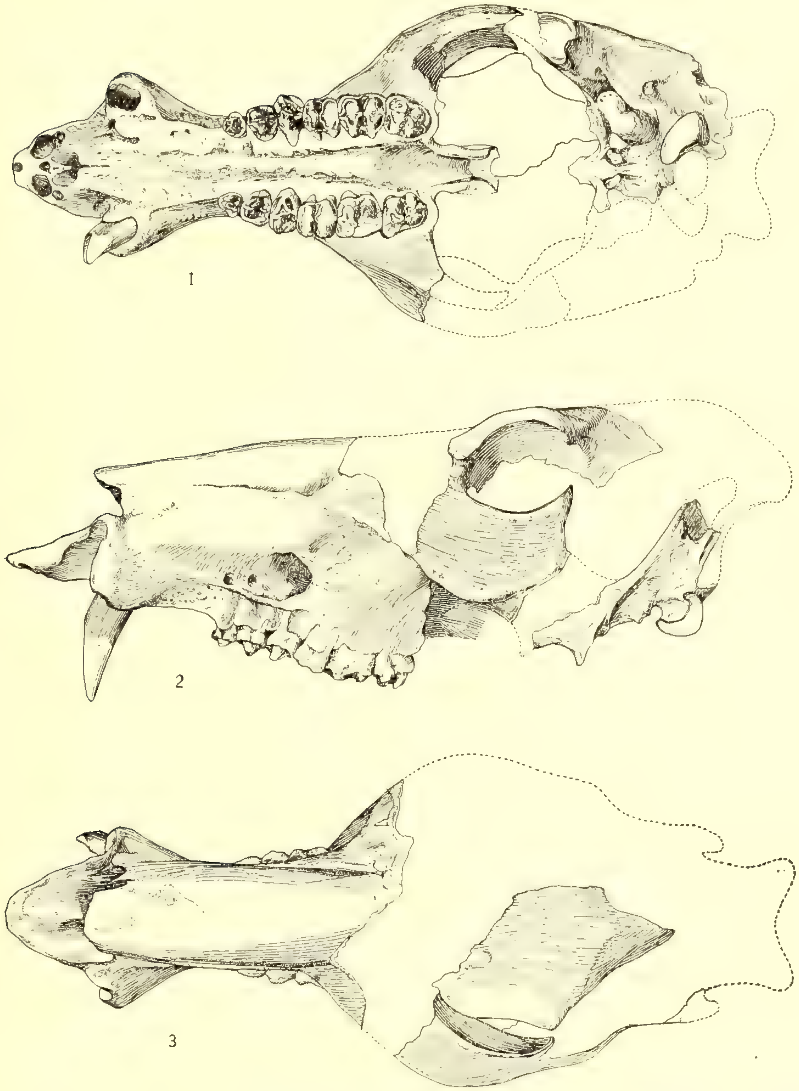
[1] Los Angeles Museum of History, Science and Art, Los Angeles, Calif.

[2] Williston, S. W., Restoration of Platygonus. Kansas Univ. Quar., vol. 3, pp. 23–39, pls. 7 and 8, 1894.

[3] Wagner, G., Observations on Platygonus compressus Le Conte. Jour. Geol., vol. 11, pp. 777–782, figs. 1–4, 1903.



Figs. 1, 2, and 3. *Platygonus*, possibly n. sp. or n. subsp. Skull, no. 4400, L. A. Mus. Hist. Sci. and Art Coll. $\times \frac{1}{3}$. Fig. 1, lateral view; fig. 2, ventral view; fig. 3, dorsal view. Rancho La Brea beds.

surface. A scar on the preserved part of the frontal suggests the end of the groove of the left side. If this does represent the dorsal termination, the latter is situated somewhat closer to the rim of the orbit than in *P. leptorhinus* or in *P. compressus.* Judging from the small portion of the parietal that remains, the dorsal margin of the temporal fossa was apparently not prominent in the specimen from Rancho La Brea. The depth of the malar below the orbit in the skull from the asphalt deposits is exceeded by the corresponding measurement in a single skull of the Kansas series. It is deeper than in the specimens from Rochester, New York, determined by Leidy[4] as belonging to *P. compressus.* The malar is only slightly deeper in no. 4400 than in the Michigan specimen of *P. compressus.*

The Rancho La Brea species, in shortened diastema, approximates more closely the modern peccaries than do other forms of *Platygonus* from the Pleistocene of North America. In no. 4400, however, the diastema between the canine and the cheek teeth is distinctly longer than in *Tayassu,* and the length of the diastema approximates closely that of the upper premolar series. The diastema in the specimen from Rancho La Brea is much shorter than in the skull from Kentucky referred by Leidy[5] to *P. compressus* and in the Pleistocene peccary skulls from Rochester, New York. It is also shorter than in specimens referred to *P. leptorhinus* by Williston, and is distinctly shorter than in the skull of *P. compressus* described by Wagner. In skulls described by Leidy and by Williston the canine tuberosity seems always to extend farther dorsally along the side of the snout than in *Platygonus* from Rancho La Brea. The height of the canine tuberosity is not so great in no. 4400 as in the specimen from Michigan, while in both skulls the height equals the length of the post-canine hiatus.

Between the alveoli for the medial incisors a canal extends forward from the anterior palatine foramen. The palate in the specimen from the asphalt beds is not so broad as that of *P. alemani* from the Pleistocene of Mexico. The median portion of the palate behind M^2 reaches upward to the postnarial notch, the angle which this slope makes with the plane of the palate being greater than in *Tayassu.* The anterior tuberosities of the basioccipital are separated in median line by a wider groove than in *P. leptorhinus,* and the lateral arm of the basisphenoid, which joins with the alisphenoid, lies more in advance of the contact between basioccipital and basisphenoid than in the Kansas

[4] Leidy, J., On Platygonus, an extinct genus allied to the peccaries. Trans. Wagner Free Inst. Sci., vol. 2, pp. 41–50, pl. 8, fig. 1, 1889.

[5] Leidy, J., Trans. Amer. Philos. Soc., vol. 10, pp. 330–341, pls. 36 and 37, 1853.

form. The comparisons of basioccipital and basisphenoid have been made, however, with only a single specimen of *P. leptorhinus* in the collections of the University of California.

Dentition

The shape of the superior premolar teeth, subject to some variation in *P. compressus,* does not seem to offer a suitable character for diagnostic purposes. In the more fundamental characters relating to structures of the tooth crown, the teeth in the Rancho La Brea skull resemble closely those of *P. leptorhinus* and of *P. compressus.* The superior premolar-molar series in no. 4400 from Rancho La Brea is longer than in specimens of *P. compressus* and *P. leptorhinus,* although this difference is slight. The cheek teeth approximate very closely in length the upper series of *P. alemani* from Mexico. The first and second molars in the California specimen are slightly larger than in the Kansas skulls, while measurements of M^3 may be exceeded by those in the latter. P^4 is slightly larger than the corresponding tooth in the Kansas specimen. All the teeth in the California skull are smaller than those of *Platygonus vetus* when comparison is made with the measurements given by Williston. With the exception of the anteroposterior diameter of M^3, the teeth are slightly larger than in *P. compressus* from Kentucky.[6]

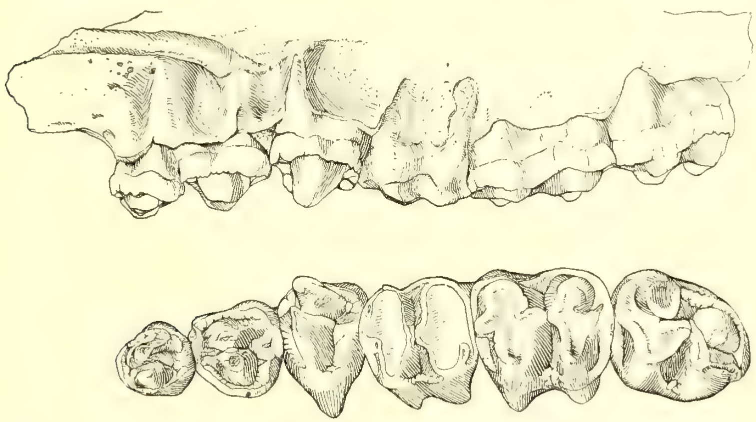


Fig. 4. *Platygonus,* possibly n. sp. or n. subsp. Superior cheek-tooth series, no. 4400, L. A. Mus. Hist. Sci. and Art Coll. × 1. Lateral and occlusal views. Rancho La Brea beds.

[6] Leidy, J., *op cit.,* 1853.

P^2 is subtriangular in horizontal section with the anterior side subacute, thus differing slightly from Leidy's specimens from Kentucky. Two cusps are developed on the crown, the inner one of which is somewhat the larger. A well defined cingulum is present, which is especially prominent on the postero-external side and is absent only at the base of the inner cusp.

P^3 is subquadrate with two cusps of nearly equal size. An incipient tubercle is present immediately behind the space between the two cusps. A cingulum is strongly developed around the entire tooth.

P^4 is shaped much as in *P. compressus.* Two nearly equal cusps are present on the crown with a tubercle, behind their interspace, slightly stronger than on the crown of P^3. This tooth is little worn. The structure of the crown of the tooth closely resembles that in *P. compressus* and in *P. leptorhinus.*

M^1 is much worn. No cingulum is present on the inner side of both protocone and hypocone, and this is true also for the two posterior molars. In M^2 a well developed cingulum is present along the anterior border. This ledge is more prominently formed along the posterior base of the hypocone than in the corresponding tooth of *P. leptorhinus.*

In M^3 the anterior pair of cusps is larger than the posterior pair and the anterior transverse ridge is wider transversely than the posterior one. A cingulum is strongly developed along the anterior border and along the outer posterior border from the paracone to the hypocone.

Measurements of Skull

Length measured from anterior end of premaxillary to anterior margin of foramen magnum	*a*255	mm.
Length of palate	181	
Length of anterior end of canine tuberosity to posterior margin of infra-orbital fossa	84	
Vertical height from palate to top of skull, measured at posterior margin of infra-orbital fossa	82.7	
Vertical height from palate between canines to top of nasals	50.5	
Width across glenoid fossae	*a*128	
Width across postorbital processes	*a*88	
Width at middle of zygomatic arches	*a*124	
Width of face at posterior margins of infra-orbital fossae	46	
Width of snout above M^2	44	
Width between outer walls of canine alveoli	73	
Width of palate measured between postero-internal roots of M^1	23	
Width of palatal portion of palatine immediately behind M^3	18.5	
Width of premaxillaries at anterior end	38.5	
Dorso-ventral depth of orbit	*a*36.7	
Greatest depth of zygomatic arch below orbit	41.7	

Length of diastema between C and P^2	36.7
Least distance between alveolar borders of lateral incisor and canine	20.3
Height of canine tuberosity	36.7

a, approximate.

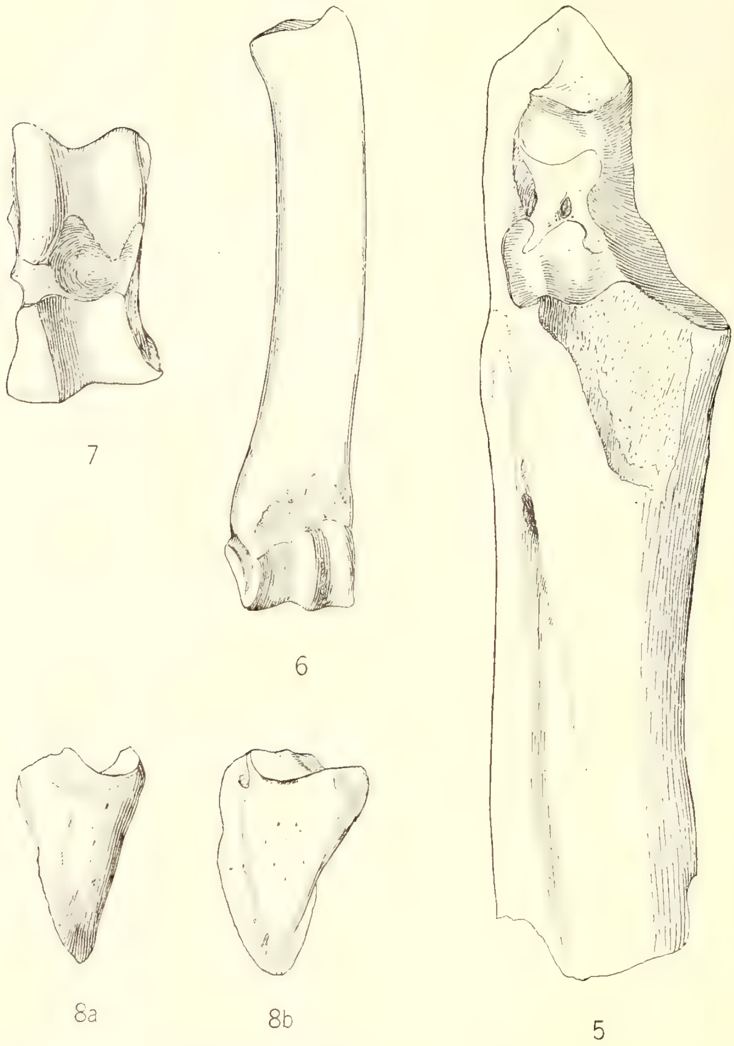
Measurements of Superior Dentition

Length, anterior end of alveolus for medial incisor to posterior side of M^3	162 mm.
Length, anterior side of canine to posterior side of M^3	134.4
Length, anterior side of P^2 to posterior side of M^3	82.2
Length of premolar series, P^2 to P^4 inclusive	32.8
Length of molar series	50
Superior canine, anteroposterior diameter	*a*15.5
Superior canine, transverse diameter	8.4
P^2, anteroposterior diameter	9.2
P^2, transverse diameter	10
P^3, anteroposterior diameter	11.4
P^3, transverse diameter	12.4
P^4, anteroposterior diameter	11.5
P^4, transverse diameter	14.2
M^1, anteroposterior diameter	14.5
M^1, transverse diameter	13.4
M^2, anteroposterior diameter	18.8
M^2, transverse diameter	15.7
M^3, anteroposterior diameter	17.3
M^3, transverse diameter	15

a, approximate.

Limb Elements

A proximal portion of the fused radius and ulna (fig. 5) agrees in size with *Platygonus leptorhinus* so far as this is indicated by the preserved specimen from Rancho La Brea. A fourth metacarpal, no. 4403 (fig. 6), is slightly shorter than the corresponding element in *P. leptorhinus.* The metapodial exhibits a small facet along the inner proximal margin for the third metacarpal. A small contact surface was possibly present at the proximo-lateral end which is now broken away. A single astragalus, no. 24066, Univ. Calif. Coll. Palae. (fig. 7), is somewhat smaller than the corresponding element in *P. leptorhinus.* This specimen possesses proportions similar to those of the astragalus in the Kansas species. An ungual phalanx (figs. 8*a*, 8*b*) presumably belongs to this dicotyline species from the asphalt deposit. In shape it much resembles the toe bones of *Platygonus.* The ventral surface is broad and flat. In lateral aspect (fig. 8*a*) the dorsal surface is seen to be inclined at an angle of approximately 27° to the horizontal plane of the ventral surface.



Figs. 5 to 8*b*. *Platygonus*, possibly n. sp. or n. subsp. Limb elements. × 1. Fig. 5, proximal portion of radius-ulna, no. 4402, anterior view; fig. 6, fourth metacarpal, no. 4403, anterior view; fig. 7, astragalus, no. 24066, dorsal view; figs. 8*a* and 8*b*, ungual phalanx, no. 4401, lateral and dorsal views. Nos. 4401, 4402, and 4403 in L. A. Mus. Hist. Sci. and Art Coll.; no. 24066 in Univ. Calif. Palae. Coll. Rancho La Brea beds.

MEASUREMENTS

Radius-ulna, no. 4402:	
Greatest transverse width of articulating surface for humerus	30.3 mm.
Least width of joined radius and ulna	27
Fourth metacarpal, no. 4403:	
Greatest length	80.1
Least width of shaft	12
Least anteroposterior diameter of shaft	12.8
Ungual phalanx, no. 4401:	
Anteroposterior diameter	28.3
Greatest proximal width	14.3
Greatest height	19.2
Astragalus, no. 24066:	
Greatest length along inner side	34.4
Greatest width of distal end	22.2
Least width across dorsal surface at distal end of trochlea for tibia	15.8

CONCLUSION

The information gained from a study of peccary remains from Rancho La Brea, consisting of a fragmentary skull, the superior dentition, and a few skeletal parts, indicates the presence there of the genus *Platygonus.* A close relationship exists between the species from the asphalt beds and *P. compressus* and *P. leptorhinus.* Certain characters of the skull suggest, however, the possibility of specific or subspecific separation from other known American forms.

UNIVERSITY OF CALIFORNIA PUBLICATIONS
BULLETIN OF THE DEPARTMENT OF
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NOTE ON AN HIPPARION TOOTH FROM THE SIESTAN DEPOSITS OF THE BERKELEY HILLS, CALIFORNIA

BY
CHESTER STOCK

Few remains of mammals are known from the Orindan and Siestan Pliocene deposits of the Berkeley Hills although diligent search for such material has been carried on from time to time during the past quarter of a century. The Orindan and the Siestan in the region of Mount Diablo have yielded likewise but scattered collections.[1] Among the more important specimens from the Orindan near Mount Diablo are several fragmentary teeth of horses of the *Hipparion* group. Recently, Professor G. D. Louderback secured a tooth of an *Hipparion* in a fresh-water limestone lentil of the Siestan on the east side of Bald Peak, in the Berkeley Hills. In the section the limestone forms part of a sedimentary series that includes also clay beds from which have been described remains of the beaver, *Dipoides lecontei.*[2]

The upper tooth, no. 24241, figure 1, discovered by Professor Louderback belongs to the premolar series. The Siestan specimen is slightly curved and possesses a fairly heavy coating of cement. In no. 24241 the parastyle and mesostyle are prominent. The borders of the fossettes show considerable crinkling. The enamel folds of the prefossette are particularly deep and numerous. The protocone narrows anteriorly and posteriorly, no. 24241 differing in this character from *Hipparion platystyle* and resembling certain teeth of *Hipparion* from the Ricardo Pliocene deposits of the Mohave Desert, California.

[1] Merriam, J. C., Vertebrate fauna of the Orindan and Siestan Beds in Middle California. Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, pp. 373–385, 1913.

[2] Merriam, J. C., Sigmogomphius lecontei, a new castoroid rodent from the Pliocene near Berkeley. Univ. Calif. Publ. Bull. Dept. Geol., vol. 1, pp. 363–370, 1896.

No. 24241 is moderately worn but is slightly smaller than premolar teeth of *Hipparion mohavense* from the Ricardo. The enamel pattern in the specimen from the Siestan resembles somewhat that in teeth of *H. mohavense.* The protocone approaches perhaps most nearly that in teeth of *H. mohavense callodonte* from the Ricardo Pliocene.

The single tooth from Orindan deposits southwest of Mount Diablo, regarded by J. C. Merriam[3] as the type of the species *Hipparion platystyle,* differs as much from the Siestan specimen as it does from teeth

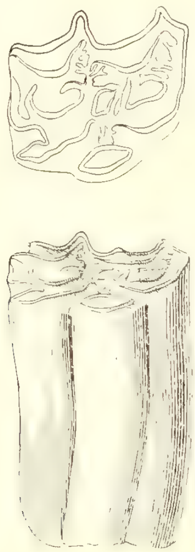

Fig. 1. *Hipparion,* near *mohavense* Merriam. P^4?, no. 24241, inner and occlusal views, × 1. Siestan Pliocene, Berkeley Hills, California.

of *Hipparion mohavense.* According to Dr. Merriam, *H. platystyle* approaches closely the *Hipparion* forms from the Mohave Desert. A second fragmentary specimen, no. 1324, apparently from Orindan beds near Bolinger Cañon, is regarded by Dr. Merriam[4] as representing a form near *Hipparion mohavense.* The prefossette in this specimen is narrow transversely, and the enamel border exhibits a number of plications. No. 1324 is a larger specimen than no. 24241. The protocone

[3] Merriam, J. C., New species of the Hipparion group from the Pacific Coast and Great Basin Provinces of North America. Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, p. 5, 1915.

[4] Merriam, J. C., *op. cit.,* vol. 7, p. 375, figs. 3*a,* 3*b,* 1913.
Merriam, J. C., Relationships of Pliocene mammalian faunas from the Pacific Coast and Great Basin provinces of North America. Univ. Calif. Publ. Bull. Dept. Geol., vol. 10, p. 426, 1917.

is short and wide, more as in typical *Hipparion mohavense,* and does not taper anteriorly and posteriorly as in the tooth from the Siestan beds.

The tooth from the Berkeley Hills suggests again that the horses occurring in the Orindan and Siestan deposits are related to forms found in the Lower Pliocene of California and are near to types known from the Ricardo beds of the Mohave Desert.

MEASUREMENTS

P^4?, anteroposterior diameter	22.6 mm.
P^4?, transverse diameter, exclusive of cement	21
P^4?, anteroposterior diameter of protocone	7.3

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PINNIPEDS FROM MIOCENE AND PLEISTOCENE DEPOSITS OF CALIFORNIA

A DESCRIPTION OF A NEW GENUS AND SPECIES OF SEA LION FROM THE TEMBLOR TOGETHER WITH SEAL REMAINS FROM THE SANTA MARGARITA AND SAN PEDRO FORMATIONS AND A RÉSUMÉ OF CURRENT THEORIES REGARDING ORIGIN OF PINNIPEDIA

BY
REMINGTON KELLOGG

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BY

REMINGTON KELLOGG

CONTENTS

INTRODUCTION

Although in paleontologic studies considerable information relating to marine invertebrates and land vertebrates of the Pacific Coast province has become available within the past few years, it is surprising how meager our knowledge remains regarding the fossil pinniped forms. The problems which members of this group present cannot be said to lack interest for the evolutionist, for much remains yet to be discovered concerning the derivation, descent, and adaptation of the marine carnivorous mammals. Nor does the present dearth of fossil pinniped material seem entirely warranted in the light of the extensive explorations for, and study of, the marine Pleistocene and, particularly, the Tertiary fauna of the west coast. While the preservation of remains of seals and allied forms may not have been so favorable, because of their mode of life, as that of invertebrate faunas, systematic search in marine deposits ought to reveal much valuable material. This seems an assured fact, considering the completeness of the Tertiary and Pleistocene marine sections, and the great geographic extent of the deposits.

The present study deals with small collections of pinniped remains that have been assembled in the Department of Paleontology, University of California, in the California Academy of Sciences and by the Geological Department of the Southern Pacific Railway Company. In a review of this material it became evident to the writer that obstacles making the problem of the pinnipeds difficult of approach were in a measure owing to the scattered nature of the literature and to confusion arising from the description and inaccurate determination of fragmentary material. A check list has therefore been added to facilitate future reference.

On the basis of the evidence afforded by the fossil pinniped described in this paper and by other previously described fossil forms, an attempt has been made to point out some of the problems involved in the evolution of the skeleton and teeth of this group together with a consideration of the phylogenetic relationships of the various genera.

ACKNOWLEDGMENTS

The writer wishes to acknowledge his indebtedness to Professor John C. Merriam for his assistance and the kindly interest which he has shown during the progress of the work, and to Dr. Roy E. Dickerson, of the California Academy of Sciences, for the loan of important additional material. The writer is also indebted to Dr. Chester Stock and Mr. E. L. Furlong for advice and criticism.

Acknowledgment is made here to the following for the loan of recent material for comparison contained in the institutions with which they are respectively connected: Mr. Gerrit S. Miller, United States National Museum; Mr. E. W. Nelson, Bureau of Biological Survey; Dr. Joseph Grinnell, Museum of Vertebrate Zoology, and Mr. Charles D. Bunker, Museum of the University of Kansas.

The major portion of the new material described in this paper is based on collections made by Mr. R. C. Stoner, Mr. Clarence L. Moody, and especially by Mr. Charles Morrice. The other material consists of an ulna collected near La Jolla by Professor T. D. A. Cockerell, portions of a mandibular ramus of a phocid collected near the northwest end of the Tejon Hills by Mr. B. L. Cunningham, and a canine from the Vaqueros formation, collected by O. A. Cavins.

To Mr. Walter Granger, of the American Museum of Natural History, and Mr. Francis Harper, of the Bureau of Biological Survey, the writer is under obligation for verifying certain references. All figures in the text were prepared by Mrs. Louise Nash.

DESCRIPTION OF NEW FORMS

Family Otariidae

Otarid remains are a rarity in all collections at the present writing and, so far as known, all the Miocene forms of North America are from the Pacific Coast. This material is of much significance because of the prophetic characters exhibited by it.

ALLODESMUS, n. gen.

ἄλλος, strange; δεσμός, bond.

Type specimen.—A right mandibular ramus, no. 275, Calif. Acad. Sci. coll., from the Temblor beds of the Kern River region, about 12 miles from Bakersfield, Kern County, California.

Referred specimens.—Teeth and skeletal element, also from the Temblor beds, near Bakersfield, California.

Characters.—Mandibular ramus massive. $M_{\bar{1}}$ large, with two roots. $M_{\bar{2}}$ reduced, with one root. Astragalus with shallow trochlea and astragalar foramen.

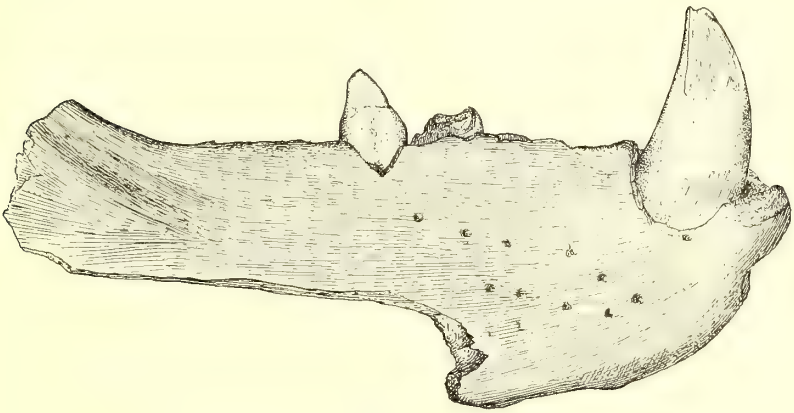
ALLODESMUS KERNENSIS, n. sp.

During one of the fossil-hunting trips of Mr. Charles Morrice, he was so fortunate as to find a right mandibular ramus (figs. 1*a*, 1*b*) which represents a new extinct pinniped evidently very closely allied to the existing otarids, though much more generalized. This specimen, together with a few teeth hereafter described, was presented by Mr. Morrice to the California Academy of Sciences and the authorities of that institution very generously allowed the writer to describe it along with the material which was presented by the same collector to the Department of Paleontology of the University of California.

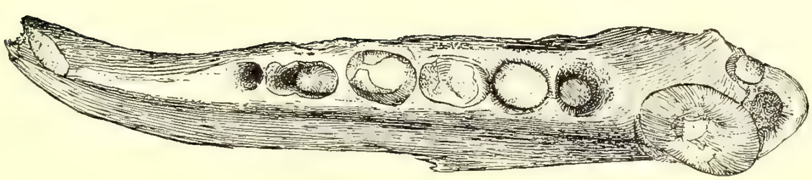
The horizontal ramus of the mandible is incomplete, with the ascending ramus broken off slightly posterior to the plane of coronoid; also the major portion of the inferior margin is missing. It is of considerable interest to note that this mandible is characterized by the great depth of the ramus behind the canine, thus differing very strongly from the Upper Miocene form *Prorosmarus alleni* which was described by Berry and Gregory[1] and interpreted by them as having certain characters which approached the Otariidae. On the whole it is suggestive of *Mirounga angustirostris* in the great depth of the horizontal ramus, the outline of the symphysis, and the anterior

[1] Berry, E. W., and Gregory, W. K., *Prorosmarus alleni*, a new genus and species of walrus from the Upper Miocene of Yorktown, Virginia, Am. Jour. Sci. (4), vol. 21, pp. 444–450, text figs. 1–4, 1906.

margin of the masseteric fossa. On close examination, however, the location of the mental foramina together with the size and position of the canine indicates that its relationships are nearer *Eumetopias*. As many as ten mental foramina can be made out in this bone.



1a



1b

Figs. 1*a*, 1*b*. *Allodesmus kernensis* n. gen. and sp. Type specimen, right mandible, no. 275, Calif. Acad. Sci. coll., × ½. Fig. 1*a*, lateral view; fig. 1*b*, superior view. Temblor formation near Bakersfield, California.

The external face of the horizontal ramus is flattened superiorly, but, as the inferior border is for the most part broken away, it is hard to formulate any opinion as to its nature. There is reason to believe, however, that it must have resembled somewhat the type exhibited by *Eumetopias*. The molariform series are situated very close to the external, not internal, face of the ramus, as is the condition in *Eumetopias*. The internal face of the ramus is so imperfect that no attempt will be made to describe it; the symphysis is very stout and heavy, obliquely oval in outline and not ankylosed. The symphysial surface is very much corrugated, yet the rami undoubtedly were appressed very closely and bound together by a ligament, as in modern otarids.

Owing to the fact that a considerable portion of the inferior margin is broken away, there is exposed the inferior dental canal for the passage of the dental nerve which traverses the mandible below the roots of the molar series; this also corresponds very well in position with that of *Eumetopias.* This canal is of large size in order to provide adequate nourishment for the heavy dental series. As a whole, this lower jaw reveals a strong resemblance in its configuration and proportions to that of *Eumetopias,* but differs in that the mandible is much thinner.

The mandible of this form resembles that of *Alachtherium* and *Prorosmarus* in the possession of incisors $I_{\overline{2}}$ and $I_{\overline{3}}$, a single canine, and in the persistent separation of the opposite rami of the jaw at the symphysis, but differs in being decidedly more robust, and in the possession of an abrupt rounded chin in contrast with the sloping chins of the former. The coronoid and the molariform series must have been in approximately the same plane, but such was not the case in either *Prorosmarus*[2] or in *Alachtherium* as illustrated by the figures of Van Beneden.[3] The molariform series are very closely spaced as in *Prorosmarus,* though the true molars are wanting in the latter.

Though the crowns have been broken off of all the teeth with the exception of the canine, the alveoli remain. From these it can be seen that the dental formula was as follows:

$$I, \overline{2}\ (I_{\overline{2}}, I_{\overline{3}})\ ;\ C, _{\overline{1}}\ ;\ Pm, \overline{4}\ (Pm_{\overline{1}}\text{-}Pm_{\overline{4}})\ ;\ M, \overline{2}\ (M_{\overline{1}}, M_{\overline{2}}).$$

MEASUREMENTS

Anteroposterior diameter of alveolus, first incisor	9. mm.
Anteroposterior diameter of alveolus, second incisor	10.5 mm.
Anteroposterior diameter of alveolus, canine	28.5 mm.
Anteroposterior diameter of alveolus, first premolar	15. mm.
Anteroposterior diameter of alveolus, second premolar	17. mm.
Anteroposterior diameter of alveolus, third premolar	17.5 mm.
Anteroposterior diameter of alveolus, fourth premolar	17.8 mm.
Anteroposterior diameter of alveolus, first molar	17.8 mm.
Anteroposterior diameter of alveolus, second molar	9.5 mm.
Height of canine crown above ramus	56. mm.
Depth of jaw below first premolar	67. mm.
Extreme length of symphysis (estimated)	105. mm.

2 Berry, E. W., and Gregory, W. K., *loc. cit.*, fig. 4*a*.

3 Van Beneden, P. J., Description des ossements fossiles des environs d'Anvers, Ann. Mus. Roy. Hist. Nat. de Belgique, atlas, vol. 1, pl. 1, fig. 2, Brussels, 1877.

The specimens that are numbered 275, Calif. Acad. Sci. coll., were collected by Charles Morrice near center of Section 28, Township 28 South, Range 29 East (Caliente Sheet), in the Temblor beds of the Kern River region. Those from locality 3083 were collected by Clarence L. Moody in Anderson's Zone "C," Sections 24 and 30, Township 28 South, Range 29 East; those from locality 1292 were collected by R. C. Stoner. All these men collected near the Kern River, about twelve miles from Bakersfield, California. As Mr. Morrice directed Messrs. Moody and Stoner to this collecting site, it is quite possible that all this material was obtained in a rather limited area. Specimens from localities 3083, 1292 are in the paleontological collections of the University of California.

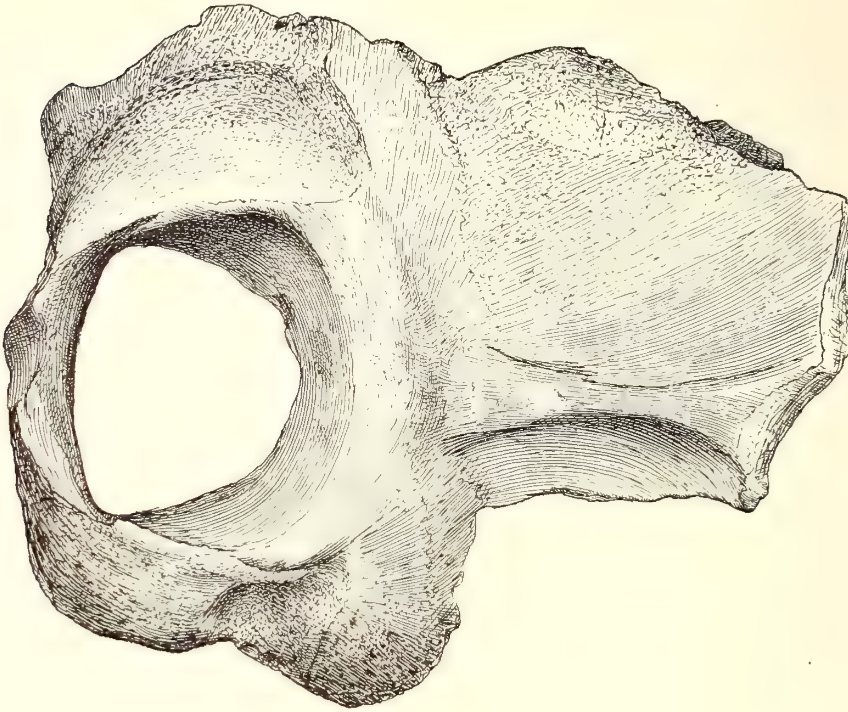
It is by no means certain that all the material described hereafter belongs to the species or even to the genus that we are discussing. There is a strong possibility that the fragment of the skull may belong to some unknown pinniped of great size. The shape and size of the occipital condyles are suggestive of the cetaceans.

Skull.—While the lateral aspect (fig. 2*b*) is characterized by the backward prolongation of the occipital crest considerably beyond the plane of the occipital condyles, the outline of the supraoccipital (fig. 2*a*) immediately above foramen magnum is more nearly vertical in contrast with the marked retreating outlines of recent Otariidae. On the posterior surface of the supraoccipital bone there is a heavy median ridge, which terminates inferiorly some 30 mm. above the superior margin of the foramen magnum, reaching its greatest development at its junction with the occipital crest, under which it acts as a brace for the latter's conspicuous posterior development. The posterior margins of the occipital crest are broken too much to allow accurate measurement. It extends backward 63 mm. beyond plane of the supraoccipital above foramen magnum.

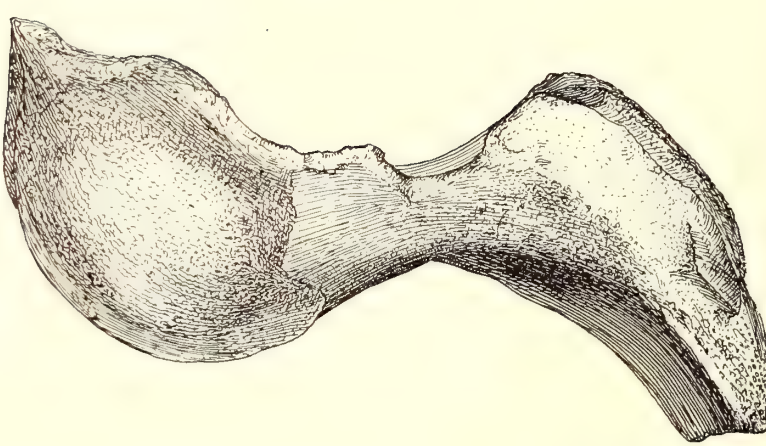
From an inferior aspect the base of the skull presents a broad, slightly convex surface in contrast with existing Otariidae, owing in part to poor development of the median longitudinal ridge of basioccipital and in part to the absence of the lateral vacuities which are so noticeable in the latter. The anterior portion of the skull is broken away near what might correspond to posterior margin of foramen lacerum posterius, which, however, according to F. W. True, is absent in *Pontolis magnus.*

It is unfortunate that the material upon which this discussion is based represents only a small part of the cranium, namely, the occipital

2a



2b



Figs. 2*a*, 2*b*. *?Allodesmus kernensis* n. gen. and sp.? Occipital portion of skull, no. 18012, U. C. Pale. coll., × ½. Fig. 2*a*, occipital view of skull; fig. 2*b*, lateral view of skull. Temblor formation near Bakersfield, California.

region, which is also somewhat imperfectly preserved. The upper surface of the skull is entirely broken away, making it impossible to determine whether or not this form approached *Pontolis magnus* and recent Otariidae in the possession of a sagittal crest.

A comparison of *Eumetopias jubata* and other Otariidae with this skull indicates that the occipital region has been somewhat modified in recent forms, though the underlying plan remains the same. During the course of time the occipital crest has been reduced in size, and gradually tilted forward or upended until now it no longer projects backward in any of the recent Otariidae. In coördination with the reduction of the lateral crest, the median supraoccipital ridge has also become reduced and persists as a feebly developed ridge, though nevertheless distinct in all cases. We find the same condition in *Odobenus* only carried much further, and accompanied by a crowding backward of the rostral region as well.

In this connection it is interesting to note that the view of the skull given by True[4] indicates that the occipital crest of *Pontolis magnus* agrees more closely with recent *Eumetopias* than with this skull. The same appears to be true of *Desmatophoca oregonensis*,[5] although Thomas Condon[6] stated that:

> The development of the occipital crest can not be determined with absolute certainty as that part of the brain case has been damaged, but it would seem to have been poorly developed as that portion of the occipital bone directly above the foramen magnum slopes forward at an angle of forty-five degrees, and there is reason to believe the general shape of the occipital or lambdoidal crest presented that characteristic U-shaped form of *Phoca* rather than that of *Otaria*.

From the measurements given by Condon[7] and also from his plates one is led to believe that *Desmatophoca* resembled more closely in size and appearance the recent *Zalophus,* though, as stated by Condon, it lacked a sagittal crest.

On first examination and before the matrix was sufficiently cleared away to reveal their true nature, the occipital condyles appeared to resemble very closely the type found in whales, but further study showed that the condyles were entirely broken away. Even in this imperfect condition one of the condyles measures forty-six millimeters in the greatest transverse diameter. The internal portion of the con-

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[4] True, F. W., Prof. Paper No. 59, U. S. Geol. Surv., pl. 22, Washington, D. C., 1909.

[5] Condon, T., A new fossil pinniped (*Desmatophoca oregonensis*) from the Miocene of the Oregon coast. Univ. Oregon Bull., vol. 3, suppl. no. 3, pp. 1–14, Eugene, 1906.

[6] Condon, T., *op cit.,* p. 7.

[7] Condon, T., *op. cit.,* p. 11.

dyle remaining on the right side indicates that it lacked the sharp internal border which is so characteristic of *Eumetopias* and *Zalophus,* though this condition may be due to the imperfect preservation and to the wearing away of the edges of the fossil skull.

Internally the outline of the foramen magnum is quadrangular, with its sides converging strongly towards its superior border. In dimensions the greatest transverse diameter of the foramen magnum measures eighty-two millimeters, while its vertical diameter is seventy millimeters.

The outer incisor ($I_{\overline{3}}$) is large (fig. 1*b*) and somewhat caniniform, with the longest diameter anteroposterior. Judging from the root and alveolus, the internal incisor ($I_{\overline{2}}$) was considerably reduced in size and, compared with the external, about equal to one-half the size of the latter, though still functional. In this connection it might be pointed out that the outer incisors tend to be broken off or to disappear in the adults of *Eumetopias jubata* while the inner ones persist, and the latter are directed forward at approximately the same angle as in *Allodesmus.* Without doubt the mandible belonged to an old individual and this indicates that the inner incisor was retained throughout life. It is situated slightly posterior to the outer incisor. The alveoli indicate that the inner incisor was directed forward at an angle of about forty-five degrees.

Figs. 3, 4, 5. *?Allodesmus kernensis* n. gen. and sp. Molar, Stanford Univ. Coll., × 2. Temblor formation near Bakersfield, California.

The canine (fig. 1*a*) is bluntly conical, directed slightly forward and outward and curving slightly backward at tip, subovate at the base in cross-section. Anterointernal portion considerably worn, due no doubt to attrition by the upper incisors. The posterior portion is slightly worn from being abraded by the upper canine but nowhere near the amount exhibited by old individuals of *Eumetopias.* Furthermore, old adults of the latter do not have the anterointernal portion of the canine worn to any appreciable extent. The root is very long, extending backward to plane of third lower premolar.

It is very hard from the material at hand, consisting mainly of imperfect premolars, to assign them to any particular place. The illustration of the premolar (fig. 6) represents a much younger individual than the ones *in situ* in the mandible. The second lower premolar (fig. 7) was slightly larger than the first, with conical crown and poorly defined cingulum. The premolars are all haplodont, no doubt secondarily, without any trace, so far as could be ascertained with the material available, of either an anterior or posterior accessory cusp. There is a progressive increase in size of the premolars from the first to the fourth, though the discrepancy in size of the first and fourth is conspicuous. The roots of $\mathrm{Pm}_{\overline{3}}$ and $\mathrm{Pm}_{\overline{4}}$ are grooved both externally and internally, though $\mathrm{Pm}_{\overline{1}}$ and $\mathrm{Pm}_{\overline{2}}$ appear to possess the groove on the external side alone. The roots completely fill the alveoli and approximate each other very closely.


6


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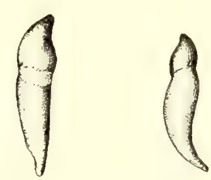

8a 8b

Fig. 6. *Allodesmus kernensis* n. gen. and sp. Premolar, no. 275, Calif. Acad. Sci. coll., × 1. Temblor formation near Bakersfield, California.

Fig. 7. *Allodesmus kernensis* n. gen. and sp. Premolar, no. 275, Calif. Acad. Sci. coll., × 1. Temblor formation near Bakersfield, California.

Figs. 8*a*, 8*b*. *?Allodesmus kernensis* n. gen. and sp. Milk teeth?, no. 275, Calif. Acad. Sci. coll., × 1. Temblor formation near Bakersfield, California.

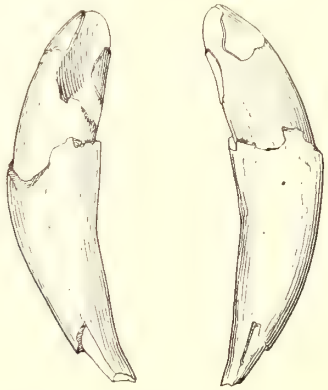
The first lower molar as indicated by the alveolus (fig. 1*b*) is twice the size of the second lower molar. It is characterized by an internal as well as an external groove. There appears to be a progressive lengthening of the alveoli from $\mathrm{Pm}_{\overline{1}}$ posteriad to $\mathrm{M}_{\overline{1}}$. The broken roots of $\mathrm{M}_{\overline{1}}$ in the mandible indicate that it was very well developed, but $\mathrm{M}_{\overline{2}}$ was very small, tending to disappear, as we know it did during late Miocene or Pliocene. There is no indication of $\mathrm{M}_{\overline{3}}$, but when we consider the size of $\mathrm{M}_{\overline{2}}$, it seems probable that $\mathrm{M}_{\overline{3}}$ had become vestigial at an even earlier stage, and that now $\mathrm{M}_{\overline{2}}$ in turn had begun to approach the same fate.

A well preserved molariform tooth was found in a mixed collection of fragmentary pinniped and cetacean remains in the Geological Department of Stanford University. These specimens were also obtained in the Temblor beds near Bakersfield. There are several imperfect teeth, collected by Charles Morrice, in the collection from the California Academy of Sciences which correspond fairly well with this tooth in size. This tooth is single rooted and may possibly be either the second or third upper molar on the left side. It corresponds closely with similar teeth in immature skulls of *Callotaria* and *Eumetopias*. The posterior cusp is better developed than the anterior cusp (fig. 3); in *Callotaria* the reverse is usually true. The cingulum is well defined, though incomplete externally. On the internal face of the cingulum (fig. 4) one well defined cusp occurs. Similar cusps can be observed on the premolars of *Callotaria*. The main haplodont crown (fig. 5) is rounded and rather blunt, the anterior and posterior margins forming a sharp cutting edge.

Measurements of Molar

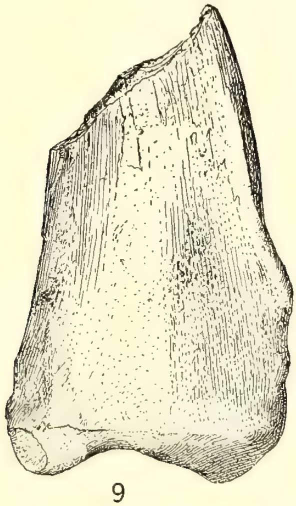
Anteroposterior diameter of tooth	7. mm.
Greatest height of crown of tooth	5. mm.
Greatest width of tooth at cingulum	5.5 mm.

A dozen or more small teeth (figs. 8*a*, 8*b*) were found with the other *Allodesmus* remains. These may possibly be the milk teeth of some pinniped, probably *Allodesmus*. They resemble the adult teeth very closely in contour and in relative proportions, and are likewise curved backward at the tip.



Figs. 15*a*, 15*b*. *Otarid*, gen. and sp.? Canine, no. 23993, U. C. Pale. coll., × ½. Fig. 15*a*, internal view of canine; fig. 15*b*, external view of same. Vaqueros formation near Stage Station on Bakersfield Quadrangle, California.

A canine tooth from the Vaqueros formation near the Stage Station, Section 4, Township 28 South, Range 38 East (Bakersfield Quadrangle), was sent to the Department of Paleontology by O. A. Cavins for determination. It is included here because it has many points in common with *Allodesmus,* though it is not considered to be of this species. This canine is much smaller than that of *Allodesmus kernensis* and may possibly belong to some immediate ancestor. The roots of the canine of *Allodesmus* are grooved, the enamel on the crown is wanting, and the internal face is much worn. The roots of this tooth from the Vaqueros are ungrooved, the enamel on the crown is relatively thick, and the internal face is deeply worn (fig. 15*a*). Conditions of deposition have caused the loss of part of the enamel layer on the external face (fig. 15*b*.).



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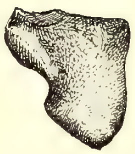


10

Fig. 9. *Allodesmus kernensis* n. gen. and sp. Distal portion of radius, no. 23168, U. C. Pale. coll., × ½. Temblor formation near Bakersfield, California.

Fig. 10. *Allodesmus kernensis* n. gen. and sp. Lateral view of distal portion of ulna, no. 23169, U. C. Pale. coll., × ½. Temblor formation near Bakersfield, California.

The radius (fig. 9) is represented by the distal portion alone, a large portion of the surface being worn away. An accurate description is therefore impossible. The shaft is narrower and was without doubt shorter than that of *Eumetopias.* The interosseous border is wider and more rounded than the posterior border. On comparison it was observed that the inner surface does not differ in any marked respect from that of *Eumetopias,* but the articulation cavity for the scaphoid, lunar, and centrale is much shallower. The articulation tuberosity for the ulna is more or less flattened and not so distinct as in *Eumetopias.*

Only the distal portion of the ulna (fig. 10) was found. It resembles in some respects that of *Eumetopias.* The head of the ulna is flattened while the cylindrical styloid process projects distally. The articulation surfaces of both the styloid process and the head lie in the same plane. In *Eumetopias* the head of the styloid process is rounded, but in this specimen it is flattened.

An interesting feature of the trapezium (figs. 11*a*, 11*b*) is the presence of a large proximal tuberosity on the radial face. The ulnar face of this bone is somewhat different from that exhibited by the modern *Eumetopias.* The facet for the trapezoid is roughly triangular and occupies about one half of the ulnar face. There is also a more extensive area, considerably roughened, for the attachment of muscles and ligaments on this ulnar face, while in *Eumetopias* the same area is confined to a small, but somewhat deepened subquadrangular area near the distal margin, and central in position.

On the proximal surface of the trapezium is an articular facet for the scaphoid or possibly for a consolidated scapho-lunar-centrale. The dorsal margin of this facet is considerably higher than the plantar border; then, too, the plantar border is conspicuously rounded over onto the plantar face. In *Eumetopias* the two margins, dorsal and plantar, are more nearly equal in height. The scaphoid in our form did not glide over the inner face for some distance as it does in the latter. This facet traverses the proximal face in such a way as to avoid completely the proximal tuberosity. A modified condition is present in *Eumetopias,* for this same facet runs transversely from the radial to the ulnar face, being reduced to a mere vestige or considerably worn down, and as a result it extends down for some distance on the radial face.

A very different plantar face is exhibited by these two forms. *Eumetopias* presents a relatively smooth, slightly depressed face with two small pits, and is larger in proportions. In our form this face is considerably roughened. The major portion of the plantar face is represented by the area between the plantar face and the proximal tuberosity on the radial side, and the plantar face proper. It has two deep pits in this area, two of which are just below the plantar border of the scaphoid facet.

MEASUREMENTS OF TRAPEZIUM

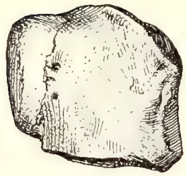
Greatest transverse diameter	46. mm.
Greatest dorsoplantar diameter	36.8 mm.
Greatest distoproximal diameter	44. mm.

The second metacarpal (fig. 12*a*) resembles the fourth metacarpal (figs. 12*b*, 12*c*) in the general contour of the distal and the proximal articulating surfaces. The facet for the trapezoid is strongly convex, running over upon the dorsal face of the shaft and extending backward to the plantar border. The transverse width of this facet across the dorsal face is much wider than that of the fourth metacarpal. No trace of a groove for the radial artery seems to be present, though there is a rugose area for the possible insertion of the extensor muscles. The lateral ulnar face is strongly expanded distally and narrows rather abruptly proximally. Ulnar and radial tubercles but slightly developed. The head and the upper end of the shaft present a number of points of difference when compared with *Eumetopias stelleri;* for instance, the articular facet for the trapezoid is strongly convex while in the latter it is decidedly flattened.

MEASUREMENTS OF METACARPAL II

Greatest length	101.4 mm.
Transverse diameter of proximal end	25.3 mm.
Narrowest transverse diameter of shaft	17.9 mm.
Transverse diameter of shaft at distal end	30. mm.
Anteroposterior diameter of shaft at distal end	16.4 mm.

The bone determined as the fourth metacarpal (figs. 12*b*, 12*c*) of the right fore limb is the lightest of the three metacarpals at hand. The proximal end is characterized by the fact that the facet for articulation with the unciform is strongly convex and not concave as in the carnivores. This suggests the conclusion that the carpal bones allowed these metacarpals much more freedom of movement, which in turn indicates that this form had apparently progressed very little toward that highly specialized flipper which is so characteristic of the pinnipeds. On the lateral ulnar face of the base there is a conspicuous tuberosity for articulation with the third metacarpal. The dorsal surface of the shaft is rather evenly convex. Ulnar and radial tubercles of the head are slightly developed. The articular surface of the head for articulation with the proximal digit is more flattened and exhibits a lesser degree of convexity than that of the base. Dis-



11a

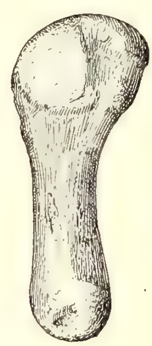
11b

12a

12b

12c

13a



13b

Figs. 11*a*, 11*b*. *Allodesmus kernensis* n. gen. and sp. Trapezium, no. 23167, U. C. Pale. coll., × ½. Fig. 11*a*, dorsal view; fig. 11*b*, superior view. Temblor formation near Bakersfield, California.

Figs. 12*a*, 12*b*, 12*c*. *Allodesmus kernensis* n. gen. and sp. Fig. 12*a*, dorsal view of metacarpal II, no. 16756, U. C. Pale. coll., × ½; fig. 12*b*, dorsal view of metacarpal IV, no. 23170, × ½; fig. 12*c*, lateral view of same. Temblor formation near Bakersfield, California.

Figs. 13*a*, 13*b*. *Allodesmus kernensis* n. gen. and sp. Metacarpal V, no. 16752, U. C. Pale. coll., × ½. Temblor formation near Bakersfield, California.

tally the metacarpal is gradually expanded. Near the distal end, on the plantar face, there are pits for the probable attachment of ligaments.

MEASUREMENTS OF METACARPAL IV

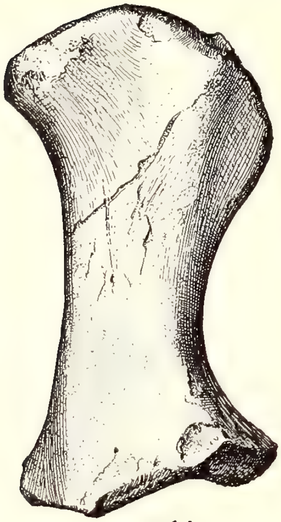
Greatest length	101. mm.
Transverse diameter of proximal end	21.9 mm.
Narrowest transverse diameter of shaft	17.6 mm.
Transverse diameter of distal end	30.3 mm.
Anteroposterior diameter at distal end	16.4 mm.

The shape of the metacarpal shown in figures 13*a*, 13*b* is so unusual when compared with those of existing pinnipeds that it is with difficulty determined as any particular metapodial. Certain features suggest, however, that it is the fifth metacarpal. The facet for the unciform is strongly convex and extends over upon the dorsal face of the shaft. The transverse width of this facet is much greater than in either the second metacarpal or the fourth metacarpal. When compared with *Eumetopias jubata* it is at once observed that the differences are very marked. The radial tuberosity for articulation with fourth metacarpal is very distinct. In *Eumetopias* the facet for the unciform slopes from ulnar to radial border, while in this specimen it slopes from dorsal face to plantar face. The head of the shaft is rounded.

MEASUREMENTS OF METACARPAL V

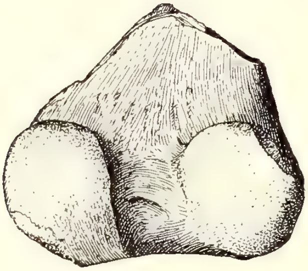
Greatest length	86. mm.
Transverse diameter of proximal end of shaft	33.7 mm.
Narrowest transverse diameter of shaft	20. mm.
Transverse diameter of shaft at distal end	30.5 mm.
Anteroposterior diameter of shaft at distal end	21.2 mm.

The femur possesses no characters of especial interest. It is perfect with the exception of the loss of the epiphyses, and is uncrushed. In general outlines it (figs. 14*a*, 14*b*) recalls the same bone in *Eumetopias*. The femur is short with heavy though somewhat flattened shaft, the greater trochanter light, somewhat lower than the head, and with the lesser trochanter internal. On the other hand the head is less elevated, the lesser trochanter smaller, the trochanteric fossa much deeper and with more uniform depression. The entire upper end of the shaft is broader in proportion to length than in *Eumetopias*. A digital groove is present on this femur though no trace of the same can be seen in the femur of *Eumetopias*. Below the lesser trochanter the shaft is slightly constricted though the transverse diameter is greater than anteroposterior diameter. Unfortunately the lesser



14 a

14 b



14 c

Figs. 14*a*, 14*b*, 14*c*. *Allodesmus kernensis* n. gen. and sp. Fig. 14*a*, dorsal view of femur, no. 16760, U. C. Pale. coll., × ½; fig. 14*b*, ventral view of same; fig. 14*c*, ventral view distal end femur, no. 16755, U. C. Pale. coll., × ½. Temblor formation near Bakersfield, California.

trochanter has been damaged, but it is located in approximately the same position as in *Eumetopias;* the greater trochanter is much less robust.

The shaft of the femur has a noticeable lateral curvature on the inner face towards the proximal end and possesses also a conspicuous mediad curvature on the outer face, while the distal end of the shaft is abruptly expanded at the epicondyles. In these respects this femur resembles the otarid type.

Measurements of Femur

Greatest length	132.2 mm.
Transverse diameter of proximal end	69.4 mm.
Narrowest transverse diameter of shaft	37.4 mm.
Greatest transverse diameter of distal end of shaft	66.7 mm.
Greatest anteroposterior diameter of distal end of shaft	31.2 mm.

An additional fragment of another femur (fig. 14*c*) was found at the same locality as the one described. It probably belonged to an older individual, as the epiphysis is firmly ankylosed. This bone comprises the distal portion with condyles which face posteriorly, as in other Otariidae. The condyles are much smaller and less elongated as compared with those of recent *Eumetopias.* The intercondylar notch is relatively wider, and the patellar groove is narrower and possibly was less expanded.

MEASUREMENTS OF FEMUR

Greatest transverse diameter of femur across condyles	78. mm.
Greatest transverse diameter of outer condyle	26.1 mm.
Greatest transverse diameter of inner condyle	32.5 mm.

The most characteristic feature of the astragalus (figs. 16*a*, 16*b*) is the absence of the groove on the neck which, in all recent forms,

16 a

16 b

Figs. 16*a*, 16*b*. *Allodesmus kernensis* n. gen. and sp. Astragalus, no. 23166, U. C. Pale. coll., × ½. Fig. 16*a*, dorsal view of astragalus; fig. 16*b*, ventral view of same. Temblor formation near Bakersfield, California.

separates the articulating surfaces of the head from those of the body. On the whole the astragalus is somewhat smaller than that of *Eumetopias,* the body is relatively wider, the neck shorter, and the head narrower. Furthermore, the head is somewhat flattened anteroposteriorly and more convex transversely than in the latter, and the neck is twisted so that the long axis of the head is directed obliquely backward internally. In living forms such as *Eumetopias* the head is considerably longer transversely, but the pit for the attachment of a tendon on the proximal border of the dorsal face is smaller and shallower.

It is interesting to note that the oval-shaped head does not set so obliquely on the body as it does in recent forms but resembles somewhat the type exhibited by *Pantolestes.* Moreover, the trochlea is wide, extended on the neck, very slightly oblique, and rather limited in its anteroposterior extension. Besides, the tibial trochlea is relatively shallow with its internal and external crests of about equal height. The fibular articulation is oblique, while in *Eumetopias* this articulation is nearly horizontal. In *Allodesmus* there is no astraglocuboid contact or it is at least very much reduced.

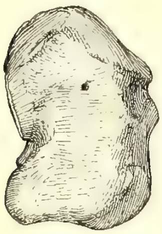
A small astragalar foramen opens proximally at the posterointernal angle of the tendinal notch. This foramen is complete, as it is also in the existing genus *Zalophus,* but in those specimens of *Eumetopias* that were examined there appears to be only one opening, a proximal one. In the seal, *Phoca richardii,* there is no trace of an astragalar foramen or of a tendinal notch. In *Eumetopias,* however, the trochlea has become more deeply grooved and extends backward to the plantar border of the proximal face while the tendinal groove has become almost unrecognizable as such. This astragalar foramen, according to F. Ameghino, transmits a branch of the peroneal artery.

In contrast with other Otariidae, the fibular facet is broad, slightly convex, and subvertical, with a sharp crest or condyle between it and the tibial facet. There is a deep and oblanceolate-shaped tendinal groove or notch behind the trochlea; in *Eumetopias* only a groove marking its closure remains. It should be noted that the ectal facet is decidedly concave, more so superiorly than inferiorly, and its distoproximal length is more than twice its width. This facet is more strongly concave in *Eumetopias,* but its distoproximal length is much less than twice its width. In this specimen the groove for the interosseous ligament which terminates at the astragalar foramen between the ectal and sustentacular facets is much deeper and wider than in *Eumetopias.* Another difference is that the sustentacular and navicular facets are continuous in this astragalus. In comparing the two it was noticed that there is a deep groove invading the sustentacular facet in *Eumetopias,* ending about two-thirds the distance across the head; yet in this astragalus the groove is represented by a notch alone on the internal face and at the proximal margin. There is no cuboid facet, so far as can be determined, in this astragalus. The pit for the ligament from the inner side of the external malleolus is well marked, though no trace of it could be found in *Eumetopias.*

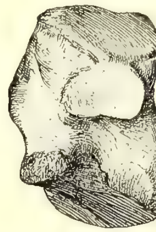
Measurements of Astragalus

Greatest vertical diameter	64.2 mm.
Greatest transverse diameter	57.5 mm.

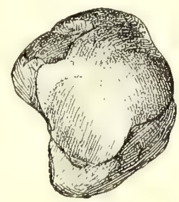
As might be expected, the cuboid (figs. 17*a,* 17*b,* 17*c*) is short and wide, differing from *Eumetopias* in that it is larger and represents a more generalized stage. Proximally, there are two facets, for the calcaneum and astragalus, respectively. The calcanear facet is subquadrate in general outline, slightly convex, but sloping less obliquely than astragalar facet.



17a

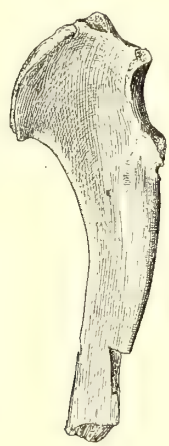


17b



17c

18



19a

19b

Figs. 17*a*, 17*b*, 17*c*. *Allodesmus kernensis* n. gen. and sp. Cuboid, no. 23165, U. C. Pale. coll., × ½. Fig. 17*a*, dorsal view of cuboid; fig. 17*b*, lateral view of cuboid; fig. 17*c*, superior view of cuboid. Temblor formation near Bakersfield, California.

Fig. 18. Phocid, indet. Metatarsal IV, no. 275, Calif. Acad. Sci. coll., × ½. Temblor formation near Bakersfield, California.

Figs. 19*a*, 19*b*. *Phoca* sp. Ulna, no. 23164, U. C. Pale. coll., × ½. Fig. 19*a*, dorsal view of ulna; fig. 19*b*, anterior view of ulna. Upper San Pedro formation near La Jolla, California.

This cuboid differs from that of *Eumetopias* in that the dorsoplantar axis of the calcanear facet is not directed so strongly internally on the dorsal face. The astragalar facet is somewhat concave, and indicates that it supported the astragalus to some extent though there is no distinct facet present on the astragalus for articulation with the cuboid. As the cuboid facet is not usually present in the Fissipedia, this may indicate relationship with that group. The astragalar facet is less oblique and the concavity not so marked as it is in *Eumetopias.*

The dorsal face, in *Eumetopias,* is very rugose for attachment of ligaments (*extensor brevis digitorum*), while it is comparatively smooth in our form; yet this is the longest face in both. A proximal-internal facet articulating with the navicular and a distal articulating with the ecto-cuneiform, are present on the dorsal face. Both facets are longest anteroposteriorly and narrowest transversely. The proximo-internal facet for the navicular or ecto-cuneiform is considerably reduced as compared with that of *Eumetopias.* This facet was probably functional for the navicular but it could hardly have reached the astragalar head. An expansion of the external side of the navicular apparently cut off this facet from contact with the astragalus. The distal facet for the cuneiform is somewhat larger than that in *Eumetopias.*

A deep indentation is also present for the attachment of some ligament between the distal facet and the plantar border; in *Eumetopias* but a trace of it remains. On the plantar face there is a slight groove for the passage of the long peroneal tendon as it passes along the plantar surface of the foot. There is also a blunt, heavy tuberosity for the attachment of muscles. In *Eumetopias* this peroneal groove is very deep and the tuberosity for the attachment of muscles is greatly developed, extending the whole width of the plantar face.

Distally, two facets can be distinguished for the articulation with the fourth and fifth metapodials, respectively. These facets are somewhat concave in both *Eumetopias* and this form, but the facets are larger in the latter. Angle between fibular and dorsal faces is much sharper and not so pitted or rugose.

Measurements of Cuboid

Anteroposterior diameter	39.4 mm.
Transverse diameter	38.9 mm.
Vertical diameter	57. mm.

Family Phocidae

PHOCID, indet.

The fourth metatarsal (fig. 18) probably belongs to some unknown phocid, as it agrees in many respects with that of the fourth metatarsal of the right hind limb of *Phoca richardii.* It differs in the obliquity of the lateral facets on the proximal end of the shaft or base. The internal facet is large and protruding, with margins sharply defined. The external facet is less protruding and more nearly vertical. Transverse width of the shaft is of nearly equal dimensions throughout entire length. There is some similarity in the development of the base of this metatarsal with that of those referred to *Allodesmus*. The articular surface is strongly convex, terminating anteriorly on the dorsal face but not quite reaching the plantar face posteriorly. The head of the metatarsal is rounded, but tibular and fibular tubercles are ill defined, if present. There is a noticeable median depression on the dorsal face of the shaft near base, with rugose area on either side, possibly for insertion of muscles.

PHOCA, sp. A

On January 20, 1917, B. L. Cunningham, of the geological staff of the Southern Pacific Railway Company, collected several fragments of a mandible together with a premolar and a molar. The molar is in place on a fragment and the premolar is loose. These, according to the label, were found near the ''N.W. end of Tejon Hills, between Comanche and Tejon Creeks, in unsurveyed N.E. ¼ Sec. 23, Range 29 East, M.D.M. In Santa Margarita white clayey sands 100 feet below Chanac Formation. *Ostrea titan* and *Pecten crassicardo* etc. occur in a bed stratigraphically but a short distance below this horizon.''

These pieces of the mandible are so small and fragmentary that accurate comparison with any known phocid is impossible. On the whole the mandible was heavier than that of any of the existing members of the genus *Phoca,* and the dimensions were probably slightly larger. The transverse diameter of the horizontal ramus was greater than that of any of the recent species of *Phoca.* An inferior dental canal was present and traversed the ramus in approximately the same position as it does in the latter. The anterior and posterior portions of both premolar and molar are broken away. The molar has two roots and the premolar has but one. The teeth differ from those of any Phocidae that have been available for comparison and resemble rather those of *Allodesmus.*

PHOCA, sp. B

In August of 1911 Professor T. D. A. Cockerell collected the ulna (figs. 19*a,* 19*b*) which is described below, in what was presumably the lower level of the Upper San Pedro beds near La Jolla, California. The label accompanying this ulna bears the following data: ''In shell bearing stratum about six feet above beach-level, at point where cliff begins (and is perhaps 20–25 feet high) on approaching the town of La Jolla from the north."

This ulna is not distinguished from that of other members of the genus *Phoca* now found on this coast by any sharply marked characters except that it is somewhat larger. The proximal portion of the shaft is wider, and the bone itself is very light and porous. The upper surface of the olecranon process is slightly worn away but no doubt was similar to that of *Phoca.* The interosseous border is rounded and the shaft shows a tendency to narrow toward the posterior border. The *incisura semilunaris* (greater sigmoid cavity) for articulation with trochlea of humerus is relatively flattened and is much larger than in *Phoca,* but the coronoid process does not differ in any essential details from that of the latter. It is impossible to determine the exact nature of the head of the ulna because it was broken away in the field in removing it from the matrix.

ANCESTRAL ODOBENIDAE

One finds, on studying the literature relating to fossil Pinnipedia, that considerable confusion has been caused by the description and inaccurate determination of fragmentary material. Many of the remains assigned by earlier writers to the Odobenidae have been found on reëxamination to belong to other groups of mammals.

Among the early writers, the account of Monti[8] on traces of the deluge is the best known. He gave an account of a fossil mandible found near Bologna, Italy, which he thought belonged to a walrus, and which he referred to as "*Phoca dentibus exsertis, Rosmari sive Odobeni.*" Some years later it was discovered that this mandible was that of a rhinoceros. About this same time another observer by the name of Leibnitz[9] made a remarkable conjecture in which he attributed to the walrus many bones and teeth of mammoths found in Siberia. Almost a century later the celebrated Georges Cuvier[10] gave Georgi[11] the credit of presenting evidence in favor of the

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[8] Monti, Jos., De monumento diluviano in agro Bononiensi detecto, dissertatio, in qua permultas ipsius inundationis vindiciae a statu terrae ante et postdiluvianae exponuntur. Bologna, 1719.

[9] Leibnitz, God. W. von, Protogaea, s. de prima facie Telluris et antiquissimae Historiae vestigiis in ipsis Naturae Monumentis (edited by Chr. L. Scheibner), cap. 33–34. Göttingen, 1749.

[10] Cuvier, G., Recherchés sur les ossemens fossiles, ed. 4, vol. 8, pt. 1, p. 458. Paris, 1836.

[11] Georgi, J. G., Geographisch-physikalische und naturhistorische Beschreibung des Russischen Reichs, zur uebersicht bisheriger Kenntnisse von demselben, nebst Nachtraegen, vol. 3, pp. 390, 591. Königsberg, 1797–1802.

PINNIPEDIA

		…NGARY, …LTA	RUSSIA, TURKEY, EGYPT	NEW ZEALAND, AUSTRALIA	
PLEISTOCENE	*Eum…* V… *Pho…* UPE… La… C…			*Zalophus lobatus* *Arctocephalus forsteri* Middle Island, Banks Peninsula, New Zealand	

GEOGRAPHIC AND GEOLOGIC RANGE OF THE KNOWN FOSSIL PINNIPEDIA

Epoch	Division	Stage	Pacific Coast N. A.	Atlantic Coast, N. A.	Argentina	Great Britain	Belgium, Holland, France, Germany, Sweden	Austria, Hungary, Italy, Malta	Russia, Turkey, Egypt	New Zealand, Australia
PLEISTOCENE			*Eumetopias jubata* Ventura, California *Phoca* sp.? UPPER SAN PEDRO, La Jolla, San Pedro, California	*Phoca groenlandica* South Berwick, Maine Montreal and Ottawa, Quebec *Odobenotherium virginianum* Accomac Co., N. J.; Long Branch, Monmouth Co., Va.; Ashley, S.C.; Martha's Vineyard, Mass.; Portland, Me.; Sable Island, N. S.	*Eumetopias byronia* POST PAMPEAN Alrededores, de La Plata, Punta de Lara, Quilmes	*Phoca vitulina* Stratheden, Grangemouth, Tyrie, Garbridge, Kirkaldy, Portobello, Cupar Muir Clay Pits, Seafield. *Phoca hispida* Puggiston, Errol, Montrose ? *Erignathus barbatus* Overstrand *Trichecodon huxleyi* Cromer	*Odobenotherium virginianum* Heyst, Holland Borgerhout, Deurne, Belgium Montrouge, St. Menehould, France Hamburg, Germany *Phoca groenlandica* Yoldia Sands, Elb River, Germany Stockholm, Sweden *Phoca hispida* Fresh water clay and Litorhina clay, Sweden			*Zalophus lobatus* *Arctocephalus forsteri* Middle Island, Banks Peninsula, New Zealand
PLIOCENE	Upper	Sicilian	*Pliopedia pacifica* PASO ROBLES, Santa Margarita, California			*Trichecodon huxleyi* CHILLESFORD, Aldeby		*Phocanella* sp. Val d'Arno, Italy		
PLIOCENE	Upper	Astian	*Otarid* FERNANDO, Soledad Cañon, California			*Phoca* sp. Bramerton, West Runton	*Pristiphoca occitana* Montpellier, France	*Pristiphoca occitana* Salino, Orciano, Volterra, Italy	*Pristiphoca* sp. Uadi Natrun, Egypt	*Zalophus williamsi* Port Phillip Heads, Cape Otway, Australia
PLIOCENE	Middle	Scaldisian	*Pontolis magnus* EMPIRE, Coos Bay, Oregon			*Trichecodon huxleyi* Felixstow, Foxhall, Sutton, Bawdsey *Phoca moori* and *Phocanella minor* Foxhall	*Alachtherium cretsii* *Alachtherium antverpiensis* *Trichecodon huxleyi* *Mesotaria ambigua* *Paleophoca nystii* *Gryphoca similis* *Platyphoca vulgaris* *Phoca vitulinoides* *Callophoca obscura* *Phocanella pumila* *Phocanella minor* Antwerp Basin, Belgium *Trichecodon huxleyi* Breskens, West Scheldt, Holland			
PLIOCENE	Lower	Diestian	? *Pontolis* sp. Humphreys, California							
MIOCENE	Upper	Pontian	*Phoca* sp. SANTA MARGARITA, Tejon Hills, California	*Prorosmarus alleni* YORKTOWN, Yorktown, Virginia *Phoca wymani* YORKTOWN, Richmond, Virginia					*Phoca pontica* Kertsch Peninsula, Akbourun, Russia MIDDLE HORIZON, Dardanellen-tertiär, Erenkoi, Turkey	
MIOCENE	Upper	Sarmatian						*Phoca holitschensis* CERITHIA, Holitsch, Sandorf, Breitenbrunn, Jablonicz, Hungary *Phoca vindobonensis* Heiligenstadt, Austria		
MIOCENE	Middle	Tortonian		? *Cystophorid* Martha's Vineyard, Mass. *Leptophoca lenis* CALVERT, Calvert Cliffs, Maryland			*Monotherium delognii* *Monotherium aberratum* Antwerp Basin, Belgium *Prophoca proxima* *Prophoca rousseaui* Antwerp Basin, Belgium	*Monotherium gaudini* Roccamorice, Pianosa Island, Italy *Monotherium rugosidens* Goza, Malta	*Monotherium maeoticum* Kishinef, Russia	
MIOCENE	Middle	Helvetian					? *Paleophoca* sp. Drôme, France MOLASSE, Baltringen, Germany			
MIOCENE	Lower	Burdigalian	*Desmatophoca oregonensis* Yaquina Bay, Oregon *Phocid* and *Allodesmus kernensis* TEMBLOR, Bakersfield, California *Phocid* and *Otarid?* Lompoc, California *Otarid* VAQUEROS, near Bakersfield, California		*Arctocephalus fischeri* PISO PATAGONICA Parana					
OLIGOCENE	Upper	Aquitanian					*Otaria oudriana* St.-Medard-en-Jalle, France			
OLIGOCENE	Middle	Rupelian					*Palaeotaria henriettae* Rennes, France ? *Phocid* STERNBERGER, Elsloo, Koerboom near Swibroek, Holland			

occurrence of fossil walrus in Russia. Cuvier also thought he recognized a vertebra of a fossil walrus among the bones found at Angers, Department of Maine-et-Loire, and also among certain teeth found in the Department of Landes, France. Blainville[12] was inclined to agree with Cuvier. To understand blunders so widespread on the part of early describers it must be recollected that their material was often very fragmentary.

In quick succession there followed many other discoveries of supposed walruses. In 1835 Jäger[13] found a canine, a fragment of a mandible, and fragments of ribs in the sandstone quarry of Baltringen near Biberach, Germany. He attributed these remains to the walrus, and proposed the name *Trichecus,* but Pictet[14] recognized them as belonging to a sirenian.

When Duvernoy[15] first mentioned two teeth found in a formation of white rock south and east of Oran, in Algeria, Africa, he thought they belonged to some marine mammal, possibly the walrus. Blainville,[16] a few years later, figured these same teeth and discussed their relationship with the ruminants.

The earliest progenitor of the Odobenidae is known only from a mandibular ramus found on the sea beach at Yorktown, Virginia. This specimen was described and figured by Berry and Gregory[17] and its age was determined as the upper Miocene.

During the Pliocene, fossil walrus remains are known only from Europe. A right mandibular ramus, found in the Upper Crag of Fort Wyneghem near Antwerp, Belgium, was described by Du Bus[18] as *Alachtherium cretsii.* Following this discovery Van Beneden reexamined the type and in his memoir associated several other skeletal

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12 Blainville, H. M. D., Ostéographie ou description iconographique, vol. 2, pp. 43–44. 1839–64.

13 Jäger, G. F., Über die fossilen Säugethiere welche in Würtemberg in verschiedenen formationen aufgefunden worden sind, nebst geognostischen bemerkungen über diese formationen, pt. 1, pp. 1–2, pl. 1, figs. 1–3; pt. 2, p. 203. Stuttgart, 1835–39.

14 Pictet, F. J., Traité de Paléontologie (2), vol. 1, p. 234. Paris, 1853.

15 Duvernoy, G. L., Note sur quelques dents fossiles d'Oran. C.-R. Acad. des Sci., Paris, vol. 5, p. 494. 1837.

16 Blainville, H. M. D., *op. cit.,* vol. 2, p. 46; Atlas, vol. 2, pl. 10, fig. 5.

17 Berry, E. W., and Gregory, W. K., *loc. cit.*

18 Du Bus, Vicomte B., Sur quelques mammifères du crag d'Anvers. Bull. Acad. Roy. Sci. de Belgique, Brussels (2), vol. 24, no. 12, p. 566. 1867.

19 Rutten, L., Over fossiele Trichechiden uit Zeeland en België. Versl. Wiss. Nat. Afd. K. Akad. Wet., Amsterdam, vol. 15, pt. 2, pp. 798–811, pl. with figs. 1–6. 1907. Proc. section sciences Roy. Acad. Sci., Amsterdam, vol. 10, pp. 2–14, pl. with figs. 1–6. 1908.

elements with this ramus. Among these bones was an incomplete skull from the "Crag," near Antwerp. Subsequently, Rutten[19] based his *Trichechus antverpiensis* upon "la tete d'*Alachtherium*" of Van Beneden, which he assumes was wrongly associated with the lower jaw which Du Bus had made the type of *Alachtherium cretsii.* Rutten called attention to the fact that several peculiar modifications in the fragmentary skull made articulation impossible with this mandibular ramus. More recently Hasse[20] concluded that all previous descriptions of fossil walruses were based on such faulty material that they should be disregarded. Following this assumption, Hasse proposed the name *Alachtherium antwerpiensis* for a nearly complete cranium unearthed during recent excavations in the Antwerp basin. The descriptions and comparisons given by Hasse are more accurately and carefully drawn up than those of any previous author. A critical study of these diagnoses and an examination of the figures shows that the walrus of Hasse was undoubtedly the same as Rutten's *Trichechus antverpiensis.*

In this same Pliocene sea there existed a quite different type of walrus which was contemporaneous with *Alachtherium.* This form was named *Trichecodon huxleyi* by Lankester[21] and was based upon portions of several tusks from the Red Crag of Sutton, Felixstow, and Bawdsey, Suffolk County, England. Previous to this account of Lankester, fossil tusks of walruses from these same beds had been identified as either the ponderous tusks of *Dinotherium* or of *Mastodon.* A few years later, Van Beneden[22] redescribed Lankester's form as *Trichecodon koninckii.* His description is based on a portion of a tusk which Nyst discovered. Van Beneden also associated with this tusk other skeletal elements which were acquired later from various points in the Antwerp basin. In this description Van Beneden mentions the tooth from Russia figured by Eichwald[23] and states that it should be referred to this genus. Later[24] he says it is hardly probable

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[20] Hasse, G., Les Morses du Pliocene Poederlien à Anvers. Bull. Soc. Belge de Geol., de Paleont. et d'Hydrol., Brussels, Mém., vol. 23, pp. 293–321, pls. 3–6. 1910. Les sables noirs dits Miocènes boldériens à Anvers, *op. cit.*, Proces Verbal, vol. 23, pp. 353–361. 1910. Une défense de morse dans le Pliocène à Anvers, *op. cit.*, Proces Verbal, vol. 25, p. 172. 1912.

[21] Lankester, R., *Trichecodon huxleyi,* a new mammalian fossil from the Red Crag of Suffolk. Quart. Jour. Geol. Soc. London, vol. 21, pt. 3, no. 83, pp. 226–231, pl. 10, figs. 1–3, 5, 6, and pl. 11, fig. 1. 1865.

[22] Van Beneden, P. J., Les Phoques de la mer scaldisienne. Bull. Acad. Roy. Sci. de Belgique (2), vol. 32, no. 7, pp. 12–17, pl. 3. 1871.

[23] Eichwald, E., Lethaea Rossica, ou Paléontologie de la Russie, vol. 3, p. 390. Stuttgart, 1853.

[24] Van Beneden, P. J., Description des ossements fossiles des environs d'Anvers. Ann. Mus. Roy. Hist. Nat. de Belgique, Brussels, vol. 1, pt. 1, p. 53. 1877.

that walruses were ever present in that part of Russia. In this connection it is well to point out that Tchihatcheff[25] erroneously credits Lankester[26] with recording remains of *Trichecodon* from Bounarbaschi, Giaour Koï, Turkey. No additional information regarding this interesting fossil walrus was recorded until 1907. In that year Rutten[27] described and figured a nearly complete cranium which had been picked up opposite the village of Breskens in the West Scheldt, Zeeland, Holland, by a fisherman. Rutten found, when he compared cross sections of the tusk of this skull to those of tusks hitherto referred to as *Trichecodon,* that they were unquestionably the same form. However, Rutten, following Lankester,[28] considered that the genus *Trichecodon* was identical with the living walrus and he threw some question on the validity of the studies of Van Beneden. The figures and descriptions given by Rutten, however, do not warrant his conclusions on the distinctness of the genus *Trichecodon.*

During the Pleistocene period, walruses occurred as far south as South Carolina in North America, and in Europe they are known from Germany, from the Antwerp basin in Belgium, and from France. Some writers have attempted to explain their presence in that latitude as the result of herds of walruses floating down from the arctic basin on immense floes which landed them in the lowlands of the places mentioned.

It is within comparatively few years that the majority of Pleistocene walrus skulls have been unearthed. The remains which have been described from the Pleistocene thus far appear to differ but little from the existing species. This may be due in a large measure to the fragmentary nature of the material upon which accounts of the discovery of fossil walrus are based, or to the fact that aquatic mammals are not so quickly modified as are their terrestrial relatives. No evidence in favor of the existence of walruses on the Pacific coast of North America or of Asia during Tertiary times has as yet been found. The first authentic account of the presence of a Quaternary walrus in Europe appears to be that of Zimmerman,[29] who reported the finding of two skulls, one belonging to the polar bear, *Ursus maritimus,*

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[25] Tchihatcheff (Chikhachev, P. A.), Asie Mineure, description physique de cette contree, pt. 4, Geologie, vol. 3, pp. 175–176. Paris, 1869.

[26] Lankester, R., *op. cit.*, p. 227. (Erroneous reference.)

[27] Rutten, L., *op. cit.*, figs. 1, 3 and 5.

[28] Lankester, R., Trans. Linn. Soc. London (2), vol. 2, p. 213, pl. 22, figs. 1–7. 1882.

[29] Zimmerman, K. G. H., Neues Jahrbuch für Mineralogie, p. 73. Stuttgart, 1845.

and the other to the walrus, *Trichechus rosmarus*. These skulls were discovered at the depth of thirty feet in an excavation in a street of Hamburg, Germany.

Nothing more was known concerning the predecessors of the walrus until Gratiolet[30] received a fragment of a walrus skull from Lartet. This skull was excavated by a workman in the digging of a well at Montrouge, near Paris, France. It is not known in exactly what formation this specimen was found, but Gratiolet thought it belonged to the diluvial deposits, and, in honor of his friend, he named it *Odobenotherium lartetianum*. A few years later Defrance[31] reported the finding of a skull of a fossil walrus in alluvial deposits near Saint-Menehould, in the Department of Marne, France. He questioned the necessity of erecting a new genus and species for the skull fragment described by Gratiolet, and states that he could find no differences between this fragment and the corresponding part of the skull of the living walrus. Still later, Van Beneden[32] states that Schaaffhausen[33] had reported, at a meeting of the Society of the Bas-Rhine, the finding of part of a walrus skull, with ligaments intact, at Cologne, Germany. This skull is undoubtedly recent, as Schaaffhausen has endeavored to show. Van Beneden[34] also mentioned the finding of a vertebra of *Trichechus rosmarus*, near Deurne, and a scaphoid, from the vicinity of Antwerp, Belgium. More recently a walrus skull floated ashore near Heyst. This skull was considered by Rutten[35] to be diluvial in origin.

In 1828 a silicified skull of a fossil walrus found on the sea beach in Accomac County, Virginia, was sent to Dr. Mitchill[36] by a Mr. Cropper. This skull was the same one upon which De Kay[37] several years later based his name *Trichecus virginianus*. Sir Charles Lyell[38]

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[30] Gratiolet, P., Note sur un fragment de crâne trouvé à Montrouge, prês Paris. Bull. Soc. Geol. de France (2), vol. 15, pp. 620–624, pl. 5, figs. 1–3. Paris, 1858.

[31] Defrance, G. A., Note sur un crâne de morse (*Trichechus rosmarus* Linn.) et autres débris fossiles trouves dans une depôt quaternaire, pres la ville de Sainte-Menehould (Marne). Bull. Soc. Geol. de France (3), vol. 2, pp. 164–170. Paris, 1874.

[32] Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, Brussels, vol. 1, pt. 1, p. 41. 1877.

[33] Schaaffhausen, Verhandl. natur. Vereines preuss. Rheinlands und Westfalens (4), vol. 3, pp. 246–248. 1876.

[34] Van Beneden, P. J., *op. cit.*, p. 46.

[35] Rutten, L., *op. cit.*, p. 11.

[36] Mitchill, S. L., Smith, J. A., and Cooper, W., Discovery of a fossil walrus in Virginia. Ann. Lyc. Nat. Hist. New York, vol. 2, pp. 271–272. 1828.

[37] De Kay, J. E., Zoology of New York, Mammalia, pt. 1, p. 56, pl. 19, fig. 1. Albany, 1842.

[38] Lyell, C., Am. Jour. Sci. (1), vol. 46, p. 319. 1844. Proc. Geol. Soc. London, vol. 4, p. 32. 1846.

on his return to London published a report concerning his geological explorations on Martha's Vineyard, Massachusetts, and mentions the finding of a skull of a fossil walrus, presumably in the Pleistocene deposits, which differed from the skulls of existing species in having six molars (i.e., three pairs) and two tusks. After some years had elapsed, another strongly silicified skull was found at Long Branch, Monmouth County, New Jersey. This find was reported upon by Leidy.[39] Again in 1878, Cope[40] reported a fossil walrus skull with tusks over five inches long from the Quaternary blue clays of Portland, Maine. Previous to this, Leidy[41] had given an account of the discovery of a fossil walrus tusk in the Ashley phosphate beds of South Carolina. More recently Rhoads[42] mentioned the finding of a fossil walrus skull on Sable Island, Nova Scotia. The last specimen to be found is the skull from Kitty Hawk Branch, North Carolina, which was discussed by Hay[43] at a meeting of the Biological Society of Washington.

The birthplace of the early ancestors of the Odobenidae cannot as yet be definitely decided, though the evidence points to the fact that they had their origin in the Holarctic region, possibly in the North Pacific Ocean. From a study of the past and present distribution of this family, it seems probable that they had their origin in the North Pacific and that during Oligocene time they migrated to the Atlantic by way of the sea which then separated North and South America. A possible criticism of this interpretation would be the fact that fossil Odobenidae are unknown from the Pacific Coast, but this is only negative evidence since explorations of marine beds in a search for vertebrates have scarcely begun. An alternative interpretation would be that the walruses had their origin in the North Atlantic and that the present North Pacific forms represent a comparatively recent invasion by way of the Arctic Ocean.

There seems to be no alternative interpretation if we are to derive the walruses from the eared seals, as we must according to our present evidence. It is well known that in the Recent period the Otariidae have been limited almost exclusively to the Pacific Ocean, though

39 Leidy, J., Notice of remains of the walrus discovered on the coast of the United States. Trans. Am. Philos. Soc., vol. 11, pp. 83–86, pl. 4, figs. 1–2, pl. 5, fig. 1. Philadelphia, 1860.

40 Cope, E. D., Fossil walrus. Am. Nat., vol. 12, p. 633. 1878.

41 Leidy, J., Am. Jour. Sci. (3), vol. 12, p. 222. 1876.

42 Rhoads, S. N., Proc. Acad. Nat. Sci. Phila., vol. 50, p. 201. 1898.

43 Hay, O. P., Proc. Biol. Soc. Washington, vol. 28, p. xiii. 1915. Jour. Washington Acad. Sci., vol. 6, p. 78. 1916.

ranging on the eastern coast of South America as far north as Uruguay, and as far east as Kerguelen Island and the Cape region of Africa. The distribution of the otarids in the past corresponds very well with this. The finding of a humerus of a marine mammal in the Pleistocene brick clays of Dunbar, Scotland, which may possibly belong to some unknown otarid[44] may prove to be an exception to this statement. The fact that the earlier Otariidae were not so well adapted to aquatic life as were the Odobenidae, and therefore were not capable of such wide dispersal may explain why they did not migrate across this open sea of submerged Central America[45] during the Oligocene or early Miocene time along with the Odobenidae. This explanation hardly seems probable because *Arctocephalus fischeri* is known, through the investigations of Ameghino,[46] from the lower Miocene of Argentina, South America. The Odobenidae, as has already been stated, are not known in Europe until the Lower Pliocene.

The resemblance of the mandibular rami of *Prorosmarus* and *Alachtherium* to the type of rami exhibited by the Otariidae is undoubtedly a common inheritance from more primitive ancestors. The bones of the manus of *Trichecodon* and of *Alachtherium* as figured by Van Beneden[47] show that there is a close resemblance between the metacarpals possessed by these genera and similar bones of the genus *Eumetopias*. Some of the differences, such as the curvature of the horizontal ramus, the reduction of the molars, and change in arrangement of the dental battery, are essentially due to subsequent specialization, and other primitive characters, such as a very long and unankylosed symphysis, the presence of the second and third lower incisors together with a single canine which still retains its caniniform shape, and the retention of the lower fourth premolar, point to a closer relationship. On the other hand, the loss of the first and second lower molars indicates a more remote divergence in the genealogical series, possibly during early Miocene or late Oligocene. At any rate the period of divergence was at a much remoter period than

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44 Thompson, A. W., Jour. Anat. and Phys., vol. 13, pp. 318–321. 1879. Turner, W., The marine mammals in the anatomical museum of the University of Edinburgh, pt. 3, p. 186, text fig. on p. 187. London, 1912.

45 Vaughn, W. T., The biologic character and geologic correlation of the sedimentary formations of Panama in their relation to the geologic history of Central America and the West Indies. Bull. 103, U. S. Nat. Mus., pp. 607–609. 1919.

46 Ameghino, F., Contribuciones al conocimiento de los mamíferos fossiles de los terrenos terciarios antiguous del Paraná. Bol. Acad. Nac. Ciencias, Córdoba, Argentina, vol. 9, p. 214. 1886.

47 Van Beneden, P. J., *op. cit.* Atlas, vol. 1, pt. 1, pl. 2, fig. 6, and pl. 7, figs. 6, 6′.

has been currently believed. The differences between *Prorosmarus* and the Temblor otarid are almost as great as those between modern Otariidae and Odobenidae.

It seems reasonable to assume from what is known of *Prorosmarus* that it possessed a skull somewhat similar to that of an otarid, with upper canines or tusks much enlarged. The arrangement of the teeth is very similar to that of the Otariidae excepting that the true molars are absent. The worn anterointernal face of the lower canine leads one to believe that *Prorosmarus* must have possessed the third upper incisor. This also relates it with the Otariidae. Another point of interest is that the canine still retains its caniniform shape and has not as yet been taken over into the molariform series to form a dental battery. The possession of a long sloping chin, the persistent separation of the rami at the symphysis, and the slender coronoid, together with the facts enumerated above, indicate that this form had not as yet progressed very far in adapting itself to feed upon mollusks.

The next stage as revealed by fossil material is comparable to *Alachtherium antverpiensis,* which marks an intermediate stage in the evolution of this family. The most noticeable modification in this form of the otarid type of skull lies in the foreshortening of the rostrum accompanied by the development of a very large crista lambdoidea and a big mastoid process. The arrangement of the molariform series in a curved line and the possession of three upper incisors in the young and two in the adult *Alachtherium* reveals how closely the walruses had up to this time retained many of the features of the otarid skull. A marked increase in the size of the tusks was undoubtedly one of the earliest steps in the modification of the otarid skull to the odobenid type.

Alachtherium cretsii resembles *Prorosmarus* in the retention of the second and third lower incisors, but the ramus as a whole is much heavier. The worn anterointernal surface of the lower canine indicates that this species also possessed a third upper incisor. Thus the reduction of the upper incisors was brought about in some more advanced type during the evolution of the Odobenidae. The mandibular ramus of *Alachtherium cretsii* as figured by Van Beneden[48] belonged to a very large animal, too large to be considered in the main line of descent. It may either belong to a very old individual or may represent an aberrant offshoot of some earlier form. It is highly probable

[48] Van Beneden, P. J., *op. cit.,* Atlas, pl. 1, figs. 2, 3; pl. 2, figs. 1, 2, 4. 1877.

that *Alachtherium cretsii* represents a surviving archaic type which disappeared at the close of the Pliocene.

A further advance in specialization may be illustrated by *Trichecodon huxleyi,* as figured by Rutten,[49] which differed from *Alachtherium antverpiensis,* and possibly from *Prorosmarus,* in the possession of a shorter and more upturned facial region. In addition to this, the third upper incisor has shifted slightly from its original position and is gradually taking its place in the molariform series. The molariform series has already aligned itself more nearly in a straight line than was the condition in *Alachtherium.* Thus in this stage of progressive modification of the Odobenidae, many of the peculiarities of the otarid skull are already lost. The mandible figured by Van Beneden[50] under the name of *Trichecodon koninckii* exhibits a further approach to the short-jawed type, with the extension and narrowing of the bony lip beyond the canine. In this mandible there is present an abrased surface in front of the molar series which has been considered by some to have lodged an enormous upper canine. This was the interpretation placed upon this cavity in the mandible by Berry and Gregory.[51] It seems more probable, however, that it is nothing more than the alveolus of the lower canine in which the external wall has been broken away. The figures of Van Beneden appear to favor this latter interpretation. The mandible figured is incomplete.

In *Trichecodon* and likewise in *Prorosmarus* it is evident, according to the figures of the original describers, that the alveoli are very close together, the septa being very narrow. This same condition is found in the existing génus *Odobenus. Alachtherium cretsii,* however, has the alveoli separated by somewhat thicker septa. With progressive evolution, as the premolars in turn specialized into a larger and more effective crushing battery in order to avail themselves more fully of the mollusks which abounded about them, there was a corresponding decrease in the distance between the molars themselves. Of course some of the important types connecting the Odobenidae to the Otariidae are so imperfectly known that the progressive stages cannot be demonstrated from actual material. Yet we possess more complete information on the dentition of the odobenids than we have on the dentition of the otarids.

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49 Rutten, L., *op. cit.,* figs. 1, 3 and 5.

50 Van Beneden, P. J., *op. cit.,* pl. 6, figs. 5–7.

51 Berry, E. W., and Gregory, W. K., *loc. cit.*

From the stage which is represented by *Prorosmarus,* the Odobenidae became more and more specialized, finally acquiring the heavy bones which mark them as bottom feeders. In correlation with the increase in size of the canines as tusks, there was a corresponding crowding backward of the rostral region until, in the present forms, *Odobenus rosmarus* and *Odobenus divergens,* it abuts against the postorbital processes. Furthermore, possibly in response to this need for a more effective crushing apparatus, the distal portion of the jaw became more massive, as is illustrated by *Prorosmarus, Alachtherium,* and *Trichecodon,* culminating in *Odobenus,* if they may be taken as respective stages. Finally, the symphysial portion of the ramus became ankylosed as it is in the latter. With time the enormous growth of the upper canines has resulted in the disappearance of the incisors, as they became functionless, and also in the transference of the lower canine to the molariform series.

While the tusklike canines were developing, the length of the skull was shortening, becoming more massive as time went on. There was no need of an increase in surface area for the attachment of muscles and ligaments since water does not require the development of as heavy muscles as are needed by a terrestrial animal. At first the upper canine was no doubt small, very similar to that possessed by the otarids. In the existing walruses it has increased to an enormous size and has become greatly specialized. This required that the skull become denser to bear its weight, and that the rostral region become heavier and upturned in order to serve as a more effective socket for its insertion.

The statement is commonly met with that the evolution and specialization of the tusks of the walrus have been in a large measure brought about through the use made of them. Several writers have erroneously stated that walruses use their tusks to enable them to crawl out of the water upon the ice, but, according to Elliott,[52] this is not true. Lankester[53] accounts for the large size of the tusks of the Crag walrus as due to the absence of hard rocks against which the tusks could be worn down. The observations of Brown[54] and of Johansen[55] have shown that the food of the walrus is composed largely

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52 Elliott, H. W., The Seal Islands of Alaska, 10th U. S. Census, pp. 94–95. Washington, D. C., 1881.

53 Lankester, R., On the tusk of the fossil walrus found in the Red Crag of Suffolk. Jour. Linn. Soc. London, vol. 15, p. 145. 1881.

54 Brown, R., Proc. Zool. Soc. London, pp. 429–430. 1868.

55 Johansen, F., Observations on seals (Pinnipedia) and whales (Cetaceae) on the ''Danmark expedition,'' 1906–1908. Danmark-Expeditionen til Grønlands Nordøstkyst, 1906–1908, vol. 5, no. 2, pp. 214–215. Copenhagen, 1910.

of mollusks, which they secure by diving to the bottom of the sea and digging the mollusks up with their tusks. According to Elliott their swimming in the open sea was remarkable in comparison with their clumsy movements in shallow water, while their size and weight made them relatively helpless on land. In landing and in climbing over low, rocky shores they used their fore-flippers, and progressed very slowly.

The enlargement and lengthening of the upper canines was paralleled by a pinching in or a constriction of the symphysial portion of the mandible. This constriction of the mandible became more pronounced as the symphysial portion was increasingly abraded by the enlarging tusks. The earliest known ancestor of the Odobenidae, *Prorosmarus,* already possessed a mandible of typical odobenid type, but it also possessed certain peculiarities which leave little doubt as to how this modification was brought about. The ancestral odobenid had the same number of teeth as the Otariidae, but, incident to progressive change and extreme specialization, the true molars became reduced and finally disappeared.

We may presume, as stated before, that the earliest offshoots of the otarid stock were merely local differentiations in adaptation to different feeding zones. If our preliminary conclusions are correct, we may assume that the more immediate ancestors of *Prorosmarus* gradually left the otarids in possession of the feeding grounds where sea fish, squids, and cuttlefish were plentiful and sought new types of food, first, partially, and finally, entirely bivalve mollusks. The dentition required to feed upon mollusks would necessarily be of a different type from that required to crush squids and cuttlefish, for in the latter case the dental battery is not required to crush anything stouter than the flesh or tough quills from the backs of squids, while in the former the dentition must of necessity be able to withstand the crushing of heavy shells.

The present shape of the rostral region of the walrus skull appears to be correlated with, or the result of, changes in the form of the dental battery. The upturning of the facial portion of the skull is undoubtedly the result of the enormous increase in size of the upper canines while the massiveness of the skull as a whole is correlated with the type of dental battery and the uses to which it is put. This may be either an orthogenetic trend or simply the response to some unknown factor.

Matthew[56] has discussed the supposed analogy of the walrus with *Smilodon* and has also pointed out the features of the skull and skeleton of *Pantolestes*[57] which agree more closely with those of the walruses than with those of the remainder of the Pinnipedia. Most of these may, as he states, be due to parallel adaptation. The following citation is taken from his memoir:

> On the whole *Pantolestes* appears to be an aquatic Insectivore of predatory habits, with marked analogy and some degree of affinity to the Pinnipedia. Its food may have been fish or turtles, or with a closer analogy to the walrus, fresh water clams; but was more probably an admixture of the three, as far as can be inferred from the characters of the teeth.

Dr. Murie[58] in his comprehensive treatise on the myology of the walrus mentioned several points wherein walruses differ from the other pinnipeds. He also showed that the resemblances between the Odobenidae and the Otariidae are closer than are the resemblances of either with the Phocidae.

It is a question of much interest today whether or not the environment can influence or control variations in form and whether or not gradual quantitative racial changes are matters of much importance in evolution. That the influence of temperature shocks on the germ plasm during the maturation stages is a factor in evolution is strongly upheld by some workers in the field of biology. If temperature, along with humidity and aridity, may be said to be a factor in evolution as Tower[59] has shown, then there will be adequate grounds for the belief that, as a factor in evolution, the entrance upon an aquatic mode of life might act in a somewhat similar fashion. The main question as regards this seems to be whether this adaptation has been a gradual one or an abrupt saltation. Castle[60] in his experiments on the hooded rats has demonstrated that selection may be effective in changing racial characters gradually; that these changes are permanent, and that selection is an agency capable of producing progressive racial evolution.

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[56] Matthew, W. D., Fossil mammals of the Tertiary of northeastern Colorado. Mem. Am. Mus. Nat. Hist., vol. 1, pt. 7, pp. 385–386. New York, 1901.

[57] Matthew, W. D., The carnivora and insectivora of the Bridger Basin, Middle Eocene. *Ibid.*, vol. 9, pt. 6, pp. 531–532. New York, 1909.

[58] Murie, J., Proc. Zool. Soc. London, vol. 7, pp. 411–464, pls. 51–55. 1871.

[59] Tower, W. L., An investigation of evolution in chrysomelid beetles of the genus *Leptinotarsa*. Carnegie Inst. Washington, Publ. no. 48, x + 321 pp., 30 pls., 31 text figs. 1906.

[60] Castle, W. E., Genetics and eugenics, vi + 353 pp., 135 text figs., 2 pls. Harvard Univ. Press, Cambridge, 1916.

Since the environmental factor is nearly constant, aquatic forms, especially the higher mammals, should show the nature and direction of this variation. It can hardly be disputed that terrestrial mammals which later become aquatic will betray somewhere in their make-up structural peculiarities which will show, in turn, the nature of the modifications that are induced by the changing environment. In such forms one should be able by a study of the recent and the fossil members to trace their evolution with a fair degree of precision. We are hampered in this case by the fact that in the Pinnipedia many of the important links in the paleontologic evidence are missing.

ANCESTRAL OTARIIDAE

Although a considerable number of genera belonging to the families Phocidae and Odobenidae have been made known in various paleontologic studies, yet very few of the earlier types of the Otariidae have been discovered. On the other hand, all authentic fossil otarids are based on portions of a skull at least, while the skulls of the fossil Phocidae, with the exception of one or two forms, are unknown.

One readily observes that some of the teeth, from various deposits in France, which have formed the basis for new forms of supposed otarids are quite like similar teeth possessed today by *Eumetopias* and *Arctocephalus*. One finds it very difficult, however, to allocate these isolated teeth with any known mammal. Until the skull or parts of the skeleton are known the true relationships of the animals to which these teeth belonged will remain in doubt. A thorough exploration of some of these deposits in France and elsewhere should reveal much interesting material. Corroborative evidence in the way of additional material for the tooth described as *Palaeotaria henriettae* by Leriche[61] will be extremely interesting. This tooth was found in deposits, assigned to the Tongrien period, in the neighborhood of Rennes, France, and was considered by Leriche to be the oldest known pinniped. No other pinnipeds are known from the Oligocene with the possible exception of the dubious phocid found associated with *Squalodon* and *Halytherium* (= *Crassitherium*) in the Rupelian clay at Elsloo, a town north of Maestricht, in the province of Limburg, Holland.

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[61] Leriche, M., Sur le plus ancien reste connu de l'Ordre des Pinnipèdes. Annales Soc. Geol. du Nord, Lille, vol. 39, pp. 369–370, fig. 1. 1910.

Delfortrie[62] thought he had discovered two forms belonging to this family in the Aquitanian shell marl of the Bone Breccia of Saint-Medard-en-Jalle, near Bordeaux, France. Owing to the fact that he based his *Otaria oudriana* on a last upper molar, and his *Otaria leclercii* on an outer lower incisor, the relationship of these forms is also questionable. Of these two forms, *Otaria oudriana* shows the closest approach to the otarid tooth, though the other, *Otaria leclercii,* is quite unlike any of the known otarids. The *Otaria prisca* which Gervais[63] described from the Miocene sandstone at Uzes, in the Department of Gard, France, was considered by Van Beneden[64] to belong to *Squalodon* instead. In view of the above facts Allen[65] concluded that none of the remains described as otarids may be accepted as satisfactory proof of the presence of the family Otariidae in the Tertiary of Europe.

During the Tertiary period, the Otariidae passed through many adaptive changes but we have no evidence to show that they were at any time as abundant in the number of genera as they are at the present time. In the Lower Miocene of South America, *Arctocephalus* first makes its appearance. Ameghino[66] described *Arctophoca fischeri* (=*Arctocephalus fischeri*), which was discovered in the "Piso patagonico de la formacion patagonica" in the Province of Parana, Argentina. This specimen very closely resembles *Arctocephalus australis.* The exact horizon in Oregon from which *Desmatophoca oregonensis* was collected is uncertain but, apparently, it comes from the same Miocene shales which yielded the *Desmostylus hesperus* figured by Hay.[67] The earliest known otarid from the Pacific coast is the *Allodesmus kernensis* described in this paper. An additional tooth, which exhibits considerable resemblance to *Allodesmus,* has just recently been collected in the Vaqueros formation close to the stage station near the town of Bakersfield. Otarid remains have also been found in the diatomaceous earth at Lompoc, and an otarid metacarpal has been

62 Delfortrie, E., Les Phoques du falun aquitanien. Act. Soc. Linn. de Bordeaux (3), vol. 8, pp. 383–386. 1872.

63 Gervais, P., Zool. et Paleont. françaises, ed. 2, p. 275, pl. 8, fig. 8. 1859.

64 Van Beneden, P. J., Description des ossements fossiles des environs d'Anvers. Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 57. 1877.

65 Allen, J. A., History of North American Pinnipeds. Misc. Publ. No. 12, U. S. Geol. and Geogr. Surv. Terr., Dept. Interior, pp. 218–219. 1880.

66 Ameghino, F., Contribución al conocimiento de los mamíferos fosiles de la República Argentina, p. 342. Buenos Aires, 1889.

67 Hay, O. P., A contribution to the knowledge of the extinct sirenian *Desmostylus hesperus* Marsh. Proc. U. S. Nat. Mus., vol. 49, No. 2113, p. 383. 1915.

available for study from the uppermost horizon of the Santa Margarita deposits near the railroad station of Humphreys, California.

Thus far our information regarding the occurrence of otarids in Pliocene beds of the Pacific coast has been very meager. McCoy[68] has proposed the name *Arctocephalus williamsi* for a skull from deposits in Australia to which he assigns the Pliocene age, but Allen[69] is inclined toward the view, judging from McCoy's description and figures, that it does not differ materially from a female skull of *Zalophus lobatus.* A pinniped of a rather unusual appearance, was studied by True[70] and described as *Pontoleon magnus* (=*Pontolis magnus*). The skull was found in a sandstone bluff, which forms part of the Empire beds, at the south end of Coos Bay, Oregon. More recently a nodule, containing a flipper of an otarid, has been collected in the Fernando beds of Soledad Cañon in the vicinity of Humphreys, California. This specimen is no doubt very closely related to the genus *Pontolis,* possibly the same form as True described, since the skeleton is unknown.

Evidence is still lacking to prove that the distribution of the Otariidae formerly embraced the marine waters of Europe. There are, however, one or two authentic otarids whose discovery was attended with such peculiar circumstances that much controversy has taken place over them. The most puzzling one of these otarids is the skull in the Geological Institute of Vienna which may have been found in the bed of the Danube River. Van Beneden[71] stated that the skull was not a fossil. Lately, Toula[72] has reëxamined this same skull and has stated that it is certainly a fossil. Nevertheless, it still remains to be proven just where this skull was found. There is also the skull mentioned by Gervais[73] which was found by Professor Valenciennes on the sea beach in the Gulf of Gascogny in the Department of Landes, France. The living sea lion, *Eumetopias byronia,* does not range northward in the Atlantic Ocean beyond the Rio de la Plata, of Brazil, while in the Pacific Ocean it formerly occurred as far north as the Galapagos Islands.

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68 McCoy, F., Prodromus of the Palaeontology of Victoria, decade 5. Geol. Surv. of Victoria, Melbourne, pp. 7–9, pls. 41–42. 1877.

69 Allen, J. A., *op. cit.,* p. 770.

70 True, F. W., Smithson. Misc. Coll. (quar. issue), vol. 48, pt. 1, p. 48. 1905. Prof. Paper No. 59, U. S. Geol. Surv., pp. 144–147, pls. 21–23. Washington, D. C., 1909.

71 Van Beneden, P. J., *op. cit.,* p. 57.

72 Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 51–52. 1898.

73 Gervais, P., Bull. Geol. Soc. France (2), vol. 10, p. 311 (footnote). 1852–53.

When we come to examine the Pleistocene records we find that the remains of Otariidae are still a rarity. In California, Bowers[74] has reported *Eumetopias stelleri* (=*jubata*) from deposits of the Pleistocene period. The skull, teeth, and vertebrae, as well as other parts of the skeleton, were found associated with *Mastodon shephardi, Holomeniscus californicus, Equus occidentalis,* and *Escrichtius davidsoni* in the grading of the streets of Ventura, California. Ameghino[75] is the authority for the statement that the remains of *Otaria jubata* were frequently found in the postpampean marine formations ("Alrededores de la Plata, Punta de Lara, Quilmes, etc.") of Argentina.

Dr. Haast[76] conducted extensive explorations in the Moa-bone Point cave, situated on Middle Island, in Bank's Peninsula of New Zealand. In the lower series of layers in the outer chamber of the cave, he found remains of pinnipeds which he designated as *Stenorynchus leptonyx* (=*Hydrurga leptonyx*), *Arctocephalus lobatus* (?) and *A. cinereus* (=*Zalophus lobatus*), and *Gypsophoca subtropicalis* (=*Arctocephalus forsteri* Lesson). Practically the same species of vertebrates, as well as objects of human workmanship, were found in the lower series of layers as in the upper series (which he assigns to the Recent period) with the exception of certain species of Moas. The presence of human remains indicate that these lower layers are also Recent. Peron[77] is credited with reporting the occurrence of fossil remains of *Otaria forsteri* (=*Arctocephalus forsteri*) in beds of Pleistocene age in New Zealand, but True[78] as well as myself found on referring to the work cited that there was no mention of this occurrence on the page given.

The Miocene genus *Allodesmus* was a pinniped of large size, closely related in general features to the living sea lions, but possessing characters common to *Prorosmarus* as well as others present in no other pinniped. A comparison of *Eumetopias jubata* and other Otariidae with this Temblor form indicates that the occipital region has been somewhat modified in recent forms, but that the underlying plan has remained the same. During the course of time the occipital crest has

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74 Bowers, S., Am. Geol., vol. 4, p. 391. 1889.

75 Ameghino, F., *op. cit.*, p. 343.

76 Haast, J., Recent cavern researches in New Zealand. Nature, vol. 14, pp. 576–579. 1876.

77 Peron, Fr., and Leseur, C. A., Voyage de découvertes aux terres australes, pendant les années 1800–1804, vol. 2, p. 37. Paris, 1807–1816.

78 True, F. W., Prof. Paper No. 59, U. S. Geol. Surv., Dept. Interior, p. 148. Washington, D. C., 1909.

been reduced in size, and gradually tilted forward and upended, until now it no longer projects backward in any of the living Otariidae. In coördination with the reduction of the occipital crest, the median supraoccipital ridge has also become reduced. It persists as a feebly developed ridge, but is, nevertheless, distinct in all cases. We find that the same thing has taken place in the Odobenidae only carried much further and accompanied by a crowding backward of the rostral region as well.

In this connection it is interesting to note that the view of the skull given by True[79] indicates that the occipital crest of *Pontolis magnus* agrees more closely with that of *Eumetopias* than that of *Allodesmus.* The same appears to be true of *Desmatophoca oregonensis,* although Condon[80] stated:

> The development of the occipital crest cannot be determined with absolute certainty as that part of the brain case has been damaged, but it would seem to have been poorly developed, as that portion of the occipital bone directly above the foramen magnum sloped forward at an angle of forty-five degrees, and there is reason to believe the general shape of the occipital or lambdoidal crest presented that characteristic U-shaped form of *Phoca* rather than that of *Otaria.*

From the measurements given by Condon, and also from his plates, one is led to the conclusion that *Desmatophoca* resembled very closely in size and appearance the existing *Eumetopias jubata,* although it may have lacked an occipital crest, as stated by Condon.

Desmatophoca oregonensis was a true otarid and not a connecting link between the Otariidae and the Phocidae. This form possessed postorbital processes, large canines, and a salient mastoid, but the contour of the nasals resembles more closely that of the Phocidae. The dentition was: $I\,\frac{3}{2}$; $C\,\frac{1}{1}$; $Pm\,\frac{4}{4}$; $M\,\frac{1}{1}$. This is the same as that of the genus *Eumetopias.* According to Condon, the outer upper incisors (I^3) are much larger than the two inner pairs (I^1, I^2); Pm^1 is single rooted; Pm^2 is two rooted; Pm^3 has two roots, while Pm^4 has three roots, with a main crown as well as an inner and a posterior cusp; yet M^1 has two roots. This description is rather doubtful for the matrix as shown by Condon's photograph, has not been sufficiently cleared away to allow one to determine whether they are three-rooted or not.

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[79] True, F. W., *op. cit.,* pl. 22.

[80] Condon, T., A new fossil pinniped from the Miocene of the Oregon coast. Univ. Oregon Bull., vol. 3, suppl., p. 7. 1906.

This skull was sent by Condon[81] to Wortman for examination. The results of his observations were given by Condon as follows:

The rapid reduction of the molars, the massiveness of the zygomatic arch, the relation of the paroccipital to the mastoid, especially the large size and backward projection of the former, the massive symphysis and great depth of the lower jaw, the great interorbital constriction, the general aspect of the skull and the structure of the fourth premolar, are all features characteristic of the creodonts especially of *Patriofelis*.

He adds further that "while there are certainly some strongly marked creodont features it is yet far removed from any known member of that group."

It is surprising to note that the earliest known member of the Otariidae on the Pacific coast possessed teeth very similar to those possessed by *Eumetopias jubata.* The molariform teeth of *Allodesmus* fail to throw much light on the evolution of this family. All the premolars and molars referred to this form possess a haplodont crown in which the main cusp is probably the paracone which has been developed at the expense of the degenerating inner cusps. The second lower molar, however, differs in many respects from the first lower molar, owing, it may be, to degeneration or to the process of reduction. The teeth of *Allodesmus* differ but little from those of *Eumetopias* except that as a rule the teeth of the latter appear to be subjected to much more abrasion.

If we may judge from analogy of the teeth possessed by this Temblor form to those of the existing genus *Eumetopias,* we may be fairly certain that it was dependent upon soft shelled animals or in all probability forms very similar to those eaten by the latter today, such as squids and cuttlefish. The Odobenidae very likely were beginning about this time to give up competing with forms like *Allodesmus* for similar types of sea food, for we know that competition is most severe between the nearest related species.

The teeth of the earliest known otarids, as mentioned before, are very similar to those possessed by the living species. *Zalophus* and *Eumetopias* have lost the second upper molar, but it is variable in its presence in both *Callotaria* and *Arctocephalus.* On the other hand, both *Callotaria* and *Arctocephalus* appear to be more highly specialized in some respects. The molariform series are simple and conical; *Callotaria* may possess accessory cusps, but the tendency is for them

[81] Condon, T., *op. cit.,* p. 14.

to disappear. No trace could be observed of these cusps in either of the teeth of young or adult skulls of *Arctocephalus australis* which I had at my disposal for comparison.

In studying the dentition of the Otariidae, the fact is gradually forced upon one that the earliest otarids slowly retrogressed from the complex, flesh-tearing dentition of the land carnivores and reverted back toward a simple, conical tooth most favorable for the capture of elusive prey. Yet this retrogressive change in dentition was not accompanied by any general degeneration, but on the contrary it brought about a high degree of both physical and mental specialization. The series of Otariidae, so far as known, show that the molariform tooth must have undergone an indirect retrogression from a tritubercular form. The simple haplodont type, with rudimentary accessory cusps, is then the final culmination of this retrogressive change.

With the advent of time, as palaeontologic investigation goes on, our series will become more complete and we may then be able to trace the backward stages from the secondarily haplodont type exhibited by the Otariidae to the tritubercular type of their predecessors. The anterior and posterior portions of all the premolars in the mandible of *Allodesmus* are broken off, which indicate that accessory cusps were probably present at least on some of the teeth; otherwise it would be difficult to explain why only those portions of a simple haplodont crown would be broken off instead of any other portion. The same is true of all the detached teeth referred to this form.

It is a question of considerable importance whether *Arctocephalus* and *Zalophus* are to be considered as highly specialized or as generalized forms of the Otariidae. If it is logical to suppose that the forms possessing high sagittal and occipital crests are the most generalized, and that those exhibiting a reduction of these crests are more specialized, then such forms as the two above mentioned genera may be said to approach more nearly the archaic type. The males and females of both of these genera are characterized by the possession of high crests, but the occipital crest is much more reduced in *Arctocephalus*. Previous workers nearly all agree that *Arctocephalus*, undoubtedly, is very closely related on one hand with *Callotaria* and on the other with *Zalophus* and the latter in turn with *Eumetopias*. That being the case, then both *Eumetopias* and *Callotaria*, which are characterized by a considerable reduction of these crests, are more specialized.

The successive cranial changes of *Callotaria alascana* have been well figured in the last report on the fur seal.[82] A glance at these plates will show what changes take place as an animal approaches maturity, and also, which is more interesting, that an individual with a fully developed sagittal crest is nearly twelve years old. With each succeeding year the lambdoidal crests became more prominent and the relative length of the interorbital region increases, while the condyles become more visible when the skull is viewed from above. The sagittal crest is conspicuous on males over ten years old.

Those types of pinnipeds which are best adapted for walking on land, such as the eared seals or Otariidae, and which are the least adapted to life in the water or have adopted an aquatic life later than the Phocidae or Odobenidae, have an astragalar foramen or at least a vestigial one. Primitive plantigrade Arctoidea also have an astragalar foramen according to Matthew.[83] This may indicate another point of resemblance of the pinnipeds to the bears. On the other hand, it appears that the increased adaptation to the life in the water, as exhibited by the stages of which *Zalophus, Eumetopias,* the Odobenidae, and the Phocidae may be taken as respective representatives, has brought about in the elapsing time a gradual constriction and a final abortion of this peroneal artery by the pinching in of the tibia against the astragalus, and by the increased flexibility of the limbs as they were developed to their efficiency as paddles, along with the eversion of the pes. Thus aquatic adaptation may also cause a closure of the astragalar foramen, as well as digitigradism, which Matthew suggested.[84] Matthew, in an earlier paper, however, states that Professor Osborn has suggested that this astragalar foramen in the creodonts may have held the extension of the interosseous ligament, instead of the peroneal artery.[85]

A study of the known fossil otarids shows, then, that the origin of this family is as yet completely unknown. This is more apparent when one learns that the earliest known members were already quite specialized for their aquatic mode of living. The best concrete evidence of this is furnished by their possession of a single haplodont

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[82] Osgood, W. H., Preble, E. A., and Parker, G. H., The fur seals and other life of the Pribilof Islands, Alaska, in 1914. Bull. U. S. Bur. Fish., vol. 34, no. 820, pls. 9–10. 1915.

[83] Matthew, W. D., The carnivora and insectivora of the Bridger Basin, Middle Eocene. Mem. Am. Mus. Nat. Hist., vol. 9, pt. 6, p. 551. 1909.

[84] Matthew, W. D., *op. cit.*

[85] Matthew, W. D., Additional observations on the creodonta. Bull. Am. Mus. Nat. Hist., vol. 14, p. 16 (footnote). 1901.

crown on the molariform series, some of which occasionally had small secondary cusps.

If future exploration should result in the discovery of true otarids in Europe during the Oligocene, then Matthew's[86] theory that the arctic North Atlantic basin afforded the most favorable region for the origin of the pinnipeds would have additional support. Most writers have assumed that the distribution of the Otariidae in the past was much the same as it is today. Since three distinct forms with otarid relationships are known from the Pacific coast during the Miocene, one is led to believe that they must have had their origin somewhere in the North Pacific Ocean.

ANCESTRAL PHOCIDAE

More difficult problems present themselves in an attempt to settle the relationships of the various members of the Phocidae than confront us in either the Otariidae or the Odobenidae. Not only, from all appearances, have they been the longest adapted to life in the water and are consequently highly specialized, but also all the known Phocidae from the Miocene appear to be almost on a par in specialization with the existing species. This is especially true of the genus *Phoca.* Indeed, some of the known fossils are with difficulty distinguished from *Phoca vitulina.* In other words, in some genera there has been little if any progress since the Miocene so far as skeletal characters are concerned. One might be led to a belief in the multiple origin of the Pinnipedia were it not for the marked uniformity in the vertebral formula and other skeletal features of the three families.

Our knowledge of the geographical distribution of the Phocidae will rapidly widen when the marine beds are more thoroughly explored. Our present knowledge is more or less the result of accidental discovery of isolated bones and not because of any systematic search for pinniped material. The famous deposits of the Antwerp Basin owe much of their importance to a government project for building a set of canals in the neighborhood of Antwerp. We first note the questionable absence of otarids in the deposits of Europe, and their occurrence in four widely separated deposits, viz.: the Argentine Republic, Australia, California, and Oregon. At the same time we note that some of the earliest known phocids resemble or appear to

[86] Matthew, W. D., Climate and evolution. Ann. New York Acad. Sci., vol. 24, pp. 223–224. 1915.

belong to the same subfamilies as are currently in use for existing forms. From the evidence afforded by fossil remains, it seems that the ancestry of the Lobodoninae is a mystery, though they may possibly be explained as an offshoot of the Monachinae.

On the other hand, the questioned presence of a presumed lobodonid type, *Lobodon vetus,* in the Upper Cretaceous green sands of New Jersey further complicates the matter. If additional fossils are ever found in the same beds or in other beds of similar age, it will place the ancestry of the phocids as far back at least as the Lower Cretaceous. On such a supposition only, could one explain the perfection of such a highly specialized tooth as is exhibited by *Lobodon vetus.* The origin of the otarids was probably not later than the Eocene and certainly not later than the Oligocene. One hesitates to assume a separate ancestry for the phocids, but that conclusion would be confirmed by the presence of phocids in the Upper Cretaceous.

As to life in the littoral areas of oceans, attention may be especially directed toward the favorable environmental conditions prevailing throughout the Miocene and the Pliocene. The changes appear to be those of progressive modification and reduction of size rather than the splitting off into new types. The early forms, so far as known, were all rather large, though for the most part somewhat specialized for pelagic life. The present forms living in the Holarctic region are relatively small compared to these types. On the other hand, almost all the forms, without exception, now existing in the Antarctic region are of large size. One form in fact, the sea elephant, *Mirounga,* occasionally reaches a length of thirty feet and attains a weight of a ton or more.

Scattered and intermingled often with these pinniped remains, are numerous teeth and other skeletal elements of squalodonts and other cetaceans, which often proved puzzling and confusing to the describer and resulted in considerable confusion in the literature on this group. It will be observed that some of the teeth figured as belonging to squalodonts, resemble in some respects the Lower Miocene *Allodesmus.* Remains of pinnipeds are far more scarce in North America than in Europe. The fact that pinnipeds are more or less gregarious and that they are restricted to certain rookeries because of littoral conditions may explain their absence from many marine formations.

The origin of the dentition of this group remains a highly debatable question. In order to make any attempt at a solution, it would be necessary to have available for study all the previously described fossil teeth and, besides, a much larger series than is now known. The dentition of many of the most important forms, phylogenetically, is totally unknown.

The discovery of the phocid in the Santa Margarita beds failed to give any evidence on this question because the cusps of the molariform teeth were broken off. The figures given by the various describers of fossil pinnipeds indicate that there is nothing to disprove the assumption that the molars have evolved secondarily out of tuberculo-sectorial molars. Professor Osborn[87] offers the following statement:

> As figured above, *Phoca gichigensis* exhibits a tooth analogous to that of the Triconodonta among the primitive marsupials, that is, with a main central and two lateral cusps. We have seen that somewhat similar molars with several cusps in a fore-and-aft line have evolved secondarily out of tuberculo-sectorial molars in the case of the marsupial *Thylacinus* and of the creodonts *Mesonyx* and *Hyaenodon*.

In conclusion, emphasis may be laid on the fact that while the oldest otarids are from the west coast of North America and the oldest odobenid from the Atlantic coast, the phocid types of North America are too imperfectly known and are based on too fragmentary material for one to determine their true relationships.

In considering the various fossils assigned to the Phocidae it was thought best to discuss them under the various stages to which they belong. This method makes possible a better understanding of the sequence of the various forms in the different deposits.

UPPER CRETACEOUS

One of the most unfortunate and questionable of all known fossil remains attributed to the pinnipeds is the form described by Leidy[88] as *Stenorhynchus vetus.* This name was based entirely on an outline drawing made by T. A. Conrad of a tooth which was supposed to have been found by Samuel A. Wetherill in the green sand of the Delaware River valley near Burlington, New Jersey. This drawing was reproduced by Leidy in his account and there is certainly a great deal of resemblance to similar teeth of *Lobodon carcinophaga.* If we are to believe this account of Leidy, and if the locality is not erroneous, then it will be hard to dispute that one, at least, of the ancestors of

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[87] Osborn, H. F., Evolution of mammalian molar teeth, pp. 143–144, fig. 103A. New York, 1907.

[88] Leidy, J., Proc. Acad. Nat. Sci. Philadelphia, vol. 6, p. 377. 1853.

the existing Antarctic Lobodoninae, was present at one time on the Alantic coast of North America.

MIDDLE EOCENE (LOWER MOKATTAM?)

Among numerous other fossils collected by Th. Lefevre during his travels in Egypt, were several fragments of bones, chiefly vertebrae and ribs, of a marine mammal. These remains were described and figured by Blainville[89] as *P.? aegyptiaca antiqua.* According to the data which accompanied the specimens, these fossils were collected in a chalky formation in the valley of the Nile on the right bank of the river, but Blainville thought it more probable that they were derived from the white calcareous limestone of the same region. The eleven fragments of bones figured by Blainville do not permit accurate determination. Ami Boue[90] is credited with an account of some teeth of a supposed phocid (*Loup marin*) found in a chalky formation at Wollersdorf, comparable to the formation in Egypt from which the specimens of Lefevre came.

MIDDLE OLIGOCENE (RUPELIAN)

Several teeth and other remains of a marine mammal were found associated with *Squalodon* and *Halytherium* (= *Crassitherium?*) in Rupelian clay on the bed of the Meuse River, at Elsloo near Maestricht, Province of Limburg, Holland. At the time of Van Beneden's visit to the Museum of Leyden, these specimens were labeled as *Phoca ambigua,* for that was the name given them by Staring.[91] If these remains are actually authentic phocids they must belong to some undescribed form. It is now known that the teeth and vertebra which Münster[92] had previously described and figured as *Phoca ambigua* and which came from the marls of Osnabruck basin near Bünde in Hanover, Germany, belonged to the family Squalodontidae. The credit for this determination belongs to Abel,[93] who has seen the type

89 Blainville, H. M. D., Ostéographie ou description iconographique, vol. 2, pp. 43, 51; and Atlas, vol. 2, pl. 10, fig. 2. Paris, 1839–64.

90 Boue, A., Journal de géologie, vol. 3, no. 9, pp. 30–31. Paris, 1831.

91 Staring, W. C. H., De Bodem van Nederland. De zamenstelling en het ontstaan der gronden in Nederland, vol. 2, pp. 282–283. Haarlem, 1860.

92 Münster, G. G., Bemerkungen über einige tertiäre Meerwasser-Gebilde in nord-westlichen Deutschland, zwischen Osnabrück und Cassel. Neues Jahrbuch für Mineralogie, Stuttgart, p. 447, 1835. Beiträge zur Petrefaktenkunde, vol. 3, p. 1, pl. 7. Bayreuth, 1840.

93 Abel, O., Les Odontocetes du Boldérien. Mus. Roy. d'Hist. Nat. de Belgique, vol. 3, pp. 46, 66. 1905.

of *Phoca ambigua*, and who has discussed its relationships in a brief footnote as follows:

> Dans le même Musée (i.e., Musee d'Histoire Naturelle de Hambourg) se trouve aussi une prémolaire du *Squalodon ambiguus*, Mstr., provenant de l'Oligocene de Bünde. Je désire faire observer que cet Odontocète ne peut pas être incorporé dans le genre *Squalodon* même. J'ai eu l'occasion de voir, bien que rapidement, les originaux de Münster, au Musée de Munich, sous la conduit du Dr. Max Schlosser. C'est un Squalodontide primitif,—ce qu'indique déjà son âge Oligocene,—qui doit faire partie du groupe caracterisé par *Neosqualodon*, Dal Piaz, et *Microsqualodon*, Ab., et cet Odontocète prouve que les Squalodontidae ne peuvent pas descendre de *Protocetus, Eocetus* ou *Zeuglodon*, mais qu'ils doivent être rattachés aux Créodontes par d'autres formes. On doit, peut-être, considérer comme un tel "missing link" le *Microzeuglodon caucasicus*, Lyd.

LOWER MIOCENE (BURDIGALIAN)

Workmen have recently uncovered in the diatomaceous shales at Lompoc, California, the impression of an entire phocid limb. This specimen is the earliest known member of the Phocidae. Fossils discovered in this horizon are usually very fragile though the impressions left after the removal of the disintegrating bones are so perfect that excellent casts can be made. This specimen will be discussed more fully in a later paper.

MIDDLE MIOCENE (HELVETIAN)

Among other bones sent by Ed. Lartet from the Sansan to Blainville was a fragment of a mandible containing a large canine tooth *in situ* and two other trilobate and palmated molariform teeth. Blainville[94] thought that this fragment exhibited points of relationship with the phocids and perhaps a few with the hunting tiger of India. It is more probable that this fragment belongs to a *Pseudaelurus* or some related genus.

Several of the teeth that the Reverend Probst had in his collections at Unteressendorf, Germany, were thought by Van Beneden[95] to be closely related to his form *Paleophoca nystii*. These teeth were found in the celebrated sandstone quarries at Baltringen, in Wurttemberg.

UPPER MIOCENE (TORTONIAN)

Although a considerable number of species of phocine pinnipeds have been described from various deposits in Europe, none are so

[94] Blainville, H. M. D., Rapport sur un nouvel envoi de fossiles provenant du depot de Sansan. Comptes Rendus Academie des Sciences, Paris, vol. 5, no. 12, p. 426. 1837.

[95] Van Beneden, P. J., *op. cit.*, vol. 1, pt. 1, pp. 25, 36.

old as *Leptophoca lenis*. This phocid was based upon a humerus found in the Calvert Cliffs, Calvert County, Maryland, between Chesapeake Beach and Plum Point. True,[96] in his description of *Leptophoca lenis*, pointed out that the humerus is more slender than in any existing genus of seals. The peculiar features of this humerus are shown in the following extract from True's paper.

> An extinct phocine pinniped mammal, having the humerus more slender than in any existing genus of seals. Deltoid ridge well developed and broad at the upper, or proximal, end, but narrowing rapidly below and terminating in a thin edge, which, at a point considerably below the middle of the bone, joins at an obtuse angle the ridge running to the inner edge of the trochlea. Lesser tuberosity only moderately developed, the bicipital groove between it and the greater tuberosity very narrow relatively. Entepicondylar foramen present.
>
> *Leptophoca lenis* was probably about the size of *Phoca groenlandica*. The humerus of the latter, while of almost the same length, is much thicker, and the deltoid ridge, as in all existing seals, is thick distally as well as proximally. The lesser tuberosity is much more massive than in *Leptophoca* and is separated from greater tuberosity by a very wide bicipital groove.

It is noteworthy that Sir Charles Lyell[97] in the course of his geological investigations on Martha's Vineyard, Massachusetts, discovered a canine tooth in the Gay Head Miocene which was identified by Professor Owen as allied to *Cystophora proboscidea*.

In the Antwerp basin of Belgium are marine beds of Miocene and Pliocene age which have already yielded a great variety of fossil pinnipeds as well as cetaceans. Van Beneden[98] has described and figured two forms, *Prophoca rousseaui* and *Prophoca proxima*, from the black sands of this basin. Abel[99] in the course of his studies on the cetaceans of the Antwerp basin referred this black sand series to the Bolderian, equivalent in time to the Upper Miocene. More recently Hasse[100] has adduced evidence to prove that the black sands belonged to the Diestian stage.

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96 True, F. W., Description of a new genus and species of fossil seal from the Miocene of Maryland. Proc. U. S. Nat. Mus., vol. 30, no. 1475, pp. 836, 837. 1906.

97 Lyell, C., On the Tertiary strata of the Island of Martha's Vineyard in Massachusetts. Proc. Geol. Soc. London, vol. 4, no. 92, p. 32. 1846.

98 Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, pp. 801–802, 1876. Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 79–81, pl. 18, figs. 1–16. 1877.

99 Abel, O., Les dauphins longirostres du Bolderien (Miocène Superieur) des Environs d'Anvers. Mem. Musee Roy, Hist. Nat. de Belgique, Brussels, vol. 1, pt. 1, p. 43. 1901.

100 Hasse, G., Les sables noirs dits Miocènes bolderiens à Anvers. Bull. Soc. Belge de Géol., de Paléont. et d'Hydrol., Proces Verbal, vol. 23, pp. 353–361. 1910.

Very little is known of the pinnipeds inhabiting the ancient delta of the Rhine and its affluents during the period in which the green sands were laid down. Only one genus, *Monotherium*, is known, and up to the present time it has been discovered only in the green sand series in the Antwerp basin. *Monotherium delognii* is based upon too fragmentary material to distinguish it from *Monotherium affine*. Therefore, since *Monotherium delognii* has page priority, it is here interpreted to include Van Beneden's[101] second species, *Monotherium affine*, as well. *Monotherium delognii*, apparently, was nearly as large as *Mesotaria*, and somewhat larger than all other pinnipeds so far known from the Antwerp basin. *Monotherium aberratum* was slightly smaller, though it must have been considerably larger than *Monotherium maeoticum* of the Black Sea.

The Italian forms of this stage all belong, apparently, to one species. Our knowledge of this form is chiefly the result of the investigations of Guiscardi,[102] who described a well preserved skull and part of a mandibular ramus from the bituminous limestone of Mount Letto, near Roccamorice, in the Compartment of Abruzzi and Molise, as *Phoca gaudini*. Simonelli[103] described a canine tooth similar to this species from the Island of Pianosa, which lies between the Tuscany Archipelago and the island of Corsica. The *Phoca* sp. indet. of Flores,[104] found in the Miocene limestone of Lecce, in the Compartment of Apulia, is based upon the *Phoca* sp. of Costa. The latter has been shown to be a cetacean and not a seal. The canine tooth from a similar formation, at Vignale, in the Compartment of Piedmont, described by De Alessandri[105] as belonging to *Pristiphoca occitana*, may also belong to *Phoca gaudini*.

A fractured left mandibular ramus from the calcareous sandstone at Gozo, Malta, was described and figured by Adams[106] as *Phoca*

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[101] Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, pp. 800–801. 1876.

[102] Guiscardi, G., Sopra una Foca fossile. Rendiconte d. Accad. Sci. Fisiche e matematiche, Naples, 9th year, fasc. 12, p. 207. 1870. Atti d. Accad. Sci. Fisiche e matematiche, Naples, vol. 5, no. 6, pp. 1–9, pls. 1–2. 1873.

[103] Simonelli, V., Terreni e fossili dell'Isola di Pianosa nel Mar Tirreno. Boll. R. Comitato Geologico d'Italia, Rome (2), vol. 10, nos. 7 & 8, p. 209 (footnote). 1889.

[104] Flores, E., Catalogo dei mammiferi fossili dell' Italia meridionale continentale. Atti della Accademia Pontaniana, Naples, vol. 35, no. 18, p. 40. 1895.

[105] De Alessandri, G., La Pietra da Cantoni di Rosignano e di Vignale (Basso monferrato). Mem. Museo civico di Storia Naturale di Milano e Soc. Ital. di Sci. Nat., vol. 6, fasc. 1, pp. 17–18, pl. 1, fig. 1. 1897.

[106] Adams, A. L., On remains of mastodon and other vertebrata of the Miocene beds of Maltese Islands. Quar. Jour. Geol. Soc. London, vol. 35, pt. 3, p. 524, pl. 25. 1879.

rugosidens. At the same time he mentioned other teeth which were of common occurrence in the nodule seams of this same sandstone and also in the sand beds of that locality. These last mentioned teeth, however, resemble very closely those of *Monachus.*

The presence of fossil phocids in the porous limestone quarries around Kishinef, Province of Bessarabia, Russia, was first reported by Eichwald,[107] but he was mistaken in referring these bones to his *Phoca pontica.* This was later pointed out by Nordmann,[108] who was able, on the basis of a large series of bones from that locality, to observe differences which warranted his describing and figuring these remains as *Phoca maeotica.* Isolated bones of *Phoca maeotica* were found associated with those of whales, sirenians, otters, and various swamp birds. *Phoca maeotica,* according to Nordmann, has longer limbs, and is related to *Monachus albiventer,* while *Phoca pontica* has short limbs and would scarcely equal *Phoca vitulina* in size.

UPPER MIOCENE (SARMATIAN)

In 1860, Bruhl[109] described *Phoca holitschensis* on the basis of a foot found at Holitsch, in the valley of the March River, in Nyitra County, Hungary. This little known form seemed to confuse many of the later writers. Paul[110] reported this same phocid, but under the name of *Phoca vitulina,* from Holitsch, Jablonicz, Sandorf, and Breitenbrunn. He was the first to definitely point out from what horizon it came and established the fact that it belonged to the Cerithia beds of that region. Theodor Fuchs[111] stated that *Phoca* remains were present in the Leithakalke, though Toula[112] was unable to corroborate his statement.

Some idea of the close similarity of the Miocene members of the Phocidae with those of living species may be illustrated by a study of the skeleton of *Phoca vindobonensis.* Quite a number of skeletal elements were found by Toula[113] in the sandy clay of Kreindl's brickyard on the Nussdorf road near Heiligenstadt, north of Vienna, in

107 Eichwald, E., Lethaea Rossica ou Paléontologie de la Russie, vol. 3, p. 391. Stuttgart, 1853.

108 Nordmann, A. v., Palaeontologie Südrusslands, pt. 4, p. 313, pl. 22, figs. 1–3, 6–11; pl. 23, figs. 1–3, 6–10; pl. 24, figs. 1–16. Helsingfors, 1860.

109 Bruhl, C. B., Mitt. a. d. k. k. Zool. Institut der Universität Pest, Wien, pl. 1–2. 1860.

110 Andrian, F. F. v., u. Paul, K. M., Verhandl. d. k. k. geol. R. Reichs.-Anst., p. 135. 1863.

111 Fuchs, T., Die Versuche einer Gliederung des unteren Neogen im Gebiete des Mittelmeers. Zeitsch. deutsch. geol. Gesellsch., vol. 37, p. 158. 1863.

112 Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 47 (footnote). 1885.

113 Toula, *op. cit.,* pp. 47–71, pls. 9, 10, 11.

Austria. His figures of the metapodials indicate that, structurally, they show closer affinities with certain living species of the genus *Phoca* than with any other known fossil genus of the Phocidae. It is to be regretted that no remains of the skull or dentition were discovered with the other bones.

Franz Steindachner[114] had reported much earlier the finding of *Phoca* remains, presumably *Phoca vindobonensis,* at Hernals, west of Vienna. Peters[115] had confused similar remains from this same locality with those of *Phoca pontica.*

The skulls of many phocids of the Sarmatian period are unknown. The dentition of most of the forms is in doubt with the exception of a mandibular ramus, containing teeth *in situ,* from Gozo, Malta.

UPPER MIOCENE (PONTIAN)

The skeletal remains described and figured by Eichwald[116] from the ferruginous clay of Mount Mithridates, near Kertch, and from a limestone formation on the promontory of Akbouron, Province of Taurida, Russia, were shown by Nordmann[117] to be distinct, and to these the name of *Phoca pontica* was restricted.

A few years later Abich[118] found isolated remains of *Phoca pontica* during his geological explorations on the peninsulas of Kertch and Taman, Russia. In the year 1880, Calvert and Neumayr,[119] in the course of their investigations on the deposits of the Hellespont, found scattered remains of this same phocid, much worn by erosion, in the clay and marl beds of Erenkoï, near the site of ancient Troja, in the Province of Bigha, Turkey. These remains were found associated with those of *Cetotherium priscum.*

Part, at least, of the fossil remains described by Wyman[120] is referable to a phocid. The form *Phoca wymani* is here restricted to the fibula and vertebra from the ravine outside of the city limits of Richmond, Virginia. The fragments of the skull found in the Shockoe

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114 Steindachner, F., Beiträge zur Kenntniss der fossilen Fisch-Fauna Osterreiche. Sitzungs. math.-naturw. Cl. k. k. Akad. d. Wissenschaften, vol. 37, No. 21, pp. 673–674. 1859.

115 Peters, K. F., *loc. cit.,* vol. 55, pt. 2, pp. 110, 111. 1867.

116 Eichwald, E., *op. cit.,* vol. 3, pp. 391–400; Atlas, pl. 13, figs. 1–37.

117 Nordmann, A. v., *op. cit.,* pt. 4, pp. 299, 313, pl. 22, figs. 4–5; pl. 23, figs. 4–5.

118 Abich, H., Études sur les presqu'iles de Kertsch et de Taman. Bull. Soc. Geol. de France, Paris (2), vol. 21, p. 260. 1863–64.

119 Calvert, F., und Neumayr, M., Die jungen Ablagerungen am Hellespont. Denkschr. d. Akad. Wissensch. Wien, math.-naturwiss. Classe, vol. 40, pp. 361, 363, 365. 1880.

120 Wyman, J., Notice of remains of vertebrated animals found at Richmond, Va. Amer. Jour. Sci. (2), vol. 10, pp. 229, 232, figs. 1–3. 1850.

Creek ravine near the base of Church Hill may possibly belong to some squalodont.

Several fragments of a mandibular ramus with a molar in place as well as a free premolar were collected in the Santa Margarita formation of the Tejon Hills in Kern County, California. These remains are too fragmentary to be of much value in comparative studies. The molar teeth of this phocid from the Santa Margarita were two-rooted, and, as the anterior and posterior portions of these teeth are broken away, it is impossible to allocate its true relationships.

MIDDLE PLIOCENE (SCALDISIAN)

A still greater variety is added to the pinniped fauna by the vast Scaldisian estuary of the Antwerp basin, which furnishes a rather large assemblage of genera and species at this stage. Van Beneden[121] has distinguished the following forms: *Mesotaria ambigua, Paleophoca nystii, Gryphoca similis, Platyphoca vulgaris, Phoca vitulinoides, Callophoca obscura, Phocanella pumila,* and *Phocanella minor.* According to Allen,[122] *Mesotaria* is closely allied to *Cystophora,* or at least referable to the Cystophorinae. He also came to the conclusion that the relationships of the other genera were to be expressed as follows: *Paleophoca* with *Monachus, Gryphoca* with *Halichoerus, Platyphoca* with *Erignathus, Callophoca* with *Pagophilus,* and *Phocanella* with *Pusa.* Altogether, this assemblage, as listed by Van Beneden, is the most comprehensive of any deposit known. A list of the localities in the Antwerp basin from which the various pinnipeds described by Van Beneden were obtained was prepared by Mourlon.[123] More precise information regarding the occurrence of the pinnipeds in the Antwerp basin, hereinafter mentioned, can be obtained from this paper.

UPPER PLIOCENE (ASTIAN)

A rather unusual find was made when *Pristiphoca occitana* was described by Gervais and Serres[124] from the marine sands of Montpellier in the Department of Herault, France. This left mandibular

121 Van Beneden, P. J., Les phoques fossiles du bassin d'Anvers. Bull. Acad. Roy. Sci. de Belgique, Brussels (2), vol. 41, no. 4, pp. 783–802. 1876.

122 Allen, J. A., Misc. Publ. No. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, pp. 478, 479. Washington, D. C., 1880.

123 Mourlon, M., Sur le classement stratigraphique des Phoques fossiles recueillis dans les terrains d'Anvers. Bull. Acad. Roy. des Sci., des Lettres et des Beaux-Arts de Belgique, Brussels (2), vol. 43, no. 5, pp. 603–609. 1877.

124 Gervais, P., and Serres, M. de, Nouvelles observations sur les mammiferes dont on trouve les restes fossiles dans les sables marins de Montpellier. Annales Sci. Nat., Paris (3), vol. 8, p. 225. 1847.

ramus was figured by Gervais,[125] and, at the same time, in his discussion of the form, he intimated that its true relationships were with *Hydrurga leptonyx.* This mandibular ramus is much smaller than the ramus of a *Hydrurga leptonyx* from Kerguelen Island, and its peculiarities do not agree with those of the latter.

Allen[126] was therefore justified in stating that its relationships were with *Monachus albiventer,* instead. Another tooth figured by Gervais[127] from Fausson, in the Department of Herault, France, may possibly belong to some cetacean. The tooth from the shell marl of Romans, in the Department of Drôme,[128] has points in common with a similar tooth of *Paleophoca nystii.*[129] Still another tooth, which was thought to resemble *Phoca vitulina,* was figured by Gervais[130] from the marine sands of Poussan, France. Judging from the figure of this tooth, its relationships are either with the Otariidae or with some toothed whale. Cope[131] considered that this tooth belonged to some species allied to his *Squalodon mento.*

Stromer[132] described a fragment of a right mandibular ramus with one molar *in situ* from the Uadi Natrûn, Egypt. According to Andrews[133] other remains such as *Hipparion aff. gracile, Hippotragus cordieri,* and a sirenian, as well as Canidae, Lutrinae, and Machaerodontinae have been found in the same deposit. The mandible apparently has its nearest affinities with the genus *Monachus,* though it is too fragmentary for any accurate comparisons. The two-rooted molariform tooth is very similar to that possessed by *Monachus.*

Newton[134] described and figured a small left humerus under the name of *Phoca moori.* This specimen was found in the nodule bed of the Red Crag at Foxhall, four miles southwest of Woodbridge,

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125 Gervais, P., Zool. et Paléont. Françaises, ed. 2, pp. 272, 273, pl. 82, figs. 4, 4a. 1859.

126 Allen, J. A., *op. cit.,* pp. 478, 479.

127 Gervais, P., *op. cit.,* pl. 8, fig. 7.

128 Gervais, P., *op. cit.,* pl. 20, figs. 5–6.

129 Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pl. 10, fig. 6. 1877.

130 Gervais, P., *op. cit.,* pl. 38, fig. 8.

131 Cope, E. D., Proc. Acad. Nat. Sci. Phila., vol. 19, p. 153. 1867.

132 Stromer, E., Fossile Wirbeltier Reste aus dem Uadi Fâregh und Uadi Natrûn in Aegypten. Abhandl. Senckenb. naturf. Gesellsch., vol. 29, p. 121, pl. 20, fig. 10. Frankfurt, 1905.

133 Andrews, C. W., Descriptive catalogue Tertiary vertebrata of the Fayûm, Egypt. Publ. Brit. Mus., p. xi. London, 1906.

134 Newton, E. T., Quar. Jour. Geol. Soc. London, vol. 46, pp. 446–447, pl. 18, figs. 3a, 3b. 1890.

Suffolk County, England, associated with another humerus, which agreed very closely with the corresponding bone of *Phocanella minor*. Newton compared this last mentioned humerus with the cast of *Phocanella minor* in the British Museum and found that it agreed precisely in certain peculiarities exhibited by this species. The term Newbournian has been proposed for this nodule bed of the Red Crag by Harmer,[135] since it is presumed to be somewhat younger than the typical Scaldisian.

The earliest mention of the discovery of fossil remains of Phocidae in Italy appears to be in the account of the travels of Gior. Targioni-Tozzetti[136] in Tuscany. He mentions the finding of supposed phocid remains in caverns along the seashore near Pisa. In 1875, Forsyth-Major[137] reported the presence of *Pristiphoca occitana* in beds of marine clay in the hills of Orciano, Saline, and Volterra, Tuscany. Lawley,[138] in his paper on Pliocene fish remains from Tuscany, incidentally mentions the finding of canines and incisors of *Pristiphoca occitana* in a horizon analogous to that of Orciano and Montpellier. During the year 1900 the Geological Museum of Pisa acquired a nearly complete skeleton of a fossil phocid from the Pliocene clay of Orciano. These remains were studied by Ugolini[139] and a report of his investigations was published. He concluded that his fossil material was indistinguishable from similar skeletal parts of the existing *Monachus albiventer* of the Mediterranean region. His comparisons are all with *Paleophoca nystii*, a very different form. On the basis of his three plates it appears that the relationships are closer with Nordmann's *Phoca maeotica*. The restoration of the femur is probably somewhat exaggerated, but otherwise it agrees in all essential details with the femur of *Monotherium maeoticum*. The humerus of this phocid is rather short and stout, conforming in all its details to the peculiar configuration of *Monachus*. As in the latter, the entepicondylar foramen is absent.

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135 Harmer, F. W., The Pliocene deposits of the East of England. Quar. Jour. Geol. Soc. London, vol. 56, no. 224, p. 720. 1900.

136 Targioni-Tozzetti, G., Relazioni di alcuni Viaggi fatti in diverse parti della Toscana, vol. 10, p. 394; vol. 12, p. 200. Florence, 1768–79.

137 Forsyth-Major, C. J., Considerazioni sulla fauna dei Mammiferi pliocenici e postpliocenici della Toscana. Atti della Soc. Toscana Sci. Nat., Pisa, vol. 1, fasc. 3, p. 226. 1876.

138 Lawley, R., Dei resti di pesci fossili del Pliocene toscano. Atti della Soc. Toscana Sci. Nat., Pisa, vol. 1, fasc. 1, p. 66. 1874. Nuovi studi sopra ai pesci ed altri vertebrati fossili della Toscana, p. 103. Florence, 1876.

139 Ugolini, R., Il *Monachus albiventer* Bodd. del Pliocene di Orciano. Palaeontographia Italica, Mem. Paleo., vol. 8, pp. 1–20, text fig. 1, pls. 1–3. Pisa, 1902.

Before the extensive studies of Forsyth-Major,[140] it was thought that the littoral marine Pliocene strata of Italy were somewhat older than the lacustrine strata of the Arno Valley. The investigations of Forsyth-Major brought forth evidence which showed that this might not be true.

The left mandibular ramus figured by Gervais[141] certainly belongs to the same genus, and possibly to the same species, as the fossil form from the Orciano in Italy. It shows further that *Pristiphoca* is not a synonym of *Paleophoca,* but that the two are, instead, very distinct genera. In the skull figured by Ugolini the second and third incisors, the canine, and the first, second, and third premolars were *in situ.* The rest of the skull is broken away, preventing an accurate study of the entire molariform series. The left mandibular ramus figured by Gervais possessed a canine, the first, second, third, and fourth premolars, and the alveolus of the first molar, the remainder of the ramus being broken away. This dentition is very similar to that of the existing genus *Monachus.* Very little if any differentiation in the molariform teeth has taken place in the Monachinae since the Pliocene at least.

Professor Osborn,[142] in his discussion of the fauna of the Val d'Arno, mentions a seal, *Phocanella,* which agrees with that found in Belgium by Van Beneden.

PLEISTOCENE

During the digging of a well in South Berwick, Maine, a humerus, a radius, and an ulna of a seal closely related to, if not identical with, *Phoca groenlandica,* were unearthed by the workmen. They were certain that these bones were those of a human being and refused to work there any longer. The bones were sent to Charles T. Jackson[143] for identification. In 1856 Leidy[144] described and figured the hind flippers of the same phocid, which were imbedded in a concretion of indurated blue clay. The concretion was found near the mouth of Green's Creek, nine miles east of Ottawa, Canada, in a bed of

140 Forsyth-Major, C. J., On the mammalian fauna of the Val d'Arno. Quar. Jour. Geol. Soc. London, vol. 41, no. 161, p. 4. 1885.

141 Gervais, P., *op. cit.,* pl. 82, figs. 4, 4a.

142 Osborn, H. F., The age of mammals, p. 321. New York, 1910.

143 Jackson, C. T., Final report on the geology and mineralogy of the state of New Hampshire, p. 94. Concord, 1844.

144 Leidy, J., Notice of the remains of a species of seal, from the Post-pliocene deposits of the Ottawa River. Proc. Acad. Nat. Sci. Phila., vol. 8, pp. 90–91, pl. 3. 1856.

blue clay containing boulders and marine shells. Logan[145] reports another specimen from a clay pit near Montreal, Quebec.

A careful study of the phocid remains of the glacial epoch in Sweden was made by Kinberg.[146] He reported the occurrence of *Phoca groenlandica* at Hastefjorden and at Stockholm. Part of the skeleton of this same seal found in the Yoldia clay of the Elbe River at Succase, Lenzen, Reimannsfelds, and Steinert, Germany, formed the basis of a paper by Jentzsch and Tenne.[147]

The reported occurrence of a mandible of *Phoca groenlandica* in the cavern of Raymonden, seven kilometers from Perigueux, and near Bordeaux, France, seems rather unusual. This mandible was found associated with a human skeleton and objects of human workmanship. It has been affirmed by Gaudry[148] that the mandible unquestionably belongs to *Phoca groenlandica* and not to *Phoca vitulina.* It is very probable, even if his disposition of the mandible is correct, that it is Recent, and not Pleistocene in occurrence.

In Scotland, remains of a fossil phocid, closely allied to *Phoca vitulina,* were first reported by Knox.[149] These remains were found in the clay bed of the Firth of Forth, near Camelon, Falkirk County. A number of years later, Page[150] reported the occurrence of this species in several other localities in Scotland. Two skulls were found in Aberdeenshire, the pelvic bones of another specimen in the brick clays of Kirkcaldy, and a skeleton of a young animal at the Springfield brickworks, Cupar Muir, in the County of Fife, Scotland. Part of the skeleton of a young seal was unearthed in a stratum of clay while a shaft was being sunk for a coal pit at Grangemouth, near Falkirk.[151] The mandible was figured by Sir William Turner.[152]

Several specimens of a seal, closely allied to *Phoca hispida,* are known from Scotland. The vertebrae and portions of ribs of a phocid,

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145 Logan, W. E., Geological survey of Canada, report of progress from its commencement to 1863, pp. 920, 965, figs. 493a, 493b. Montreal, 1863.

146 Kinberg, J. G. H., Om arktiska Phocaceer, funna uti mellersta Sveriges glaciallera. Ofversigt af Kongl. Vetens. Akad. Forhandl., vol. 26, no. 1, pp. 13, 14, 15. Stockholm, 1869.

147 Jentzsch, A., and Tenne, C. A., Ueber den Seehund des Elbinger Yoldia-Thones. Zeitsch. deutsch. geol. Gesellsch., vol. 39, pp. 496–498. 1887.

148 Gaudry, A., Comptes Rendus Academie Sci., Paris, vol. 111, pp. 352, 353. 1890.

149 Knox, R., Mem. Wernerian Natural History Society, Edinburgh, vol. 5, pt. 2, p. 572. 1826.

150 Page, D., On the skeleton of a seal from the Pleistocene clays of Stratheden, in Fifeshire. Report of 28th Meeting Brit. Assoc. Advancement Sci., Trans. Sections, pp. 103–104. Leeds, 1859.

151 Turner, W., Jour. Anat. and Physiol., vol. 4, p. 260. 1870.

152 Turner, W., The marine mammals in the anatomical museum of the University of Edinburgh, pt. 3, fig. on p. 186. London, 1912.

regarded as this species, were described by the Reverend Thomas Brown[153] from the brick clay of Errol and Elie. Another specimen of a fossil seal, presumably *Phoca hispida,*[154] was found in the brick clay at Puggiston, near Montrose, Forfar County, Scotland. As shown by Turner's figures, the angle of the mandible of this fossil form is poorly developed, thus differing slightly from the living representative. More recently, Lönnberg has reported the finding of *Phoca hispida* in the fresh-water clay[155] and also in the Litorhina clay[156] of Sweden.

A humerus slightly smaller than that of *Erignathus barbatus,* but otherwise agreeing with it in every particular, was described by Newton.[157] This humerus was found in the Cromer Forest beds near Overstrand, Norfolk County, England. Dr. Eugene Robert[158] is also credited with the finding of a fragment of the ilium of a seal, supposedly this species, in the shell tufa of Iceland. There is a strong possibility that this specimen belongs to a Recent phocid.

Professor T. D. A. Cockerell collected an ulna of an indeterminable phocid in what was presumably the lower level of the Upper San Pedro beds near La Jolla, San Diego County, California. Miller[159] also has reported the occurrence of the remains of seals associated with those of *Bison, Equus,* and certain birds in the Upper San Pedro Pleistocene at San Pedro, California.

Many of the Pleistocene phocids were imperfectly described and in some instances the original describer did not have skeletons of Recent seals at his disposal for direct comparison. Thus the original describers were at a great disadvantage, and the results of their labors are more or less open to criticism. However, there still remains to be considered a humerus, a radius and an ulna, found in the brick

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[153] Brown, T., On the Arctic shell clay of Elie and Errol, viewed in connection with our other glacial and more recent deposits. Trans. Roy. Soc. Edinburgh, vol. 24, pt. 3, p. 629. 1867.

[154] Turner, W., On the species of seal found in Scotland in beds of glacial clay. Jour. Anat. and Physiol., vol. 4, p. 260. 1870.

[155] Lönnberg, E., Några fynd af subfossila verterbrater. Arkiv för Zoologi utgifvet af K. Svenska Vetenskapsakademien i Stockholm, vol. 6, no. 3, pp. 9–12. 1910.

[156] Lönnberg, E., Om några fynd i Litorhina-Lera i Norrköping 1907. *Ibid.,* vol. 4, no. 22, pp. 3–16, figs. 1–2. 1908.

[157] Newton, E. T., Geological Magazine, n.s. (3), vol. 6, no. 4, pp. 147–148, pl. 5, figs. 2, 2a. 1889.

[158] Robert, E., Voyages en Islande et au Groenland, 1835 et 1836. Paris, 1840–44.

[159] Miller, L. H., Contributions to the avian palaeontology from the Pacific Coast of North America. Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, no. 5, p. 115. 1912.

clays of Dunbar, Scotland, and described by D'Arcy Thompson,[160] which have been made the subject of much controversy. The absence of an entepicondyloid foramen in the humerus has been the stumbling block for all of those who have discussed this specimen. There is undoubtedly considerable variation in regard to the presence of this foramen. Robert B. Thompson[161] found that the entepicondyloid foramen was absent in the humeri of the Lobodoninae, *Mirounga,* and *Monachus.* Two humeri of *Phoca vitulina* were also found which lacked this foramen. A comparison of the figure of this fossil humerus with a humerus of a young *Halichoerus grypus* reveals a striking resemblance, though the latter lacks the entepicondyloid foramen.

PHOCINAE

The ancestry of the Phocinae previous to the Miocene is unknown and our present information concerning them during that stage is far from satisfactory. Our knowledge of the prevailing forms of the Oligocene is based upon such dubious material that it may well be disregarded entirely. The few teeth and vertebrae from Holland are totally insufficient to afford a basis for any deductions as to their real affinities.

No phocids are known from the Lower Miocene in Europe and as late as the Middle Miocene their remains are still a rarity. Several teeth found in the Baltringen quarries may be related either to this group or to the Monachinae. The phocid remains which have been found in the diatomaceous earth at Lompoc, California, are limited to impressions of flippers. The discussion of their relationships will have to await more detailed studies of these impressions. With the beginning of the Upper Miocene, phocids become better known. The genus *Prophoca,* whose relationships are still uncertain, was present in the Antwerp Basin. In Austria-Hungary two forms, *Phoca vindobonensis* and *Phoca holitschensis*, occur. At the same time an allied form, *Phoca pontica,* existed in the region now known as the Black Sea. Evidence for the occurrence of additional forms in North America is unsatisfactory, resting as it does upon four forms, the *Phoca wymani,* of Virginia, the *Leptophoca lenis,* of Maryland, the phocid from the Santa Margarita formation in California, and the phocid flippers from Lompoc, California. An interesting thing is that the three European forms, *Phoca vindobonensis, Phoca holitschensis,* and *Phoca pontica*

160 Thompson, d'A. W., On some bones of a fossil seal from the Post-Tertiary clay at Dunbar. Jour. Anat. and Physiol., vol. 13, pp. 318–321. 1879.

161 Thomson, R. B., Osteology of the Antarctic seals. Trans. Roy. Soc. Edinburgh, vol. 47, pp. 187–201. 1909.

appear to be closely allied with *Phoca*, so much so, that for many years the remains of the first two mentioned were attributed to *Phoca vitulina*. Little change appears among the Phocidae since the Upper Miocene, so that the divergence into racial lines must have taken place during a considerable period subsequent to this stage.

Again in the Middle Pliocene we find that there were present a relatively large number of phocid genera in the North Atlantic region. Most of these appear to be intimately related with or were, at least, forbears of our existing genera. In this estimate, as previously pointed out, the passage of time has not resulted so much in the extinction of aberrant types, as in the increased divergence or accentuation of racial peculiarities in the types already in existence during the Middle Pliocene. In support of this, it should be remembered that *Callophoca* is allied to *Pagophoca*, *Platyphoca* with *Erignathus*, *Gryphoca* with *Halichoerus*, *Phocanella* with *Pagomys*, and *Phoca vitulinoides* with *Phoca vitulina*.

A review of the Pleistocene phocids shows that there is a surprising similarity between them and their existing representatives. In fact, in respect to some of the forms of this stage, many investigators have concluded that there were no points of difference as the fossil remains agreed in every particular with similar skeletal parts of living phocids. Among these are *Phoca groenlandica*, *Phoca vitulina*, *Phoca hispida*, and *Erignathus barbatus*.

Thus the belief seems to be confirmed that the phocidae are a very old group and their specialization and adaptation to a pelagic life have proceeded along somewhat different lines than those of the Sirenia and Cetacea. The most specialized seals have been commonly assumed to be those that are the least dependent upon land for any part of their existence. Conversely, the most generalized would be those that are confined to the vicinity of or dependent upon land or ice. The most specialized should show the most marked structural and anatomical changes.

Starting with the most generalized we may be able to observe some structural indications as to how specialization has proceeded. Seals have not as yet reached the stage, like whales and sirenians, of being able to bring forth their young in the water. The period that elapses between birth and the time they take to water has been thought by some to be one indication of their degree of adaptation. According to Lloyd,[162] the young of *Phoca vitulina* may take to water at birth

[162] Lloyd, L., The game birds and wild fowl of Sweden and Norway, p. 381. London, 1867.

while the young of *Phoca groenlandica*[163] do not enter the water until their woolly coat is shed. This moulting usually takes from fourteen to twenty days. It is nearly a month before the young of *Halichoerus grypus* enter the water, according to the observations of Hallgrimsson.[164] Very little seems to be known concerning the length of time that elapses before the young of *Monachus* enter the water. Dr. Racovitza[165] has furnished the most complete observations regarding this point on *Lobodon carcinophaga.* From his observations it seems that the young enter the water in about three days, though the young of *Leptonychotes weddelli,*[166] a form in many respects the most specialized, wait until they are nearly a month old. The young of *Mirounga leonina* apparently require the longest time of all the phocids, for Lydekker[167] claims that it is more than two months before they enter the water.

The time that elapses before the young of the various forms enter the water seems to be dependent upon the time required to moult the natal pelage. When that has been accomplished the young assume their pelagic life. However, this does not necessarily mean that the particular type which may happen to enter the water first, is the most specialized. On the contrary, the young of many of the most specialized terrestrial mammals are helpless for a considerable period after birth. It merely supplies the information that the cycle of moulting advances further *in utero* in some forms than in others.

The variations in the number of accessory cusps on the teeth of *Phoca vitulina* have been studied and excellent figures prepared by Allen.[168] In this species the first upper and lower molars are alone retained. However, Nehring[169] has, in his account of the variations in the skull of *Halichoerus grypus* that are brought about by age, pointed out that the number of roots and cusps of the premolars may vary considerably, and, what is more interesting, the second upper molar frequently persists.

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163 Brown, R., Notes on the history and geographical relations of the Pinnipedia frequenting the Spitzbergen and Greenland Seas. Proc. Zool. Soc. London, p. 419. 1868.

164 Hallgrimsson, J., Bemaerkninger om den islandske Utselur. Krøyer's Naturh. Tidsskrift, vol. 2, p. 91. 1838–39.

165 Racovitza, E. G., La vie des animaux et des plantes dans l'Antarctique, p. 29. 1900.

166 Wilson, E. A., National Antarctic Expedition, 1901–1904, Mammalia. Publ. Brit. Mus., vol. 2, p. 57. London, 1907.

167 Lydekker, R., The Royal Natural History, p. 147. London, 1894.

168 Allen, J. A., The hair seals (Family Phocidae) of the North Pacific Ocean and the Bering Sea. Bull. Am. Mus. Nat. Hist., vol. 16, pp. 467–470. New York, 1902.

169 Nehring, A., Sitz. Gesellsch. naturf. Freunde, pp. 107–126. Berlin, 1883.

Table Showing Variations in Dental Formulae of the Suborder Pinnipedia

	Incisors		Canines		Premolars		Molars	
Odobenidae	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Prorosmarus	×	2	×	1	×	4	×	0
Alachtherium antverpiensis								
Milk dentition	3	×	1	×	4	×	1	×
Permanent dentition	2	×	1	×	4	×	1	×
Alachtherium cretsii	×	2	×	1	×	3	×	0
Trichecodon	2	×	1	×	4	×	1	×
Odobenotherium	1	0	1	1	3	3	0	0
Odobenus								
Milk dentition	3	3	1	1	4	4	1	1
Permanent dentition	1	0	1	1	3	3	0	0
Otariidae								
Eumetopias	3	2	1	1	4	4	1 or 2	1
Allodesmus	×	2	×	1	×	4	×	2
Zalophus	3	2	1	1	4	4	1 or 2	1
Desmatophoca	3	2	1	1	4	4	1	1
Arctocephalus	3	2	1	1	4	4	1 or 2	1
Callotaria	3	2	1	1	4	4	1 or 2 or 3	1
Phocidae								
Phocinae								
Phoca								
Milk dentition	3	2	1	1	3	3	0	0
Permanent dentition	3	2	1	1	4	4	1	1
Erignathus	3	2	1	1	4	4	1	1
Halichoerus	3	2	1	1	4	4	1 or 2	1
Monachinae								
Monachus	2	2	1	1	4	4	1	1
Paleophoca	×	2	×	1	×	4	×	1
Pristiphoca	2	×	1	1	4	4	×	1
Monotherium	3	2	1	1	4	4	1	1
Lobodoninae								
Leptonychotes	2	2	1	1	4	4	1 or 2	1
Hydrurga	2	2	1	1	4	4	1	1
Lobodon	2	2	1	1	4	4	1	1
Ommatophoca	2	2	1	1	4	4	1 or 2	1
Cystophorinae								
Cystophora	2	1	1	1	4	4	1 or 2	1
Mirounga	2	1	1	1	4	4	0 or 1	0 or 1 or 2

There appears to be considerable variation in the number of cusps exhibited by the molariform teeth of the Phocidae. The number of cusps on the lower molars varies from three to four in *Phoca vitulina, P. richardii, P. ochotensis,* and *P. hispida.*[170] This variation is true

[170] Allen, J. A., *op. cit.*, p. 478.

not only for the Phocinae but of the other subfamilies as well. Captain Barrett-Hamilton[171] has figured a remarkable series of variations in the teeth of *Ommatophoca rossi.*

One is at once impressed, in studying the dentition of the Phocidae, by the wide range of variation both in the number of the teeth in the series and in the number of the cusps possessed by the premolars and molars. Either the dentition of this family is in a very plastic state or else the acquisition of additional cusps is very irregular. Recently, Gregory[172] has advanced the theory that the molariform teeth of *Phoca gichigensis* may readily be derived from those of *Cyanarctus saxatilis.* The molariform teeth of the existing Phocidae have so many secondary modifications that little reliance can be placed on attempts to homologize their teeth with those of other fossil carnivora. Until we know the dentition of the Phocidae from forms older than the Upper Miocene it will be hopeless to attempt to trace their derivation.

As already remarked, there are a number of facts that lead one to believe that all the Pinnipedia may not have a common ancestor. It is at least conceivable that the otarids may have been derived from an ursid type while the phocids may have been derived from another, possibly from an aeluroid type. On the basis of osteological characters, Sir George Mivart[173] has adduced a series of relationships that go far toward showing that the phocids are considerably unlike the otarids. His summary is as follows:

1. In the Phocidae, as in *Lutra,* there is no alisphenoid canal, while in both *Otaria* and *Ursus* it is present.
2. In the Phocidae and *Lutra* the paroccipital and mastoid processes are not united by a prominent ridge of bone, while in *Otaria* and *Ursus* they are so united.
3. In the Phocidae and *Lutra* the mastoid process does not much depend; in *Otaria* and *Ursus* it depends considerably.
4. The bulla of *Lutra* could be easily made to resemble that of *Phoca* by giving a rounded form to the mastoid; in both genera there is the same sort of groove between the mastoid, and the tympanic. The bulla of *Otaria,* on the contrary, is exceedingly like that of *Ursus,* and in both these genera the sort of groove which exists between the mastoid and tympanic in *Lutra* and *Phoca* is absent.
5. The angle of the mandible is large in *Otaria* and *Ursus,* while in *Lutra* and *Phoca* it is smaller.

[171] Barrett-Hamilton, G. E. H., Report on the collections of natural history made in the Antarctic regions during the voyage of the Southern Cross. Publ. Brit. Mus., pl. 1. London, 1902.

[172] Gregory, W. K., The orders of mammals. Bull. Am. Mus. Nat. Hist., vol. 27, p. 314. New York, 1910.

[173] Mivart, G., Notes on the Pinnipedia. Proc. Zool. Soc. London, p. 498. 1885.

6. The femur is very short in *Lutra* and *Phoca;* it is considerably longer relatively in *Otaria* and *Ursus.*
7. In *Lutra* and *Enhydra* the floor of the orbit formed by the maxilla is very large, as it is also in *Leptonyx,* at least, amongst the Phocidae, while in others of that family it is of moderate size. It is very small in *Otaria* and *Trichechus,* as it also is in *Ursus.*
8. There are noteworthy defects in the ossification in the cranial walls in *Lutra* and the Phocidae. There are no such defects in *Ursus* or *Trichechus,* while they are but of small extent in *Otaria.*
9. The suborbital foramen is very large in *Lutra* and *Phoca barbata* and *Trichechus.* It is small in the Bears, and of moderate size in most Otaries.

In support of this theory there are certain structural peculiarities in the early Lutrinae which are certainly worthy of consideration. *Potamotherium valetoni,* of the famous lacustrine beds of St. Gerand-le-Puy, Department of Allier, France, presents many characters which may indicate relationship with the Phocidae. There is a striking similarity in certain peculiarities and proportions of the humerus, radius, ulna, femur, and tibia of *Potamotherium valetoni* with those of *Phoca richardii,* the resemblance being even closer with the Miocene form, *Phoca vindobonensis.* The teeth of *Phoca gichigensis* may as readily be derived from a pattern like *Potamotherium valetoni* as from a pattern like *Cynarctus.* A comparison of the humerus of *Potamotherium* with one of *Phoca* shows that an entepicondylar foramen, an expanded and flaring supinator ridge, and a prominent deltoid ridge are present in both. In *Potamotherium* the internal tuberosity is rudimentary while it is greatly produced in *Phoca.* On the other hand the external tuberosity is produced in *Potamotherium* though it is wanting in *Phoca.* The following differences may be pointed out in the femur. There is present a rounded depression in the head of the femur of *Potamotherium* for insertion of *ligamentum teres,* which is absent, however, in *Phoca* and *Latax.* The shaft of the femur is relatively longer and slenderer, the neck is longer, and the head proportionately smaller than in *Phoca.* The lesser trochanter is wanting in *Phoca* though it is present in *Potamotherium.*

The writer does not wish to convey the impression that *Potamotherium* might itself be considered the ancestor of the Phocidae. If the phocids are derivatives of this stock, then it is probable that one of the forbears of *Potamotherium* was the source and that the Lutrinae and the Phocidae are both descendants of that type. In this connection it should be pointed out that Andrews[174] figured and

[174] Andrews, C. W., Descriptive catalogue Tertiary vertebrata of the Fayum, Egypt. Publ. Brit. Mus., pp. 218, 229–230, text fig. 74. London, 1906.

discussed a humerus of *Apterodon macrognathus* from the Upper Eocene of Egypt which exhibits certain structural peculiarities that are practically identical with some in *Potamotherium.* The fact that certain limb bones of some of the hyaenodonts indicate that one or two forms lived an aquatic or semi-aquatic life may throw additional light upon the origin of this group. As pointed out before, the solution of the ancestry of the Phocidae will necessarily remain an uncertainty until we know the skull and dentition of the Miocene Phocidae.

MONACHINAE

Considerable uncertainty exists as to whether or not the Monachinae should be placed nearest the Phocinae or the Lobodoninae. On the whole their relationships with the other members of the Phocidae are rather confusing. The Upper Miocene members of the Monachinae, referable to five species and probably all belonging to the same genus *Monotherium,* had at that stage a range extending from the Antwerp basin to the Mediterranean and Black seas. The most interesting member of the Monachinae is the *Monotherium gaudini,* represented by a well preserved skull and part of the mandibular ramus. Ugolini examined the skull and pointed out that three upper incisor teeth were present. This places its affinities more closely with the Phocinae and breaks down one of the subfamily distinctions which was assumed to be diagnostic. Allen, many years previously, had stated that *Monotherium gaudini* was the prototype of the Mediterranean *Monachus.*

During the Pliocene, but one species, *Paleophoca nystii,* is known from the Antwerp basin of Belgium. At this stage, the Scaldisian seas covered the greater part of Holland, the Antwerp basin of Belgium, and part of Germany, and extended over the counties of Norfolk and Suffolk in England. *Paleophoca* was a larger and bulkier form than *Pristiphoca* of the Mediterranean region, and may have descended from *Monotherium.* The femur and humerus of *Paleophoca* are considerably larger and of a rather different type than those of *Pristiphoca occitana.* It is probable that *Paleophoca* died out at the close of the Pliocene. The phocid from the Wadi Natrûn in Egypt is of a type allied to *Pristiphoca* rather than to *Paleophoca.* The mandibular ramus is evidently of the long, slender type characteristic of *Pristiphoca,* and not the larger, heavier type exhibited by *Paleophoca.* The skull and mandibular ramus of *Pristiphoca,* so far as known, agree very closely in many respects with those of the existing genus *Monachus.*

It would be premature to attempt to set forth the relationships of the Monachinae with other phocids until we can trace their ancestral history by means of fossil forms. However, in studying the osteological characteristics of the various known forms, several points clearly present themselves. The humerus is more like that characteristic of the Cystophorinae, though in cranial and other skeletal features it is even more widely separated from the latter than from the Phocinae. One observes that the number of incisors, the peculiar form and reduced size of the auditory bullae, and the similar prolongation backward of the malar process of the maxilla, as pointed out by Allen[175] are points of similarity with the Antarctic Lobodoninae, which differ as much from each other as they do from *Monachus*.

The presence of *Monachus schauinslandi*[176] in the Pacific Ocean, particularly in the vicinity of Laysan Island, shows that the Monachinae must have had a very extensive distribution in the tropical seas as early as or even before the Lower Miocene. Otherwise, it would be difficult to account for their presence today in the Pacific Ocean. Another form, *Monachus tropicalis*,[177] occurs at Yucatan, Florida, Jamaica, and Cuba, its range being restricted chiefly to the Caribbean Sea and the Gulf of Mexico. The European form, *Monachus albiventer*,[178] ranges from the Black, Adriatic and Mediterranean seas to the Canary Islands, and possibly farther south along the east coast of Africa.

In some respects the Monachinae appear to be related to the Otariidae. This relationship is indicated by the absence of the entepicondylar foramen on the humerus, the presence of strong vertebral processes, and the general form of the skull. But these characters are very slight in comparison to the wide differences which separate the Monachinae from the Otariidae. The Otariidae are characterized by the presence of an alisphenoid canal, a defective inner wall of the orbit, reduced size of the tympanic bullae, basicranial region of an ursid type, and an astragalus without a calcanear process. On the other hand, the Phocidae lack an alisphenoid canal, the inner wall of the orbit is complete or nearly so, the tympanic bullae are usually

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175 Allen, J. A., The West Indian seal (Monachus tropicalis Gray). Bull. Am. Mus. Nat. Hist., vol. 2, no. 1, p. 22. New York, 1887.

176 Matschie, P., Sitz.-Ber. Ges. naturf. Freunde, p. 254. Berlin, 1905. Dill, H. R., and Bryan, W. A., Report of an expedition to Laysan Island in 1911. Bull. No. 42, U. S. Dept. Agric., Bur. Biol. Surv., p. 9. Washington, D. C., 1912.

177 Gray, J. E., Catalogue of the seals and whales in the British Museum, p. 20. London, 1850. Allen, J. A., Bull. Am. Mus. Nat. Hist., vol. 2, no. 1, pp. 1–2. New York, 1887.

178 Boddaert, J., Elenchus animalium, Quadrupedia, p. 170. Rotterdam, 1785.

swollen, the basicranial region approaches that of the felid type, and the astragalus has a calcanear process. On the whole the Monachinae appear to be more closely allied with the Lobodoninae than with the Phocinae.

LOBODONINAE

As already remarked, the Antarctic Lobodoninae appear to be very closely allied to the Monachinae. In considering the relationships of the Lobodoninae with the Holarctic Phocinae, it is at once evident that many great difficulties yet remain to be settled. This subfamily, as a whole, differs considerably from any known fossil or living form of the Holarctic Phocinae.

It is difficult, however, to draw the exact differences that exist between the Monachinae and the Lobodoninae. With the exception of certain American writers, all other previous investigators, including Sir William Turner, placed the genus *Monachus* in the Lobodoninae. If *Monachus* is a member of this subfamily, then the affinities of a large number of fossil pinnipeds are diverted to it.

In regard to aquatic modifications, it has been found that the most perfectly adapted marine mammals possess an exceedingly flexible thoracic wall, and associated with it certain peculiarities in the affected muscles. This condition is probably better developed in *Leptonychotes* than in any other member of the Lobodoninae. The anatomy of this seal was carefully studied by Hepburn,[179] and as a result of his studies he came to the conclusion that pelagic mammals require a more flexible chest than do terrestrial mammals. This flexibility, however, becomes a source of danger to such a highly specialized marine mammal when it comes ashore. In the case of the cetaceans, death is caused as much by suffocation as by starvation. According to the observations of Wilson,[180] few seals are more fully adapted to pelagic life than *Leptonychotes*. This seal is an excellent swimmer, though landing is very difficult for it to accomplish. After it has succeeded in landing, its gait is exceedingly clumsy. Thus it would appear that a long period must have elapsed since it enjoyed the power of using its limbs as an ordinary terrestrial mammal, for it has almost entirely lost the use of its limbs on land or ice.

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[179] Hepburn, D., Observations on the anatomy of the Weddell Seal (Leptonychotes weddelli). Trans. Roy. Soc. Edinburgh, vol. 47, pp. 57–63, 191–194, 321–332, pl. 4. 1909.

[180] Wilson, E. A., National Antarctic Expedition, 1901–1904, Mammalia. Publ. Brit. Mus., vol. 2, pp. 23–24. London, 1907.

As remarked before, all the phocids now existing in the Antarctic regions are of large size. Under the prevailing conditions of life, competition is most severe between those forms which are dependent, in the main, on the same types of food. The present occurrence of the Lobodoninae in the Antarctics strikingly confirms this. Both *Leptonychotes weddelli* and *Lobodon carcinophaga* occur in relatively large numbers, though neither encroaches on the other to any marked extent, either in the types of food or in the feeding grounds. The former is a fish eater, and *Lobodon* has acquired the name of crab eater because its food is composed to a large extent of crustaceans. The other two genera of this subfamily, *Hydrurga* and *Ommatophoca,* are not so plentiful, the latter in fact is quite a rarity, but their food is more varied.

In the Lobodoninae are to be found the most conspicuous examples of secondary modification of tooth pattern in the pinnipeds. They can hardly be called the less progressive types of the Phocidae. The dubious lobodonid tooth from the Upper Cretaceous of New Jersey, if valid, would necessarily upset many of our present concepts on the history or derivation of the present type of dentition in the Phocidae. In this tooth there are present the same cusps as are possessed by the living genus, *Lobodon.*

The present distribution of this subfamily indicates that its members for some reason or other left the Phocinae in possession of the Holarctic region while they in turn took possession of the Antarctics. Whether or not they were forced out or crowded into new feeding grounds is a matter of conjecture in the light of our present evidence. The fact is that they have maintained themselves and now exist there to the exclusion of the Phocinae.

CYSTOPHORINAE

During the Middle Pliocene, the form *Mesotaria ambigua,* allied to *Cystophora,* is known from the deposits of the Antwerp basin, and in the uppermost Miocene another form, closely allied to *Mirounga,* ranged along the eastern coast of North America at least as far north as Massachusetts. Today the genus *Mirounga* is limited for the most part to southern oceans, though until very recently *Mirounga angustirostris* was fairly common on the coast of Lower California. The other form, *Mirounga leonina,* is only an occasional visitor to the Antarctic shores, though its range extends from the Heard and Kerguelen Islands, in the Indian Ocean southeast of Madagascar, to South

Georgia in the South Atlantic Ocean, west to Juan Fernandez Island, off the coast of Chili, and in the South Pacific to New Zealand. At present, our collections do not contain sufficient material to confirm the contention of Peters[181] that this last mentioned form really comprises four distinct species.

According to morphological evidence, the nearest relative of *Mirounga* is *Cystophora* of the North Atlantic Ocean. Until recently it was supposed that *Cystophora antillarum*[182] of the West Indies was a hypothetical species. The various circumstances affecting its validity need not be discussed here. Miller[183] has recently published a record of the occurrence of an immature *Cystophora* that was killed during the winter of 1916 on the beach at Canaveral, Florida. The northern representative, *Cystophora cristata*[184] ranges from Spitzbergen and Scotland west to Greenland and the Arctic Sea, south to Nova Scotia, and probably occasionally as far south as Maryland. Thus it is evident that the Cystophorinae is the only subfamily of the Phocidae which is present in both Holarctic and Antarctic regions.

The assumption that *Ommatophoca* is more closely related to the Cystophorinae than to the Lobodoninae has recently been advocated by Wilson,[185] but as no skeleton was available for study, nothing further can be added to his statement. In this discussion Wilson attempts to show that the genus *Mirounga* is closely related to the Otariidae. The facts that he has adduced in support of his contention are hardly worthy of acceptance for the establishment of such a relationship. He further cites the long series of characters drawn up by Professor Flower in an effort to prove that *Mirounga* was more perfectly adapted to a pelagic life than any other phocid. Undoubtedly, in point of size, this genus has far outstripped the others, but the possession of a short, stout femur, and the rudimentary condition of the calcanear process, do not necessarily mean a high degree of specialization.

In conclusion it may be said that our knowledge of this subfamily is so unsatisfactory that the solution of its ancestry must await additional discoveries of fossil forms.

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181 Peters, W., Monatsb. K. P. Akad. Wissensch. zu Berlin, p. 394. 1876.

182 Gray, J. E., Proc. Zool. Soc. London, p. 93. 1849.

183 Miller, G. S., A hooded seal in Florida. Proc. Biol. Soc. Washington, vol. 30, pp. 121–124. 1917.

184 Erxleben, J. C. P., Systema Regni Animalis, vol. 1, p. 590. Lispius, 1777.

185 Wilson, E. A., *op. cit.*, vol. 2, pp. 47–48, 57–59.

PALEONTOLOGIC EVIDENCE BEARING ON THE ORIGIN OF THE PINNIPEDIA

Among living Mammalia the seals, sea lions and walruses comprise a group whose ancestry has so far been shrouded in mystery. Even if one were not familiar with the relative scarcity of known specimens from the Tertiary marine beds of this and other countries he would be justified, from the highly specialized aquatic adaptations of this group, in placing their origin far back in the Tertiary, at a time when the primitive divergence of the various lines of Carnivora was taking place.

The ancestry of the Pinnipedia has been the subject of investigation by many of our foremost paleontologists. The subject is especially interesting, for these men have not succeeded in convincing each other as to the correct interpretation of the evidence which they had at hand. Anyone who has had occasion to look up information concerning this group is no doubt aware that of the two best and latest books on fossil mammals, one contains an incidental mention of but two species, while the other contains the statement that, since so little is known concerning the pinnipeds, they will not be dealt with at all.

In dealing with such a controversial subject as the ancestry of the pinnipeds, it seems advisable to consider briefly, at least, the essential criteria on which the interpretation of the various factors concerned must depend. A consideration of the genealogy of this group involves not only the morphologic evidence but also the stratigraphic occurrence, and the nature of the deposit as well, whether fresh-water or marine. Morphologically, we are confronted with the problem of distinguishing between characteristics which would theoretically belong to a definite stage in evolution and those due possibly to retrogression or to other causes that must be taken into account. These morphologic criteria, while of prime importance, are frequently masked by aquatic adaptations. In general, to establish beyond doubt the geological antiquity of the pinnipeds, it must be shown that the characters possessed by the earliest known forms are considerably more specialized than those possessed by their assumed terrestrial relatives.

Unfortunately the known fossils are not as yet sufficiently complete to enable one to trace the history of the group below the Lower Miocene or Temblor stage. From this stage on to the present time, while there is much to be desired in the way of intermediate forms to establish a closely connected series extending to modern types, yet those that are known furnish some clews as to how specialization has proceeded. The early history of this group has long been a subject of much controversy and will likely remain so until a series of connecting forms is discovered to unite the known Miocene forms with their ancestral group. However, what now remains is to direct attention to the marine beds preceding the Temblor stage with the hope that such connecting forms will be found and to ascertain if possible the various points which will clear up the ancestry of this very interesting group. While many writers have expressed opinions as to the ancestry of this group, none of them have successfully traced the origin of the group back to any particular genus, or even to any particular family. This is largely due to the fact that, while quite a number of forms have been described, most of the descriptions were based on scanty material.

Evolutionary changes have not progressed equally in all the families of the Pinnipedia. These changes may be progressive in one direction or retrogressive along another. There may be an apparent standstill, as in the case of *Phoca*, or even a complete disappearance of one or more lines. Such considerations complicate very much the problem of following out the lines of descent of any group. At each period some individuals were doubtless more advanced than others. Numerous changes have taken place in the structural organization of the different members of the three families of pinnipeds and these changes may appear more pronounced in one part of the body than in others.

In considering the evolution of the Pinnipedia it has to be admitted that the earliest forms of this group of which we have any knowledge were even then somewhat highly modified for aquatic life. The pinnipeds were well specialized in the Miocene for a pelagic life and the distribution of the fossil forms corresponds very well, in most respects, with the present distribution of their living representatives. There are some doubtful exceptions to this statement which have as yet to be confirmed by future exploration.

The earliest forms, as already mentioned, of which we have any knowledge, are found in the Lower Miocene; at the same time it is certain that the group was detached from the main stem of the Carnivora at a much earlier date. Several theories at wide variance with each other have been proposed to explain the origin of this group. Their relationships with *Pantolestes, Smilodon, Patriofelis, Cynarctus,* and *Synoplotherium* have been discussed by various writers. The derivation of the Pinnipeds from the arctoid Fissipedia has been supported by George Mivart, Thomas Huxley, W. H. Flower, and more recently by Max Weber, and W. D. Matthew. In view of the highly debatable nature of the evidence that has been offered, I hesitate somewhat to offer any opinion. Only two of these theories will be here considered. The rest may be put in the doubtful column, for no adequate evidence has so far been adduced to place these speculations on an acceptable basis.

The first theory which will be considered is the derivation of the Pinnipedia from the Oxyaenidae, a family of inadaptive creodonts. These Oxyaenidae of the Eocene fauna appear to correspond with the Mustelidae among modern Carnivora. The exponent for this derivation of the Pinnipedia from *Patriofelis* or from the Oxyaenidae is Wortman.[186] He states that the primitive pinnipeds retain many characters in common with the Oxyaenidae, and has adduced the following points which have yet to be explained before the ursid derivation can be accepted.

1. The presence of a subungual foramen.
2. A large astragalo-cuboid contact.
3. An oblique cubo-calcaneal facet.
4. The exceptionally large size of the trapezium.

Dr. Matthew[187] has pointed out the chief objections to Wortman's theory and has adduced a series of characters to show that the evidence is, instead, in favor of the derivation of the pinnipeds from the arctoid Fissipedia. The following is his summary.

1. The lachrymal is large and broadly expanded upon the face in both the Inadaptive Creodont groups. In the Adaptive Creodonta it is smaller, in the Fissipedia still further reduced, especially in Ursidae and some Mustelidae. In the Pinnipedia it has entirely disappeared.

2. The mode of molar reduction indicated in the Pinnipedia corresponds well with that generally indicated in the Adaptive Creodontia and Fissipedia, and disagrees fundamentally with the Oxyaendae and Hyaenodontidae. In the Pinnipedia $M\frac{1}{1}$ are always present and of large size; a small M^2 is occasionally present, but never any trace of $M_{\bar{2}}$. Their more generalized ancestors must therefore have had $M\frac{2.3}{2.3}$ small, early reduced and lost. This agrees with the Adaptive Creodonts and Fissipedia, in particular with Mustelidae and Ursidae. In the Oxyaenidae $M\frac{2.3}{3}$ are early reduced and lost, but $M_{\bar{2}}$ is the largest of the lower teeth, and progressively increased and specialized. If the seals were descended from Oxyaenidae their formula might vary from $M\frac{1}{1.2}$ to $M\frac{1.2}{1.2}$ but not from $M\frac{1}{1}$ to $M\frac{1.2}{1}$. In the Hyaenodontidae $M\frac{1.2}{1.2.3}$ or $M\frac{1.2.3}{1.2.3}$ would be the molars likely to be preserved.

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186 Wortman, J. L., Bull. Am. Mus. Nat. Hist., vol. 6, p. 157. 1894. Am. Jour. Sci. (4), vol. 13, no. 73, pp. 115–128. 1902. Science, n.s., vol. 24, p. 89. 1906.

187 Matthew, W. D., The Carnivora and Insectivora of the Bridger Basin, Middle Eocene. Mem. Am. Mus. Nat. Hist., vol. 9, pt. 6, pp. 413–417. 1909.

3. The ungual phalanges in Pinnipedia are unfissured, as in Adaptive Creodonts and Fissipedia. In both groups of Inadaptive Creodonts the claws are fissured.

4. The seals possess a tympanic bulla very similar to that of the Ursidae and larger Mustelidae. In the Creodonta the tympanic is not usually expanded into a bulla; in the later Mesonychidae a substantially similar bulla is present, and in certain species of *Hyaenodon* a bulla of rather different type. In the Oxyaenidae, as far as known, there is no tendency to form a tympanic bulla, and in the latest survivor (*Oxyaenodon*) an incipient petrosal bulla takes its place.

5. The united scapho-lunar of the Pinnipedia is a character which must have preceded their aquatic adaptation, as in aquatic vertebrata generally the carpals tend to become reduced and imperfectly ossified but not to become fused. In the Inadaptive Creodonts there is little or no tendency to fusion of the scaphoid and lunar; the Adaptive Creodonts on the contrary early manifest a tendency in this direction, and it has become complete and universal in the Fissipedia, and in the Pinnipedia as well.

6. In the form of the petrosal the Pinnipedia agree better with the Adaptive Carnivora and Fissipedia than with any of the Inadaptive groups, and differ most from the Oxyaenidae.

7. There are a number of points of resemblance to the Ursidae and to a less extent to the Arctoidea generally in the soft anatomy of the Pinnipedia.

However, even this derivation is beset with several difficulties. The following objections might be pointed out.

1. The increase in size of the orbit due to enlargement of the visual organ for sight under water would cause the orbit to encroach on the facial extension of the lachrymal and in a comparatively short time it would be entirely within the orbit. In other words the absence of the facial extension of the lachrymal may be attributed to aquatic adaptation.

2. An M_2 is present in *Allodesmus* from the Temblor beds and it is also occasionally present in *Mirounga*. An M^2 is sometimes present in *Callotaria*. The evidence shows that the reduction of the true molars was very rapid in the Otariidae, at least, whether due to the nature of the food or to unknown reasons. In *Eumetopias* there is a wide separation between the surviving molar and the premolar series. There might be some question as to what molar this one really is. *Erignathus* has the upper molars widely separated from the premolars. The molariform series as a whole are but slightly implanted, becoming defective early by attrition and partly deciduous or abortive in old age. The disappearance or reduction of teeth in the pinnipeds is very irregular.

3. The statement that the seals possess a tympanic bulla very similar to that of the Ursidae has been refuted by Van Kampen,[188] who has shown that the bulla of both the Otariidae and the Phocidae is a composite one, formed of the entotympanic and the annulus tympanicus or true tympanic as in the Æluroidea or cats, though in external appearance it does resemble the arctoid type.

4. The possession of a wholly consolidated scapho-lunar-centrale in the Pinnipedia may not preclude its derivation from a form which possesses these as separate elements. Aquatic adaptation may or may not increase the separation of these bones. The consolidation of the scaphoid, lunar, and centrale in the Sirenia weakens Dr. Matthew's argument here.

5. The bears are of comparatively recent origin, being derived from the dog-line

[188] Van Kampen, P. N., Die Tympanalgegend des Säugetierschädels. Morphol. Jahrb., vol. 34, pts. 3, 4, pp. 537, 542, 545. 1905.

of ancestry. The earliest known pinnipeds are as old or older than any bear known, and the differences between these and the bears are almost as great as between modern seals and bears. Thus the relationships of the bears cannot be very close. The pinnipeds of the Miocene were already highly specialized and the gap between them and Miocene land Carnivora is wide. The same criticism is applicable to *Megalictis*.

6. The superficial resemblance of the maxilloturbinals of ursids and pinnipeds may be a case of convergence. When *Monachus* is compared with boreal Phocidae this extreme hypomycterous condition of the turbinated bones appears to be merely a case of convergence. According to Gregory[189] this hypomycterous condition is an aquatic adaptation for warming inspired air. *Monachus tropicalis* has the maxilloturbinals reduced to mere vestiges while *Erignathus barbatus*, an inhabitant of boreal seas, has them developed to an exceedingly complicated degree.

7. The astragalus of *Allodesmus* possesses a very shallow trochlea, with groove on neck absent. An astragalar foramen is also present. This astragalus is very unlike that of any known ursid, mustelid or amphicyonid astragalus.

There are certain points in the soft anatomy of the Ursidae which are also retained by the Pinnipeds, though many of the assumed weighty characters cited by Max Weber[190] may not really be as important as they have been considered. The similarity of the following structures in both pinnipeds and bears were considered by him to indicate relationship.

1. Absence of duodeno-jejunal flexure of the long intestine which lies in a simple mesentery.
2. The division of the kidneys and liver into a number of separate lobules.
3. The absence of Cowper's glands in the male.
4. Presence of deciduous and zonary placenta and bicornuate uterus.

It has also been shown by Haig[191] that the histogenic features of the kidney of the foetus of *Hydrurga leptonyx* place the seals in a small group of Carnivora to which the bears also belong.

Many of the characters cited by Weber may be due to convergence. The investigations on the brains of pinnipeds and bears by Fish[192] show that while there appear to be many characters in common between the two groups, yet the bears differ from the majority of the pinnipeds in seven points out of sixteen. The studies of Mitchell[193]

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189 Gregory, W. K., The Orders of Mammals. Bull. Am. Mus. Nat. Hist., vol. 27, p. 428. 1910.

190 Weber, M., Die Säugetiere: Einführung in die Anatomie und Systematik der recenten und fossilen Mammalia, pp. 543–551. Jena, 1904.

191 Haig, H. A., A description of the systematic anatomy of a foetal sea leopard (*Stenorhynchus leptonyx*) with remarks upon the microscopical anatomy of some of the organs. Scot. Nat. Antarctic Exped., vol. 4, pp. 461–462, Publ. Brit. Mus. London, 1915.

192 Fish, P. A., The cerebral fissures of the Atlantic walrus. Proc. U. S. Nat. Mus., vol. 26, pp. 675–688, pls. 28–29. 1903.

193 Mitchell, P. C., Further observations on the intestinal tract of mammals. Proc. Zool. Soc. London, pt. 1, pp. 183–251. 1916.

on "gut-patterns" also indicate that the similarities observed in the long intestine may also be a case of convergence. The bears differ from all other Carnivora in the possession of an ansa coli dextra and the lack of a caecum.

At present we may say that the verdict is not proven for any of the hypotheses that have been offered.

CONCLUSIONS

Aquatic adaptation has undoubtedly masked many changes in structure in the evolution of the Pinnipedia and these changes have profoundly affected the whole internal as well as external organization of the various members of the group. The most obvious changes relate largely to those of the limbs and skull. The vertebrae of most fossil pinnipeds are very imperfectly known. We can only surmise the incipient transformations that marked the transformation of some member of the land carnivora into a pelagic pinniped.

According to the theory proposed by Kükenthal[194] we may assign the relationships of aquatic animals in proportion to the length of time that has elapsed since their separation from their terrestrial relatives. Also that the amount of adaptation is intimately connected with the length of time that has elapsed since they were subjected to the influence of the water and with the degree of connection that they have retained with the land. This theory explains, to some extent, why the pinnipeds have not been so strongly modified as either the whales or sirenians, for they are dependent upon land to bring forth their young.

In course of time, aquatic adaptation has brought about a shortening of the fore limbs and a lengthening of the hind pes. At the same time there has been a marked change in the nature of the molariform teeth. The reduction of the angular tuberosities, as pointed out by Osburn[195] is generally indicative of aquatic adaptation, for water does not require the development of such heavy muscles as are needed for progression on land or for support. There is also an increased flexibility of the vertebral column, along with the reduction of the interlocking processes, a shortening and a heightening of the centra

[194] Kükenthal, W., Ueber die Anpassung von Säugethieren an das Leben im Wasser. Zool. Jahrb., vol. 5. 1890.

[195] Osburn, R. C., Adaptation to aquatic, arboreal, fossorial and cursorial habits in mammals, aquatic adaptations. Am. Nat., vol. 37, no. 442, pp. 651–665. Adaptive modifications of the limb skeleton in aquatic reptiles and mammals. Ann. Acad. Sci. New York, vol. 16, p. 449. 1906.

and the enlargement of the intervertebral foramina in an adaptation to pelagic life. The pinnipeds possess a pelvis more nearly parallel to the vertebral column than do any of the terrestrial carnivora.

The length of the skull of the pinnipeds seems to be conditioned largely by the length of the jaw, and its shape, as previously pointed out, is largely the result of certain muscular adaptations. In no case, excepting *Mirounga,* do we find the elongation of the head, which is usually so characteristic of prolonged aquatic adaptation. In most cases the face is short, while the cranium may be nearly flat as it is in the genera, *Phoca, Monachus, Erignathus* and *Cystophora.* It has been stated by Williston[196] that "it seems to be a law of evolution that no large creatures can give rise to races of smaller creatures," and that "the largest sea animals have been the final evolution of their respective races." As the history of the animals in the past appeared to confirm this, it was assumed by some that the sea lions, walruses, and elephant seals therefore represent a higher degree of specialization than do the smaller seals and that the latter approximate more nearly in size the ancestral group. Furthermore, Pocock[197] has found in many instances within the limits of a single order that the species which were defective in the matter of vibrissae were the higher derivative types, whereas those in which all or most of the vibrissae persist were the most generalized types. He found that in the Pinnipedia only the mystacial and superciliary tufts of vibrissae were retained. In the Otariidae the supercilliaries were short and few, while in the Phocidae they were well developed.

On the other hand, the Phocidae show many evidences of being the most specialized. For instance, the hind limbs have undergone a greater modification than those of either the Odobenidae or Otariidae and are consequently no longer capable of being turned forward in progression on land. The external nares are more dorsal in the Phocidae than in either of the others. The testes are inguinal and not scrotal as they are in the Otariidae. Many other modifications could be cited.

In some respects the Odobenidae appear to have been under the influence of water the longest, namely, in the possession of a heavy and dense skeleton in correlation with its bottom feeding habits, in the moving of the lower canines over into the molariform series and

[196] Williston, S. W., Water reptiles of the past and present, p. 61. Chicago Univ. Press. 1914.

[197] Pocock, R. I., Proc. Zool. Soc. London, p. 912. 1914.

their subsequent modification for a crushing function, in the enormous development of the upper canines as tusks, and finally in the loss of most of the hair and its replacement by blubber.

The Otariidae, taking all the evidence into consideration, appear to be the least adapted to a pelagic life or at least have adopted such a life at a much later period than either the Phocidae or Odobenidae. One writer, Sclater,[198] misled by the lack of authentic fossil otarids, went so far as to state that *Otaria* (=*Eumetopias*) was originally an Antarctic form, the present forms on the west coast of North America being offshoots of that stock.

In the matter of cranial changes it is difficult to say with any degree of precision what has actually occurred. The form, *Allodesmus,* throws some light on these changes. There are certain cranial changes in the configuration of the skull with evolution in the carnivora as was shown by Dr. Matthew.[199] He pointed out that the high sagittal and occipital crests become reduced with the lateral expansion of the parietals and squamosals. With the increase in area for attachment of temporal muscles of the lower jaws the need of such additional supports is lessened. This change can be best illustrated by a comparison of *Arctocephalus australis* with *Callotaria alascana.* The former possesses a high sagittal crest, small brain case with long interorbital region, but with orbit far forward. The latter has a marked lateral expansion of the parietals, no sagittal crests except in old adults, a relatively large brain case, and a short broad interorbital region. This enlargement of the orbit may be due to an increase in the size of the eye to adapt the animal for under water vision, paralleling conditions in this respect observed by Professor John C. Merriam[200] and others in the ichthyosaurs.

An attempt to account for the evolution of the Pinnipedia on the basis of successive adaptive changes to an aquatic mode of life will probably be critized by experimentalists. They have endeavored to show that such characters would not be inherited and have brought forward much evidence to support their contention. But no matter how we may try to explain these modifications in the various members of the Pinnipedia, it is evident that changes in food and habits have

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198 Sclater, P. L., On the distribution of marine mammals. Proc. Zool. Soc. London, p. 350. 1897.

199 Matthew, W. D., The carnivora and insectivora of the Bridger Basin, Middle Eocene. Mem. Am. Mus. Nat. Hist., vol. 9, pt. 6, p. 312. 1909.

200 Merriam, J. C., Triassic ichthyosauria, with special reference to the American forms. Mem. Univ. Calif., vol. 1, p. 74. 1908.

occurred along with correlated changes in structure in each of the three families of pinnipeds.

An enquiry into the morphological characters of the Pinnipedia leads one to the conclusion that the nature of the characters exhibited by the various members indicates that the changes must have been brought about by slow though gradual variations. Even if the dentition and the correlated changes in skeletal and anatomical structure were modified before they sought new food or assumed new habits, or, in other words, structure precedes function as held by most experimentalists, it appears that the Pinnipedia passed through the following stages of evolution:

1. A terrestrial type, chiefly carnivorous with tritubercular dentition. The skull must have possessed well developed sagittal and occipital crests. It must have had an astragalus with slight or ungrooved trochlea, an astragalar foramen, an entepicondylar foramen, and an alisphenoid canal. The vertebral formulae was: C7, D15, L5, S3–4, Ca8–12. The dentition was: I. $\frac{3\text{-}3}{3\text{-}3}$, C. $\frac{1\text{-}1}{1\text{-}1}$, Pm. $\frac{4\text{-}4}{4\text{-}4}$, M. $\frac{3\text{-}3}{2\text{-}2}$.

2. A subaquatic type subsisting in part on a carnivorous diet though largely on turtles and fish. The teeth were greatly abraded because of the nature of their food and probably exhibited an incipient retrogression of the tritubercular type to the haplodont type.

3. A pelagic type subsisting largely on cephalopods and fish. The skull possessed a high sagittal crest. The dentition now, in the otarids at least, was of a haplodont type.

4. A highly specialized pelagic type subsisting largely on fish and crustacea. Skull now marked by lateral expansion of parietals and reduction of sagittal crest. Molariform teeth now characterized by the remarkable specialization of secondary cusps.

In conclusion it may well be stated that the origin of the Pinnipedia is completely unknown as yet. From a careful study of this Temblor form it appears that we must look for the ancestral otarids among the Carnivora long before there were any true bears or wolves. Our evidence for assuming such an early divergence from the parent stock is warranted by the fact that the families Phocidae, Otariidae and Odobenidae were already well differentiated from each other before the end of the Miocene. These differentiations probably represented at first local changes in adaptation to different feeding zones, terrestrial, littoral, and pelagic. Furthermore, as specialization proceeded, each of these types has diverged further and further from each other.

With regard to the phocids, they may or may not have descended from the same ancestor as the otarids. It is possible that much of the confusion and uncertainty that has arisen in phylogenetic studies of the pinnipeds is due to a polyphyletic origin.

A CHECK LIST OF FOSSIL PINNIPEDIA
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Type locality.—Sea beach of Accomac County, Virginia. Pleistocene.

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Type, *Allodesmus kernensis* Kellogg.

ALLODESMUS KERNENSIS Kellogg

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Type locality.—Temblor beds of the Kern River region, near center of Section 28, Township 28 South, Range 29 East (Mount Diablo Base and Meridian), California. Lower Miocene.

Genus PONTOLIS True

Pontolis. True, F., Proc. Biol. Soc. Washington, vol. 18, p. 253, 1905.

Type, *Pontoleon magnus* True.

PONTOLIS MAGNUS True

Pontoleon magnus. True, F., Smithson. Misc. Coll. (quar. issue), vol. 48, pt. 1, p. 48. 1905.

Pontolis magnus. True, F., Prof. Paper no. 59, U. S. Geol. Surv. pp. 144–147, pls. 21–23. Washington, D. C., 1909.

Type locality.—Sandstone bluff on the east side of the lower part of Coos Bay, between Empire City and the south slough, Coos County, Oregon. Lower Pliocene.

Genus EUMETOPIAS Gill

Eumetopias. Gill, T., Proc. Essex Inst., vol. 5, Communications, p. 7. 1866.

Type, ''*Otaria californiana*'' = *Otaria stelleri* Lesson.

EUMETOPIAS JUBATA (Schreber)

Eumetoppias stelleri. Bowers, S. Am. Geol, vol. 4, p. 391. 1889.

Eumetopias stelleri. Hay, O. P., U. S. Geol. Surv., Bull. no. 179, p. 783. Washington, 1902.

Type locality.—Ventura, Ventura County, California. Pleistocene.

EUMETOPIAS BYRONIA (Blainville)

Otaria jubata. Ameghino, F., Act. Acad. Nac. Ciencias, Cordoba, Argentina, vol. 6, p. 343. 1889.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 219. Washington, D. C., 1880.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 53. Wien und Leipzig, 1898.

(*Otaria*) *jubata foss.* Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 73. Augsburg, 1896.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 370. Berlin, 1897.—True, F., Prof. Paper no. 59, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 148. Washington, D. C., 1909.

Otarie. Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 52. Brussels, 1877. (Bed Danube River, Austria.)—Gervais, P., Bull. Soc. Geol. de France (2), vol. 10, p. 311. Paris, 1852–53. (Sea beach, Department of Landes, France.)

Genus DESMATOPHOCA Condon

Desmatophoca. Condon, T., Univ. Oregon Bull., Suppl., vol. 3, no. 3, p. 11. Eugene, 1906.

Type, *Desmatophoca oregonensis* Condon.

DESMATOPHOCA OREGONENSIS Condon

Desmatophoca oregonensis. Condon, T., Univ. Oregon Bull., vol. 3, Suppl., no. 3, pp. 6–13, pl. 2. Eugene, 1906.—Wortman, J. L., Science, n.s., vol. 24, no. 603, pp. 89–92. 1906.—Hay, O. P., Proc. U. S. Nat. Mus., vol. 49, p. 383. Washington, D. C., 1915.

Desmatognathus oregonensis. Lydekker, R., International Catalogue Scientific Literature for 1906, pt. N, Mammalia, p. 68. London, 1908. (*Lapus* for *Desmatophoca.*)

Type locality.—Miocene shales along beach just west of town of Newport, eight miles south of Yaquina Bay, Lincoln County, Oregon. ~~Upper~~ Lower Miocene.

Genus ZALOPHUS Gill

Zalophus. Gill, T., Proc. Essex Inst., vol. 5, Communications, p. 7. 1866.
Type, *Otaria gillespii* MacBain = *Otaria californiana* Lesson.

ZALOPHUS WILLIAMSI McCoy

Arctocephalus williamsi. McCoy, F., Prodromus of the Palaeontology of Victoria, decade 5, Geol. Surv. of Victoria, pp. 7–9, pls. 41–42. Melbourne, 1877.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 770. Washington, D. C., 1880.—True, F., Prof. Paper no. 59, U. S. Geol. Surv., p. 148. Washington, D. C., 1909.

(*Zalophus*) *williamsi.* Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 372. Berlin, 1897.

Type locality.—From the incoherent beds alternating with the Pliocene Tertiary limestones of Queenscliff at entrance to Port Phillip Heads, and at Cape Otway, Australia. Upper Pliocene.

ZALOPHUS LOBATUS (Gray)

Arctocephalus lobatus?. Haast, J., Nature, vol. 14, p. 577. 1876.

A(*rctocephalus*) *cinereus.* Haast, J., Nature, vol. 14, p. 577. 1876.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 35, 38, 29. Brussels, 1877.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 217. Washington, D. C., 1880.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 52. Wien und Leipzig, 1898.

Type locality.—Moa Bone Point Cave, Middle Island, Bank's Peninsula, New Zealand. ?Recent.

Genus ARCTOCEPHALUS F. Cuvier

Arctocephalus. Cuvier, F., Dict. des sci. nat., vol. 39, p. 554. 1827.
Type, *Arctocephalus ursinus* F. Cuvier = *Phoca ursina* Linnaeus.

ARCTOCEPHALUS FISCHERI (Ameghino)

Otaria fischeri. Gervais, H., and Ameghino, F., Les mammiferes fossiles de l'Amerique du Sud, p. 223. Buenos Aires and Paris, 1880. (A *nomen nudum.*)—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 73. Augsburg, 1896.

Arctophoca fischeri. Ameghino, F., Bol. Acad. Nac. Ciencias, Cordoba, Argentina, vol. 9, p. 214. 1886.—Ameghino, F., Act. Acad. Nac. Ciencias, Cordoba, Argentina, vol. 6, pp. 342, 343. 1889.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 53. Wien und Leipzig, 1898.

(*Arctocephalus*) *fischeri.* Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 374. Berlin, 1899.—True, F., Prof. Paper no. 59, U. S. Geol. Surv., p. 148. Washington, D. C., 1909.

Type locality.—''Piso patagonico de la formacion patagonica'' in the province of Parana, Argentina. Lower Miocene.

ARCTOCEPHALUS FORSTERI (Lesson)

Gypsophoca subtropicalis. Haast, J., Nature, vol. 14, p. 577. 1876.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 35. Brussels, 1877.

Gypsophoca tropicalis. Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 217. Washington, D. C., 1880.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 52. Wien und Leipzig, 1898.

Ot(aria) forsteri. Roger, O., Berich naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 73. Augsburg, 1896.

Type locality.—Moa Bone Point Cave, Middle Island, Bank's Peninsula, New Zealand. ?Recent.

INCERTAE SEDIS

OTARIA OUDRIANA Delfortrie

Otaria oudriana. Delfortrie, E., Actes de la Societe Linneenne de Bordeaux (3), vol. 8, pp. 384–385, figs. 1a, 1b. 1872.—Gervais, P., Jour. de Zool., vol. 1, p. 325, figs. 1a, 1b. Paris, 1872.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 25. Brussels, 1877.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 218. Washington, D. C., 1880.—Zittel, K. v., Traité de Paléontologie, pt. 1, Paléozoologie, vol. 4, p. 690. Paris, 1894.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns, vol. 11, pp. 51, 55. Wien und Leipzig, 1898.

(*Mesotaria*) *oudriana.* Roger, O., Berich naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 378. Berlin, 1897.

Otaria ondriana. True, F., Prof. Paper no. 59, U. S. Geol. Surv., p. 147. Washington, D. C., 1909.

Type locality.—Bone breccia of Saint-Medard-en-Jalle, near Bordeaux, France. Upper Oligocene.

Genus PALAEOTARIA Leriche

Palaeotaria. Leriche, M., Annales Soc. Geol. du Nord, Lille, vol. 39, pp. 369–370. 1910.

Type, *Palaeotaria henriettae* Leriche.

PALAEOTARIA HENRIETTAE Leriche

Palaeotaria henriettae. Leriche, M., Annales Soc. Geol. du Nord, Lille, vol. 39, pp. 369, 370. 1910.

Type locality.—In the "Calcaire grossier à *Archiacina armorica*" in the vicinity of Rennes, France. Middle Oligocene.

PHOCIDAE

Gray, J. E., Thompson's Ann. Philos., vol. 26, p. 340. 1825.

Genus MESOTARIA Van Beneden

Mesotaria. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, pp. 796–797. Brussels, 1876.

Type, *Mesotaria ambigua* Van Beneden.

MESOTARIA AMBIGUA Van Beneden

Mesotaria ambigua. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, pp. 796–797. Brussels, 1876.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 56–60, pl. 9. Brussels, 1877.—Mourlon, M., Bull. Acad. Roy. des Sci., des Léttres et des Beaux-Arts de Belgique (2), vol. 43, no. 5, p. 607. Brussels, 1877. (Berchem; Wommelghem; Deurne?; Borgerhout?.)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, pp. 219, 478. Washington, D. C., 1880.—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Palmer, T. S., North Am. Fauna no. 23, p. 416. Washington, D. C., 1904.—True, F., Prof. Paper no. 59, U. S. Geol.

Surv., p. 147. Washington, D. C., 1909.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 52, 55. Wien und Leipzig, 1898.

Type locality.—Second and third sections, also at Wommelghem, Antwerp Basin, Belgium. Middle Pliocene.

MESOTARIA? sp.

Cystophora proboscidea. Lyell, C., London and Edinburgh Philos. Mag., vol. 33, p. 188. 1843.—Lyell, C., Neues Jahrbuch f. Mineralogie, pp. 221–222. Stuttgart, 1844.—Lyell, C., Am. Jour. Sci., vol. 46, p. 319. 1844.—Lyell, C., Proc. Geol. Soc. London, vol. 4, no. 92, p. 32. 1846. —Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 470. Washington, D. C., 1880.

Ph. (Cystophora) proboscidea. Giebel, C. G., Fauna der Vorwelt, vol. 1, p. 224. Leipzig, 1847.

Ph(oca) proboscidea. Pictet, F. J., Traité de Paléontologie (2), vol. 1, p. 233. Paris, 1853.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 33. Brussels, 1877.

Cystophora cristata. Hay, O. P., U. S. Geol. Surv., Bull. no. 179, p. 785. Washington, 1902.

Type locality.—In the yellowish and dark brown clay near the uppermost part of the section at Gay Head and in the green sand immediately resting upon it, Martha's Vineyard, Massachusetts. Upper Miocene.

Genus PRISTIPHOCA Gervais

Pristiphoca. Gervais, P., Mem. Acad. Sci. Montpellier, vol. 2, pt. 2, pp. 308–309, pl. 6, fig. 4. 1852–53.

Type, *Phoca occitana* Gervais and Serres.

PRISTIPHOCA OCCITANA (Gervais and Serres)

Phoca occitana. Gervais, P., and Serres, M. de, Ann. Sci. Nat., Paris (3), vol. 8, p. 225. 1847.—Gervais, P., Zoologie et Paléontologie françaises (1), vol. 1, p. 140. (Part.) Paris, 1848–52.—Gervais, P., Ann. Sci. Nat., Paris (3), vol. 16, p. 152. 1851.—Gervais, P., Mem. Acad. Sci. Montpelier, vol. 2, pt. 2, pp. 308–309, pl. 6, fig. 4. 1852–53.—Gervais, P., Ann. Sci. Nat., Paris (3), vol. 20, pp. 281–282, pl. 13, figs. 8, 8a. 1853.—Gervais, P., Bull. Soc. Geol. de France (2), vol. 10, p. 311. Paris, 1853. (Part.)—Palmer, T. S., North Am. Fauna, no. 23, p. 563. Washington, D. C., 1904.

Phoca occitanica. Pictet, F. J., Traité de Paléontologie (2), vol. 1, p. 233. Paris, 1853.

Pristiphoca occitana. Gervais, P., Zoologie et Paléontologie françaises (2), pp. 272, 273, pl. 82, figs. 4, 4a. Paris, 1859. (Part.)—Gervais, P., Journal de Zoologie, vol. 1, p. 66. Paris, 1872. (Part.)—Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 32, no. 7, p. 5. Brussels, 1871.—Lawley, R., Atti della Soc. Toscana Sci. Nat. resid. in Pisa, vol. 1, fasc. 1, p. 66. 1874. (Orciano.)—Lawley, R., Nuovi studi sopra ai pesci ed altri vertebrati fossili delle colline

Toscane, pp. 103–104. Florence, 1876. (Orciano.)—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 25, 27, 64. Brussels, 1877. (Part.)—De Alessandri, G., Mem. Museo civico di Storia Naturale di Milano e Soc. Ital. di Sci. Nat., vol. 6, fasc. 1, pp. 17–18, pl. 1, fig. 1. 1897.

Pristophoca occitana.—Forsyth-Major, C. I., Atti della Soc. Toscana Sci. Nat. resid. in Pisa, vol. 1, fasc. 3, p. 226. 1876.

Pristiophoca occitana. Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, pp. 477, 478, 479. Washington, D. C., 1880.

Pristiphoca occitanica. Zittel, K. v., Traité de Paléontologie, pt. 1, Paléozoologie, vol. 4, p. 689 (translation Barrois). Paris, 1894.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 49, 54. Wien und Leipzig, 1898.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 379. Berlin, 1897.

Monachus albiventer. Ugolini, R., Palaeontographia Italica, Mem. Paleo., vol. 8, pp. 1–20, pls. 1–3. Pisa, 1902.

TYPE LOCALITY.—Pliocene marine sands of Montpelier, Department of Herault, France. Upper Pliocene.

PRISTIPHOCA sp.?

Phocidae. Stromer, E., Abhandl. Senckenb. naturf. Gesellsch., vol. 29, p. 121, pl. 20, fig. 10, Frankfurt, 1905.—Andrews, C. W., Desc. cat. Tert. vert. Fayûm, Egypt, p. xi. London, 1906.

TYPE LOCALITY.—Wadi Natrûn, Egypt. Upper Pliocene.

Genus PALEOPHOCA Van Beneden

Paleophoca. Van Beneden, Bull. Acad. Roy. Sci. de Belgique (2), vol. 8, no. 11, p. 142. Brussels, 1859.

Type, *Paleophoca nystii* Van Beneden.

PALEOPHOCA NYSTII Van Beneden

Phoque. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique, vol. 20, pp. 255–258, text fig. 1. Brussels, 1853.

Paleophoca nystii. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 8, pt. 8, no. 11, pp. 123–146. Brussels, 1859.—Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, p. 797. Brussels, 1876.—Palmer, T. S., North Am. Fauna, no. 23, p. 506. Washington, D. C., 1904.

Palaeophoca nystii. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 8, pt. 8, no. 11, p. 145. Brussels, 1859.—Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 32, no. 7, pp. 10–12, pl. 2. Brussels, 1871.—Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 32, nos. 9–10, p. 171. Brussels, 1871.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 27, 60, 65, pl. 10. Brussels, 1877.—Mourlon, M., Bull. Acad. Roy. des Sci., des Léttres et des Beaux-Arts de Belgique (2), vol. 43, no. 5, p. 607.

Brussels, 1877. (Wommelghem; Deurne et Borgerhout?.)—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 54. 1898.

Palaeophoca nysti. Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, pp. 477, 478, 479. Washington, D. C., 1880.

(*Pristiphoca*) *nystii.* Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 380. Berlin, 1899.

Paläophoca nystii. Roger, O., Berich naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, pp. 73–74. Augsburg, 1896.

Palaophoca nystii. Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 52. Wien und Leipzig, 1898.

Phoca nystii. Gervais, P., Journal de Zoologie, vol. 1, p. 65. Paris, 1872.

Phoca d'Anvers. Gervais, P., Zoologie et Paléontologie françaises (2), pp. 274–275; Atlas, pl. 82, figs. 1, 1a. Paris, 1859.

TYPE LOCALITY.—Upper Crag of St. Nicholas, near Antwerp, Belgium. Middle Pliocene.

PHOCID?

Phoca ambigua. Staring, W. C. H., De Bodem van Nederland, vol. 2, pp. 282, 283. Haarlem, 1860.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 25. Brussels, 1877. (Preoccupied by *Phoca ambigua* Münster.)

"*Phoque.*" Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 32, no. 7, p. 7. Brussels, 1871. (Koerboom, near Swilbroek, Holland.)

Palaeophoca nystii. Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 25, 61. Brussels, 1877.

TYPE LOCALITY.—In the bed of the Meuse River at Elsloo, near Maestricht, Holland. Middle Oligocene.

Genus MONOTHERIUM Van Beneden

Monotherium. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, pp. 800–801. Brussels, 1876.

Type, *Monotherium delognii* Van Beneden.

MONOTHERIUM DELOGNII Van Beneden

Monotherium delognii. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, p. 800. Brussels, 1876.—Palmer, T. S., North Am. Fauna, no. 23, p. 431. Washington, D. C., 1904.

Monatherium delognii. Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 75–76, pl. 16, figs. 1–6. Brussels, 1877.—Mourlon, M., Bull. Acad. Roy. des Sci., des Léttres et des Beaux-Arts de Belgique (2), vol. 43, no. 5, p. 608. Brussels, 1877. (Borgerhout et Deurne.)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geogr. Surv. Terr., Dept. Interior, p. 479. Washington, D. C., 1880.—Lydekker, R., Cat. Foss. Mamm. Brit. Mus., pt. 1, pp. 206–207. London, 1885.—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Toula, F., Beiträge

z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 49, 52, 54. Wien und Leipzig, 1898.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 380. Berlin, 1897.

Monotherium affine. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, pp. 800, 801. Brussels, 1876.

Monatherium affine. Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 76–77. Brussels, 1877.—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 380. Berlin, 1897.

Monatherium affinis. Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, Atlas, vol. 1, pt. 1, pl. 16, figs. 7–14. Brussels, 1877.—Mourlon, M., Bull. Acad. Roy. des Sci., des Léttres et des Beaux-Arts de Belgique (2), vol. 43, no. 5, p. 608. Brussels, 1877. (Borgerhout et Deurne.)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 479. Washington, D. C., 1880.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 52, 54. Wien und Leipzig, 1898.

Type locality.—At Borgerhout and throughout second and third sections, Antwerp Basin, Belgium. Upper Miocene.

MONOTHERIUM ABERRATUM Van Beneden

Monotherium aberratum. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, p. 801. Brussels, 1876.

Monatherium aberratum. Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 77–78, pl. 17. Brussels, 1877.—Mourlon, M., Bull. Acad. Roy. des Sci., des Léttres et des Beaux-Arts de Belgique (2), vol. 43, no. 5, p. 608. Brussels, 1877. (Contrescarpe du fossé de l'enciente à Berchem.)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv., Dept. Interior, p. 479. Washington, D. C., 1880.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 53, 54. Wien und Leipzig, 1898.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 380. Berlin, 1897.

Type locality.—In second and third sections, at Borgerhout and Turnhout, etc., Antwerp Basin, Belgium. Upper Miocene.

MONOTHERIUM GAUDINI (Guiscardi)

Ph(oca) gaudini. Guiscardi, G., Rendiconto dell'Accad. d. Sci. Fisiche e Matem., fasc. 12, p. 207. Naples, 1870.

Phoca gaudini. Guiscardi, G., Societa Reale di Napoli, Atti dell'Accad. delle Sci. Fisiche e Matem., vol. 5, no. 6, pp. 1–9, pls. 1–2. Naples, 1873.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 26. Brussels, 1877.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, pp. 478–479. Washington, D. C., 1880.—Simonelli, V., Boll. R. Comitato Geologico d'Italia (2), vol. 10, nos. 7 and 8, p. 209, footnote. Rome, 1889.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 51, 54. Wien und Leipzig, 1898.

"*Phoque.*" Gervais, P., Journal de Zoologie, vol. 1, pp. 64–65. Paris, 1872.

Palaeophoca gaudini. Flores, E., Atti della Accademia Pontaniana, vol. 35, no. 18, pp. 39–40. Naples, 1895.

(*Pristiphoca*) *gaudini.* Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 380. Berlin, 1899.

Type locality.—In the bituminous lime deposits of an open cave in the neighborhood of Mount Letto, about two miles to the east of Roccamorice and rear Majella, in the Compartment of Chietino, Italy. Upper Miocene.

MONOTHERIUM MAEOTICUM (Nordmann)

Phoca pontica. Eichwald, E., Lethaea Rossica, ou Paléontologie de la Russie, vol. 3, pp. 391–400, pl. 13. Stuttgart, 1853. (Part.)

Ph(*oca*) *maeotica.* Nordmann, A. v., Palaeontologie Sudrusslands, pt. 4, p. 313, pl. 22, figs. 1–3, 6–11; pl. 23, figs. 1–3, 6–10; pl. 24, figs. 1–16. Helsingfors, 1860.

Phoca maeotica. Van Beneden, Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 26. Brussels, 1877.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, pp. 478, 479.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 50. Wien und Leipzig, 1898.—True, F. W., Proc. U. S. Nat. Mus., vol. 30, no. 1475, pp. 838–839. Washington, D. C., 1906.

Phoca moetica. Zittel, K. v., Traité de Paléontologie, pt. 1, Paleozoologie, vol. 4, p. 689 (translation Barrios). Paris, 1894.

Ph(*oca*) *möotica.* Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 54. Wien und Leipzig, 1898.

(*Monatherium*) *maeoticum.* Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 380. Berlin, 1899.

Type locality.—Limestone quarries in vicinity of Kischinef, province of Bessarabia, Russia. Upper Miocene.

MONOTHERIUM RUGOSIDENS (Adams)

Phoca rugosidens. Adams, A. L., Quar. Jour. Geol. Soc., vol. 35, pt. 3, p. 524, pl. 25, figs. 1–2. London, 1879.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 773. Washington, D. C., 1880.—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 53, 54. Wien und Leipzig, 1898.

(*Monatherium*) *rugosidens.* Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 380. Berlin, 1899.

Type locality.—From the calcareous sandstone of Gozo, Maltese Islands. Upper Miocene.

Genus HYDRURGA Gistel

Hydrurga. Gistel, J., Naturgeschichte des Thierreichs für höhere Schulen, p. xi. Stuttgart, 1848.

Type, *Phoca leptonyx* Blainville.

HYDRURGA LEPTONYX (Blainville)

Stenorynchus leptonyx. Haast, J., Nature, vol. 14, p. 577. 1876.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 35. Brussels, 1877.

Type locality.—Moa Bone Point Cave, Middle Island, Bank's Peninsula, New Zealand. Recent.

Genus LOBODON Gray

Lobodon. Gray, J. E., Zool. Voy. H. M. S. "Erebus and Terror," pt. 1, Mamm., p. 2. 1844.

Type, *Phoca carcinophaga* Hombron and Jacquinot.

LOBODON VETUS (Leidy)

Stenorhynchus vetus. Leidy, J., Proc. Acad. Nat. Sci. Phila., vol. 6, p. 377. 1853.—Gray, J. E., Cat. whales and seals Brit. Mus., p. 10. London, 1866.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, pp. 475–476. Washington, D. C., 1880.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 50. Wien und Leipzig, 1898.

Lobodon vetus. Leidy, J., Jour. Acad. Nat. Sci. Phila. (2), vol. 7, pp. 415–416. 1869.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 28. Brussels, 1877.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 381. Berlin, 1897.

Type locality.—Green-sand marl near Burlington, Burlington County, New Jersey. Upper Cretaceous.

Genus GRYPHOCA Van Beneden

Gryphoca. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, pp. 798–799. Brussels, 1876.

Type, *Gryphoca similis* Van Beneden.

GRYPHOCA SIMILIS Van Beneden

Gryphoca similis. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, pp. 798–799. Brussels, 1876.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 69–70, pl. 13, figs. 1–21. Brussels, 1877.—Mourlon, M., Bull. Acad. Roy. des Sci., des Léttres et des Beaux-Arts de Belgique (2), vol. 43, no. 5, p. 607. Brussels, 1877. (Wommelghem; Deurne et Borgerhout.)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 479. Washington, D. C., 1880.—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 75. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 52, 55. Wien und Leipzig, 1898.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 382. Berlin, 1897.

Type locality.—In second and third sections, at Moortsel and Wommelghem, etc., Antwerp basin, Belgium. Middle Pliocene.

Genus PROPHOCA Van Beneden

Prophoca. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, pp. 801–802. Brussels, 1876.

Type, *Prophoca rousseaui* Van Beneden.

PROPHOCA ROUSSEAUI Van Beneden

Prophoca rousseaui. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, pp. 801–802. Brussels, 1876.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 79–80, pl. 18, figs. 1–11. Brussels, 1877.—Mourlon, M., Bull. Acad. Roy. des Sci., des Léttres et des Beaux-Arts de Belgique (2), vol. 43, no. 5, p. 608. Brussels, 1877. (Fort 3 [Borsbeeck]; fosse capital pres Deurne et Vieux-Dieu [Mortsel].)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 479. Washington, D. C., 1880. —Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 383. Berlin, 1897.—Palmer, T. S., North Am. Fauna, no. 23, p. 574. Washington, D. C., 1904.

Prophoca rousseani. Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 53, 54. Wien und Leipzig, 1898.

Type locality.—Black sands in second and third sections, at Moortsel, near Deurne, etc., Antwerp basin, Belgium. Upper Miocene.

PROPHOCA PROXIMA Van Beneden

Prophoca proxima. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, p. 802. Brussels, 1876.—Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 80–81, pl. 18, figs. 12–16. Brussels, 1877.—Mourlon, M. Bull. Acad. Roy. des Sci., des Léttres et des Beaux-Arts de Belgique (2), vol. 43, no. 5, p. 609. Brussels, 1877. (Borgerhout et Vieux-Dieu [Mortsel].)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 479. Washington, D. C., 1880.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 53. Wien und Leipzig, 1898.—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 383. Berlin, 1897.

Type locality.—Black sands in second and third sections, at Borgerhout, Moortsel, etc., Antwerp basin, Belgium. Upper Miocene.

Genus ERIGNATHUS Gill

Erignathus. Gill, T., Proc. Essex Inst., vol. 5, Communications, p. 5. 1866.
Type, *Phoca barbata* Erxleben.

ERIGNATHUS BARBATUS (Erxleben)

P(hoca) barbata. Blainville, H. M. D., Ostéographie ou description iconographique, vol. 2, p. 42. Paris, 1839–64. (Iceland?.)—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 34. Brussels, 1877.

Ph(oca) barbata foss. Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 54. Wien und Leipzig, 1898.

Phoca (Erignathus) barbata. Newton, E. T., Geological Magazine, n.s., decade 3, vol. 6, no. 4, pp. 147–148, pl. 5, figs. 2, 2a. London, 1889.—Newton, E. T., Vertebrata of Pliocene deposits of Britain, Mem. Geol. Surv. United Kingdom, p. 19. London, 1891.

(Erignathus) barbatus foss. Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 383. Berlin, 1897.

Type locality.—From the Cromer Forest bed at Overstrand, near Cromer, Norfolk County, England. ?Upper Pliocene.

Genus PLATYPHOCA Van Beneden

Platyphoca. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, p. 798. Brussels, 1876.

Type, *Platyphoca vulgaris* Van Beneden.

PLATYPHOCA VULGARIS Van Beneden

Platyphoca vulgaris. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, p. 798. Brussels, 1876.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 67–68, pl. 12, figs. 1–11. Brussels, 1877.—Mourlon, M., Bull. Acad. Roy. des Sci., des Léttres et des Beaux-Arts de Belgique (2), vol. 43, no. 5, p. 607. Brussels, 1877. (Deurne; Anvers et Borgerhout.)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 479. Washington, D. C., 1880.—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 75. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 52, 55. Wien und Leipzig, 1898.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 384. Berlin, 1897.—Palmer, T. S., North Am. Fauna, no. 23, p. 545. Washington, D. C., 1904.

Type locality.—In the second and third sections, at Borgerhout, Deurne, etc., Antwerp basin, Belgium. Middle Pliocene.

Genus PHOCA Linnaeus

Phoca. Linnaeus, K. v., Systema Naturae, 10th ed., vol. 1, p. 37. Holmiae, 1758.

Type, *Phoca vitulina* Linnaeus.

PHOCA, near VITULINA Linnaeus

"Seal." Knox, R., Mem. Wernerian Nat. Hist. Soc., vol. 5, pt. 2, p. 572. Edinburgh, 1826. (Camelon.)—Allman, G. J., Proc. Royal Soc. Edinburgh, vol. 4, p. 99. 1858. (Tyrie; Kirkaldy.)—Allman, G. J., Proc. Royal Soc. Edinburgh, vol. 4, p. 190. 1859. (Portobello.)

Phoca vitulina. Holl, F., Handbuch der Petrefactenkunde, p. 69. Dresden, 1829. (Part.)—Page, D., The Athenaeum, no. 1537, p. 479. London, 1857. (Cupar Muir clay pits.)—Page, D., Archiv Sci., Phys. et Nat., vol. 35, p. 69. Geneva, 1857.—Page. D., Report 28th meeting Brit. Assoc. Adv. Sci., Trans. sections, p. 104. Leeds, 1859. (St. Andrews Bay; brick clays at Garbridge and Seafield.)—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 28, 34. Brussels, 1877.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 50. Wien und Leipzig, 1898.

Phoca groenlandica?. Walker, R., Ann. and Mag. Nat. Hist. (3), vol. 12, no. 71, pp. 382–387. London, 1863. (Stratheden.)

Phoca hispida. Turner, W., Jour. Anat. and Phys., vol. 4, pp. 260–270. London, 1870. (Grangemouth.)—Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 32, no. 7, p. 6. Brussels, 1871.—Turner, W., The marine mammals in the anatomical museum of the University of Edinburgh, pt. 3, pp. 185–186. London, 1912.

Type locality.—Brick clays of Camelon in the upper basin of the Forth, Linlithgow County, Scotland. Pleistocene.

PHOCA sp.

Phoca vitulina. Bell, R., and Bell. A., Proc. Geol. Assoc., vol. 2, p. 212. 1872.

Phoca. Woodward, H. B., The geology of Norwich, Mem. Geol. Surv. United Kingdom, p. 55. London, 1881.—Newton, E. T., Vertebrata of Forest bed series of Norfolk and Suffolk, Mem. Geol. Surv. United Kingdom, p. 26. London, 1882.—Newton, E. T., Vertebrata of Pliocene deposits of Britain, Mem. Geol. Surv. United Kingdom, pp. 18–19, pl. 2, figs. 1a, 1b. London, 1891.

Type locality.—Norwich Crag of Bramerton, England. Upper Pliocene.

PHOCA VITULINOIDES Van Beneden

Phoca vitulinoides. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 32, no. 7, pp. 8–9, pl. 1. Brussels, 1871.—Gervais, P., Jour. de Zool., vol. 1, p. 65. Paris, 1872.—Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, p. 800. Brussels, 1876. —Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 27, 72–74, pl. 15. Brussels, 1877.—Mourlon, M., Bull. Acad. Roy. des Sci., des Léttres et des Beaux-Arts de Belgique (2), vol. 43, no. 5, p. 608. Brussels, 1877. (Borgerhout; Fort 3, Borsbeeck.)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 479. Washington, D. C., 1880.—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 385. Berlin, 1897.

Phoca vitilinoides. Toula, F., Beiträge z. Paläont u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 52. Wien und Leipzig, 1898.

Type locality.—In the third section, at Borsbeek, etc., Antwerp Basin, Belgium. Middle Pliocene.

PHOCA MOORI Newton

Phoca moori. Newton, E. T., Quar. Jour. Geol. Soc. London, vol. 46, pp. 446–447, pl. 18, figs. 3a, 3b. 1890.—Newton, E. T., Mem. Geol. Surv. United Kingdom, p. 19, pl. 2, figs. 2a, 2b. London, 1891. (Red Crag Nodule-bed of Waldringfield.)—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 54. Wien und Leipzig, 1898.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 385. Berlin, 1897.

TYPE LOCALITY.—Nodule bed of the Red Crag at Foxhall, four miles southwest of Woodbridge, Suffolk County, England. Middle Pliocene.

PHOCA VINDOBONENSIS Toula

Phoca vindobonensis. Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 47–71, pls. 9, 10, 11. Wien und Leipzig, 1898.

Phoca pontica. Peters, K. F., Sitzungsber. math.-naturw. Cl. d. k. Akad. Wissensch., vol. 55, pt. 2, pp. 110, 111. Wien, 1867. (Hernals.)

Phoca. Steindachner, F., Sitzungsber. math.-naturw. Cl. K. k. Akad. Wissensch., vol. 37, no. 21, p. 674. Wien, 1859.

Phoques. Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 25, 26. Brussels, 1877.

TYPE LOCALITY.—Kreindl's brickyard on the Nussdorf road near Heiligenstadt, Province of Nieder-Osterreich, Austria. Upper Miocene.

PHOCA VIENNENSIS Blainville

Phoca vitulina. Holl, F., Handbuch der Petrefactenkunde, p. 69. Dresden, 1829. (Holitsch.)—Andrian, F. F. v. and Paul, K. M., Verhandl. d. k. k. geol. R. Reichs.-Anst., p. 135. 1863.

Phoca holitschensis. Bruhl, C. B., Mittheil. A. d. k. k. Zool. Institute der Universität Pest, pls. 1–2. Wien, 1860.—Zittel, K. v., Traité de Paléontologie, pt. 1, Paleozoologie, vol. 4, p. 689 (translation Barrois). Paris, 1894.—Roger, O., Berich naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 49, 50, 51, 54. Wien und Leipzig, 1898.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 385. Berlin, 1897.

Phoca halitschensis. Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, pp. 477, 479. Washington, D. C., 1880.

Phoca halitchensis. Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 24, 26. Brussels, 1877.

Phoque. Cuvier, G., Recherches sur les ossemens fossiles, vol. 8, pt. 1, p. 456. Paris, 1836.

Phoca viennensis antiqua. Blainville, Ostéographie ou description iconographique, vol. 2, pp. 42, 51, Atlas, vol. 2, pl. 10, fig. 1. Paris, 1839–64. —Pictet, F. J., Traité de Paléontologie (2), vol. 1, p. 232. Paris, 1853.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 49, 50. Wien und Leipzig, 1898.

Phoca viennensis. Gervais, P., Zoologie et paléontologie françaises (2), p. 274. Paris, 1859.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 385. Berlin, 1897.

Phoca antiqua. Suess, E., Sitzungsber. math.-naturw. Cl. d. k. Akad. Wissensch., vol. 54, p. 11. Wien, 1866. (Holitsch.)—Peters, K. F., Sitzungsber. math.-naturw. Cl. d. k. Akad. Wissensch., vol. 55, pt. 2, p. 111. Wien, 1867.

Type locality.—Holitsch, Nyitra County, Hungary, on the right bank of the Morava River about 30 miles northeast of Vienna. Upper Miocene.

PHOCA PONTICA Eichwald

Phoca pontica. Eichwald, E., Lethaea Rossica ou Paléontologie de la Russie, vol. 3, pp. 391–400, 1853, Atlas, pl. 13, figs. 1–37. Stuttgart, 1852.—Lartet, E., Bull. Soc. Geol. de France (2), vol. 21, p. 260. Paris, 1864. (Peninsulas of Kertch and Taman.)—Peters, K. F., Sitzungsber. math.-naturw. Cl. d. k. Akad. Wissensch., vol. 55, pt. 2, pp. 110, 111. Wien, 1867. (Part.)—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 26, 74. Brussels, 1877.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, pp. 477, 479. Washington, D. C., 1880.—Calvert, F., and Neumayr, M., Denkschr. k. Akad. Wissensch. Wien. math. naturwiss. Cl., vol. 40, pp. 361, 363, 365. Wien, 1880. (Erenkoi, Turkey.)—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 49, 50, 51, 53, 54. Wien und Leipzig, 1898.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 385. Berlin, 1897.

Ph(oca) pontica. Nordmann, A. v., Palaeontologie Sudrusslands, pt. 4, pp. 299, 313, Atlas, pl. 22, figs. 4–5; pl. 23, figs. 4–5. Helsingfors, 1860. —Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.

Type locality.—In ferruginous clay on Mount Mithridates, near Kertch, and in limestone formation on promontory of Akbouroun, Province of Taurida, Russia. Upper Miocene.

PHOCA WYMANI Leidy

Phocidae. Wyman, J., Am. Jour. Sci. (2), vol. 10, p. 229. 1850. (Part.)

Phoca wymani. Leidy, J., Smithson. Contrib. to Knowledge, vol. 6, p. 8. Washington, D. C., 1854. (Part.)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 472. Washington, D. C., 1880.—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.

Type locality.—In the ravine at the eastern extremity of Richmond, and in the neighborhood of the penitentiary, Henrico County, Virginia. ~~Middle~~ Upper Miocene.

PHOCA sp. B Kellogg

"Seals." Miller, L. H., Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, no. 5, p. 115. Berkeley, 1912. (San Pedro.)

Phoca sp. B. Kellogg, R., Univ. Calif. Publ., Bull. Dept. Geol., vol. 13, no. 4, pp. 45–46. Berkeley, 1922.

Type locality.—In shell bearing stratum about six feet above beach level at the point where cliff begins on approaching the town of La Jolla from the north. Presumably the lower level of the upper San Pedro beds near La Jolla, San Diego County, California. Pleistocene.

PHOCA, sp. A Kellogg

Phoca, sp. A. Kellogg, R., Univ. Calif. Publ., Bull. Dept. Geol., vol. 13, no. 4, p. 45. 1922.

Type locality.—Northwest end of Tejon Hills, Kern County, California, in unsurveyed N.E. ¼, Section 23, Township 32 South, Range 29 East (Mount Diablo Base and Meridian). In Santa Margarita white clayey sands, 100 feet below Chanac formation. *Ostrea titan* and *Pecten crassicardo,* etc., occur in a bed stratigraphically but a short distance below this horizon. Upper Miocene.

PHOCA, near HISPIDA Schreber

Calocephalus vitulinus. Brown, T., Trans. Roy. Soc. Edinburgh, vol. 24, pt. 3, p. 629. 1867. (Errol.)

Phoca vitellinus. Howden, J. G., Trans. Edinburgh Goel. Soc., vol. 1, p. 141. 1868. (Montrose.)

Phoca hispida. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 32, p. 6. Brussels, 1871.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 28. Brussels, 1877.—Lönnberg, E., Arkiv för Zoologi utgifvet af K. Svenska Vetenskapsakademien i Stockholm, Uppsala and Stockholm, vol. 4, no. 22, pp. 3–16, figs. 1–2. 1908. (Litorhina clay.)—Lönnberg, E., Fauna och Flora, Populär Tidskrift för Biologi, Häft 4, pp. 165–173, figs. 1–2. 1908.—Lönnberg, E., Arkiv för Zoologi utgifvet af K. Svenska Vetenskapsakademien i. Stockholm, Uppsala and Stockholm, vol. 6, no. 3, pp. 9–12. 1910. (Fresh water clay.)—Turner, W., The marine mammals in the anatomical museum of the University of Edinburgh, pt. 3, pp. 185–186. London, 1912. (Puggiston; Montrose; Errol.)

Ph(oca) hispida foss. Roger, O., Berich naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 55. Wien und Leipzig. 1898.

(*Pusa*) *hispida* foss. Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 386. Berlin, 1897.

Type locality.—In arctic shell clay of brickfield near Errol, Scotland. Pleistocene.

Genus PHOCANELLA Van Beneden

Phocanella. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, p. 799. Brussels, 1876.

Type, *Phocanella pumila* Van Beneden.

PHOCANELLA PUMILA Van Beneden

Phocanella pumila. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, p. 799. Brussels, 1876.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 70–71, pl. 14, figs. 1–12. Brussels, 1877.—Mourlon, M., Bull. Acad. Roy. des Sci., des Léttres et des Beaux-Arts de Belgique (2), vol. 43, no. 5, p. 607. Brussels, 1877. (Deurne et Borgerhout.)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 479. Washington, D. C., 1880.—Roger, O., Berich naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 75. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 52, 55. Wien und Leipzig, 1898.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 387. Berlin, 1897.—Palmer, T. S., North Am. Fauna, no. 23, p. 533. Washington, D. C., 1904.

Type locality.—In the third section, Antwerp, Basin, Belgium. Middle Pliocene.

PHOCANELLA MINOR Van Beneden

Phocanella minor. Van Beneden, P. J., Bull. Acad. Sci. de Belgique (2), vol. 41, no. 4, p. 799. Brussels, 1876.—Van Beneden, P. J., Ann. Mus. Roy. Hist Nat. de Belgique, vol. 1, pt. 1, pp. 71–72, pl. 14, figs. 13–25. Brussels, 1877.—Mourlon, M., Bull. Acad. Roy. des Sci., des Léttres et des Beaux-Arts de Belgique (2), vol. 43, no. 5, p. 608. Brussels, 1877. (Borgerhout et Vieux-Dieu?.)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 479. Washington, D. C., 1880.—Newton, E. T., Quar. Jour. Geol. Soc., vol. 46, p. 447, pl. 18, figs. 4a, 4b. London, 1890.—Newton, E. T., Vertebrata of Pliocene deposits of Britain, Mem. Geol. Surv. United Kingdom, pp. 19–20. London, 1891. (Red Crag Nodule bed, Foxhall.)—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 75. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 52, 54, 55. Wien und Leipzig, 1898. —Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 387. Berlin, 1897.—Palmer, T. S., North Am. Fauna, no. 23, p. 533. Washington, D. C., 1904.

Type locality.—In the third section and at Moortsel, Antwerp basin, Belgium. Middle Pliocene.

PHOCID near? HALICHOERUS GRYPUS

"Fossil seal." Thompson, A. W., Jour. Anat. and Phys., vol. 13, pp. 318–321. London, 1879. (Dunbar.)—Turner, W., The marine mammals in the anatomical museum of the University of Edinburgh, pt. 3, p. 186, text fig. p. 187. London, 1912.

Type locality.—In brick clay at Dunbar, Haddington County, Scotland. Pleistocene.

Genus LEPTOPHOCA True

Leptophoca. True, F. W., Proc. U. S. Nat. Mus., vol. 30, no. 1475, p. 835. Washington, D. C., 1906.

Type, *Leptophoca lenis* True.

LEPTOPHOCA LENIS True

"Fossil seal." True, F. W., Science, n.s., vol. 22, no. 572, p. 794. 1905.

Leptophoca lenis. True, F. W., Proc. U. S. Nat. Mus., vol. 30, no. 1475, pp. 836–840, pls. 75–76. Washington, D. C., 1906.

TYPE LOCALITY.—In the Calvert Cliffs bordering on Chesapeake Bay, Calvert County, Maryland; between Chesapeake Beach and Plum Point, and in what is known as Zone 10. Middle Miocene.

Genus PAGOPHOCA Trouessart

Pagophoca. Trouessart, E. L., Catalogue mammalium tam viventium quam fossilium, Suppl., p. 287. Berlin, 1904.

Type, *Phoca groenlandica* Erxleben.

PAGOPHOCA, near GROENLANDICA (Erxleben)

Seal. Jackson, C. T., Final Report Geol. and Mineral. New Hampshire, p. 94. Concord, 1844.—Proc. Acad. Nat. Sci., Phila., vol. 8, pp. 90–91, pl. 3. 1856.

Phoca groenlandica. Logan, W. E., Geol. Surv. Canada, Montreal, p. 920, figs. 493a, 493b, on p. 965. 1863.—Kinberg, J. G. H., öfversigt af Kongl. Vetens, Akad. Förhandl., vol. 26, no. 1, pp. 13, 14, 15. Stockholm, 1869.—Leidy, J., Jour. Acad. Nat. Sci., Phila. (2), vol. 7, p. 415. 1869.—Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 32, no. 7, p. 7. Brussels, 1871.—Van Beneden, Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 28, 34. Brussels, 1877.—Dawson, J. W., Canadian Naturalist (2), vol. 8, p. 341. Montreal, 1878.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, pp. 474, 475. Washington, D. C., 1880.—Jentzsch, A., and Tenne, C. A., Zeitsch. deutsch. geol. Gesellsch., vol. 39, pp. 497, 498. 1887.—Gaudry, A., Compt. Rend. Acad. Sci. Paris, vol. 3, pp. 352, 353. 1890.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 50, 53. Wien und Leipzig, 1898.

Ph(oca) grönlandica foss. Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.

(*Pagophilus*) *groenlandica* foss. Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 388. Berlin, 1897.

TYPE LOCALITY.—In marine mud, at a depth of thirty feet from surface, South Berwick, York County, Maine. Pleistocene.

Genus CALLOPHOCA Van Beneden

Callophoca. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, p. 798. Brussels, 1876.

Type, *Callophoca obscura* Van Beneden.

CALLOPHOCA OBSCURA Van Beneden

Callophoca obscura. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 41, no. 4, p. 798. Brussels, 1876.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 65–67, pl. 11, figs. 1–13. Brussels, 1877.—Mourlon, M., Bull. Acad. Roy. des Sci., des Léttres et des Beaux-Arts de Belgique (2), vol. 43, no. 5, p. 607. Brussels, 1877. (Deurne et Borgerhout.)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 479., Washington, D. C., 1880.—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburn (a. V.), vol. 32, p. 75. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 52, 55. Wien und Leipzig, 1898.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 388. Berlin, 1899.—Palmer, T. S., North Am. Fauna, no. 23, p. 153. Washington, D. C., 1904.

Type locality.—In the third section, Antwerp Basin, Belgium. Middle Pliocene.

Fossil Remains Incorrectly Referred to the Pinnipedia

CARNIVORA

PSEUDAELURUS? sp.

Phoque. Blainville, H. M. D., Compt. Rend. Acad. Sci., Paris, vol. 5, no. 12, p. 426. 1837.

Phoca. Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 48. Leipzig und Wien, 1898.

Type locality.—Sansan, Department of Gers, France. Middle Miocene.

URSUS sp.?

Phoque. Esper, J. Fr., Mag. Berlin Naturf. Freunde, vol. 5, p. 98, 1784.—Esper, J. Fr., Frankfurt Archiv, vol. 1, p. 77; vol. 2, p. 165. 1790.—Cuvier, G., Recherches sur less ossemens fossiles (4), vol. 8, pt. 1, p. 453. Paris, 1836.—Blainville, H. M. D., Ostéographie ou description iconographique, vol. 2, pp. 37–38. Paris, 1839–64.—Figuier, P., La terre avant le déluge, p. 441. Paris, 1874.

Type locality.—Gailenreuth in Bavaria and Kahlendorf in Aichstedt. Pleistocene.

PERISSODACTYLA

RHINOCEROTID gen. and sp.?

Phoca. Monti, J., De monumento diluviano in agro Bononiensi detecto, Bologna, 1719.—Cuvier, G., Recherches sur les ossemens fossiles (4), vol. 8, pt. 1, pp. 457,458. Paris, 1836.—Blainville, H. M. D., Ostéographie ou description inconographique, vol. 2, p. 38. Paris, 1839–64. —Pictet, F., Traité de Paléontologie (2), vol. 1, p. 234. Paris, 1853.

Type locality.—Bologna, Italy. Middle Pliocene.

ARTIODACTYLA

RUMINANT gen. and sp.

Morse. Duvernoy, G. L., Compt. Rend. Acad. Sci. Paris, pp. 494–495. 1837.—Blainville, H. M. D., Ostéographie ou description iconographique, vol. 2, p. 46; Atlas, vol. 2, pl. 10, fig. 5. Paris, 1839–64.

Type locality.—In formation of white rock, south and east of Oran in Algeria, Africa. ?Lower Eocene.

PROBOSCIDEA

? ELEPHAS PRIMIGENIUS

Morse. Lebnitz, G. W., Protogaea, cap. 33–34. Göttingen, 1749.—Georgi, J. G., Geog.-physik. u. naturh. Beschr. d. Russischen Reichs, vol 3, pp. 390, 591. Koenigsberg, 1797–1802.—Cuvier, G., Recherches sur les ossemens fossiles (4), vol. 8, pt. 1, p. 457. Paris, 1836.—Blainville, H. M. D., Ostéographie ou description iconographique, vol. 2, p. 37. Paris, 1839–64.

Type locality.—Siberia. Pleistocene.

SIRENIA

SIRENID? gen. and sp.?

P(hoca) aegyptiaca antiqua. Blainville, H. M. D., Ostéographie ou description iconographique, vol. 2, pp. 43, 51; Atlas, vol. 2, pl. 10, fig. 2. Paris, 1839–64.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 49. Wien und Leipzig, 1898.

Type locality.—In white calcareous limestone on right bank of valley of the Nile, Egypt. ? Middle Eocene.

HALIANASSA? sp.

Trichechus rosmarus. Schuebler, Neues Jahrbuch für Mineralogie, pp. 79–80. 1832.

''*Wallross.*'' Jaeger, G. F., Ueber die fossilen Säugethiere, welche in Würtemberg aufgefunden worden sind, pt. 1, pp. 1–2, pl. 1, figs. 1–3. Stuttgart, 1835.

Trichechus molassicus. Bronn, H. G., Neues Jahrbuch für Mineralogie, p. 732. Stuttgart, 1837.—Bronn, H. G., Lethaea Geognostica, vol. 2, p. 840. Stuttgart, 1838.

Trichecus. Jaeger, G. F., Uber die fossilen Säugethiere welche in Würtemberg in verschiedenen formationen aufgefunden worden sind, pt. 2, p. 203. Stuttgart, 1839.

Tr(ichecus) molassicus. Giebel, C. G., Fauna der Vorwelt, vol. 1, pp. 222–223. Leipzig, 1847.—Pictet, F. J., Traité de Paléontologie (2), vol. 1, p. 234. Paris, 1853.

"Morse." Blainville, H. M. D., Ostéographie ou description iconographique, vol. 2, p. 44. Paris, 1839–64.

Type locality.—Stone pit of Baltringen near Biberach, Wurttemberg, Germany. Middle Miocene.

METAXYTHERIUM CUVIERI Christol

Phoque. Cuvier, G., Recherches sur les ossemens fossiles (4), vol. 8, pt. 1, pp. 454–455; Atlas, vol. 2, pl. 220, figs. 24–26, 28–29. Paris, 1836.—Blainville, H. M. D., Ostéographie ou description iconographique, vol. 2, pp. 38–41. Paris, 1839–64.

Metaxytherium. Christol, J., Ann. Sci. Nat. Paris (2), vol. 15, pp. 307–331. 1841.

Phoca fossilis. Pictet, F., Traité de Paléontologie (2), vol. 1, p. 232. Paris, 1853.—Gervais, P., Zoologie et Paléontologie françaises (2), p. 272. Paris, 1859.—Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 32, no. 7, p. 5. Brussels, 1871.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 48. Wien und Leipzig, 1898.

Type locality.—In the sandstone of Angers, Department of Maine-et-Loire, France. ? Middle Miocene.

ODONTOCETI

SQUALODONTIDAE

NEOSQUALODON AMBIGUUS (Von Meyer)

Phoca ambigua. Münster, G. G., Neues Jahrbuch für Mineralogie, p. 447. Stuttgart, 1835. (*Nomen nudum.*)—Bronn, H. G., Lethaea Geognostica, vol. 2, p. 840. Stuttgart, 1838.—Meyer, H. von, Beiträge zur Petrefaktenkunde, vol. 3, p. 1, pl. 7, figs. 1–6. Bayreuth, 1840.—Meyer, H. v., Neues Jahrbuch für Mineralogie, p. 96. Stuttgart, 1840.—Giebel, C. G., Fauna der Vorwelt, vol. 1, p. 224. Leipzig, 1847.—Pictet, F. J., Traité de Paléontologie (2), vol. 1, p. 233, pl. 6, figs. 1–3. Paris, 1853.—Guiscardi, G., Atti della R. Acad. d. Sci. Fisiche e Matem., vol. 5, no. 6, p. 7. Naples, 1873.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, pp. 24, 25. Brussels, 1877.—Zittel, K. v., Traité de Paléontologie, Mamm., vol. 4, p. 690. Paris, 1894.—Roger, O., Berich naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 77. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 54. Wien und Leipzig, 1898.—Abel, O., Mem. Mus. Roy. d'Hist. Nat. de Belgique, vol. 3, pp. 46, 66 (footnotes). Brussels, 1905.

Type locality.—Tertiary marls of the Osnabruck basin near Bünde, Oldenburg, Germany. Middle Oligocene.

SQUALODON SCILLAE (Agassiz)

"Fossil." Scilla, A., La Vana Specvlazione disingannata dal Senso. Lettera responsiva circa i corpi Mariné, che Petrificati fi trouana in

varij loughi terrestri, p. 123, pl. 12, fig. 1. Naples, 1670.—Scilla, A., De Corporibus Marinis Lapidescentibus quae defossa reperiuntur, p. 47, pl. 12, fig. 1. Rome, 1747.—Scilla, A., De Corporibus Marinis Lapidescentibus quae defossa reperiuntur (2nd ed.), p. 54, pl. 12, fig. 1. Rome, 1759.

Phocodon scillae Agassiz, L. Valentin's Repertorium Anat. et Physiol., Berne et St. Gallen, vol. 6, p. 236. 1841. (Considered tooth a phocid.) —Zittel, K. v., Handbuch der Palaeontologie, vol. 4, p. 170. 1893.—Palmer, T. S., North Am. Fauna, no. 23, p. 533. Washington, D. C., 1904.

Phoca? melitensis antiqua. Blainville, H. M. D., Ostéographie ou description iconographique, vol. 2, p. 51; Atlas, vol. 2, pl. 10, fig. 4. Paris, 1839–64.—Meyer, H. v., Neues Jahrbuch f. Mineralogie, p. 242. Stuttgart, 1841.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 49, 50. Wien und Leipzig, 1898.

P(hoca) dubia melitensis. Blainville, H. M. D., Ostéographie ou description iconographique, vol. 2, p. 46. Paris, 1839–64.

Zeuglodon. Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 24. Brussels, 1877.—Gregory, W. K., Bull. Amer. Mus. Nat. Hist., vol. 27, p. 411. New York, 1910.

"Squalodont." Allen, J. A., Bull. U. S. Geol. and Geog. Surv. Terr., vol. 6, no. 3, pp. 420, 448, 456. Washington, D. C., 1882.

Sq(ualodon) (Phocodon) scillae. Zittel, K. v., Handbuch der Palaeontologie, vol. 4, p. 171. 1893.

Type locality.—Tophus of Malta. Miocene.

SQUALODON DEBILIS (Leidy)

Phoca debilis. Leidy, J., Proc. Acad. Nat. Sci. Phila., vol. 8, p. 265. 1856.—Bronn, H. G., Neues Jahrbuch f. Mineralogie, p. 252. 1858.—Cope, E. D., Proc. Acad. Nat. Sci. Phila., vol. 19, p. 153. 1867.—Leidy, J., Jour. Acad. Nat. Sci. Phila. (2), vol. 7, p. 415, pl. 28, figs. 12–13. 1869.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., p. 473. Washington, D. C., 1880.—Roger, O., Berich naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 49. Wien und Leipzig, 1898.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 388. Berlin, 1897.

Squalodon debilis. Hay, O. P., Bull. U. S. Geol. Surv. no. 179, p. 589. Washington, 1902.

Type locality.—Sands of Ashley River, South Carolina. Upper Miocene.

SQUALODON sp.?

Phoca pedronii. Gervais P., Compt. rend. Acad. Sci. Paris, vol. 28, p. 644. 1849.—Gervais, P., Zoologie et Paléontologie françaises (2), p. 274, pl. 41, fig. 1. Paris, 1859.—Cope, E. D., Proc. Acad. Nat. Sci. Phila., vol. 19, p. 153. 1867.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 49. Wien und Leipzig, 1898.

Phoca pedroni. Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 32, no. 7, p. 5. Brussels, 1871.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 25. Brussels, 1877.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., p. 477. Washington, D. C., 1880.

(*Pristiphoca*) *pedroni.* Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 379. Berlin, 1899.

Type locality.—From Leognan near Bordeaux, France. Middle Miocene.

?SQUALODON MIRABILIS (Von Meyer)

Pachyodon mirabilis. Meyer, H. v., Neues Jahrbuch für Mineralogie, p. 414. Stuttgart, 1838.—Münster, G. G., Beiträge zur Petrefaktenkunde, vol. 3, p. 2, pl. 8. Bayreuth, 1840.—Giebel, C. G., Fauna der Vorwelt, p. 225. Leipzig, 1847.—Pictet, F. J., Traité de Paléontologie (2), vol. 1, p. 233. Paris, 1853.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 25. Bussels, 1877.—Palmer, T. S., North Am. Fauna, no. 23, p. 494. Washington, D. C., 1904.

Type locality.—Moeskirch, Baden, Germany. Middle Miocene.

SQUALODON MODESTUS (Leidy)

Phoca modesta. Leidy, J., Jour. Acad. Nat. Sci. Phila. (2), vol. 7. p. 415, pl. 28, fig. 14. 1869.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., p. 474. Washington, D. C., 1880.—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 53. Wien und Leipzig, 1898.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 388. Berlin, 1897.

Squalodon? modestus. Hay, O. P., Bull. U. S. Geol. Surv., no. 179, p. 589. Washington, 1902. (Eocene.)

Type locality.—Ashley River Phosphate deposits, South Carolina. Upper Miocene.

SQUALODON RUGIDENS (H. v. Meyer)

Phoca? rugidens. Meyer, H. v., Neues Jahrbuch für Mineralogie, p. 309. Stuttgart, 1845.—Meyer, H. v., Neues Jahrbuch für Mineralogie, p. 201. Stuttgart, 1850.—Meyer, H. v., Berich. Mittheil. v. Freunden Naturwiss. in Wien, vol. 7, p. 45. 1851. (Tegel von Baden near Vienna.)—Pictet, F. J., Traité de Paléontologie (2), vol. 1, p. 233. Paris, 1853.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 24. Brussels, 1877.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 477. Washington, D. C., 1880.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, pp. 49, 51. Wien und Leipzig, 1898.

Ph(oca) rugidens. Giebel, C. G., Fauna der Vorwelt, vol. 1, p. 224, Leipzig, 1847.—Guïscardi, G., Soc. Reale di Napoli, Atti dell'Accad. delle sci. fisiche e matem., vol. 5, no. 6, p. 9. Naples, 1873.

Pristiphoca? rugidens. Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 380. Berlin, 1897.

Type locality.—Neudorfl on the March River near Presburg in Hungary. Middle Miocene.

PHYSETERIDAE

? SCALDICETUS GRANDIS Du Bus

? Phoca sp. Costa, O. G., Paleontologia del regno di Napoli, pt. 1, pp. 12–14, pl. 1, fig. 1. Naples, 1850.—Flores, E., Atti della Accademia Pontaniana, vol. 35, no. 18, p. 40. Naples, 1895.

Physodon leccense. Capellini, C. G., Mem. dell'Accad. delle sci. dell' Instituto di Bologna (3), vol. 9, fasc. 2, pp. 246–247. 1878.

?Scaldicetus grandis. Abel, O., Mem. Mus. Roy. Hist. Nat. Belgique, vol. 3, p. 68. Brussels, 1905.

TYPE LOCALITY.—From ''Marna calcare'' of Lecce, near Otranto, in southeastern Italy. Miocene.

SCALDICETUS sp.

''Phoque.'' Gervais, P., and Serres, M. de, Annales Sci. Nat. Paris (3), vol. 8, p. 225, footnote [Uchaux (Vaucluse) errore]. 1847.—Gervais, P., Zoologie et Paléontologie françaises (1), pl. 8, fig. 8. Paris, 1848–52.—Gervais, P., Bull. Soc. Geol. de France (2), vol. 10, p. 311. Paris, 1853.

Otaria? prisca. Gervais, P., Zoologie et Paléontologie françaises (2), p. 275, pl. 8, fig. 8. Paris, 1859.—Van Beneden, P. J., Bull. Acad. Roy. Sci. de Belgique (2), vol. 32, no. 7, p. 5. Brussels, 1871.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 57. Brussels, 1877.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., p. 218. Washington, D. C., 1880.—Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 76. Augsburg, 1896.

Phoca sp. Cope, E. D., Proc. Acad. Nat. Sci. Phila., vol. 19, p. 153. 1867.

Phoca gervaisi. Rouault, M., Compt. Rend. Acad. Sci. Paris, vol. 47, p. 100. 1858. (Shell marl of S. Juvat.)—Gervais, P., Journal de Zoologie, vol. 1, p. 67. Paris, 1872.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 50. Wien und Leipzig, 1898.

Squalodon [*bariensis*]. Gervais, P., and Van Beneden, P. J., Ostéographie des Cétacés vivants et fossiles, p. 434, pl. 28, fig. 10. Paris, text 1880, Atlas 1868–79.

Squal(odon) grateloupii. Roger, O., Bericht naturwiss. Vereins. f. Schwaben und Neuburg (a. V.), vol. 32, p. 76. Augsburg, 1896.

Scaldicetus sp. Abel, O., Mem. Mus. Roy. Hist. Nat. Belgique, vol. 3, p. 28, footnote. Brussels, 1905.

TYPE LOCALITY.—Sandstone of Uzes, Department of Gard, France. Upper Miocene.

? SCALDICETUS sp.

Phoca larreyi. Rouault, M., Compt. Rend. Acad. Sci. Paris, vol. 47, p. 100. 1858. (Le Quiou.)—Gervais, P., Journal de Zoologie, vol. 1, p. 67. Paris, 1872.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 50. Wien und Leipzig, 1898.

TYPE LOCALITY.—In the shell marl of Le Quiou, Bretagne, France. Miocene?

ZIPHIIDAE

? CETORHYNCHUS CHRISTOLI Gervais

Phoca occitana. Gervais, P., Bull. Soc. Geol. de France (2), vol. 10, p. 311. Paris, 1853. (Part: Poussan.)

Prisitiphoca occitana. Gervais, P., Zoologie et Paléontologie françaises (2), p. 273, 274, pl. 38, fig. 8 (Languedoc, Poussan); pl. 8, fig. 7 (Fausson). Paris, 1859. (Part.)—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 477. Washington, D. C., 1880. (Part.)

Type locality.—Poussan and Fausson, in the Department of Herault, France. Miocene.

DELPHINIDAE

DELPHINODON LEIDYI Hay

Seal. Wyman, J., Am. Jour. Sci. (2), vol. 10, p. 229, 232, fig. 1–3. 1850. (Part.)

Phoca wymani. Leidy, J., Smithson. Contrib. to Knowledge, vol. 6, p. 8. Washington, D. C., 1854.—Leidy, J., Proc. Acad. Nat. Sci. Phila., vol. 8, p. 265. 1856. (Part.)—Bronn, H. G., Neues Jahrbuch f. Mineralogie, p. 252. Stuttgart, 1858.—Leidy, J., Jour. Acad. Nat. Sci. Phila. (2), vol. 7, p. 415, pl. 30, fig. 12. 1869.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., pp. 470, 471, 473, 480. Washington, D. C., 1830.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns u. d. Orients, vol. 11, p. 49. Wien und Leipzig, 1898.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 388. Berlin, 1897.

Squalodon wymanii. Cope, E. D., Proc. Acad. Nat. Sci. Philo., vol. 19, p. 152. 1867.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., p. 473. Washington, D. C., 1880

Delphinodon wymani. Leidy, J., Jour. Acad. Nat. Sci. Phila. (2), vol. 7, p. 426. 1869.—True, F. W., Proc. Biol. Soc. Washington, vol. 24, pp. 37–38. 1911.

Delphinodon leidyi. Hay, O. P., Bull. U. S. Geol. Surv. no. 179, p. 591. Washington, 1902.

?Acrodelphis sp. Abel, O., Mem. Mus. Roy. Hist. Nat. Belgique, vol. 3, pp. 138. Brussels, 1905.

Type locality.—Shockoe Creek ravine at base of Church Hill, near Richmond, Virginia. Upper Miocene.

ORDINAL POSITION UNCERTAIN

DOLPHIN?

Ph(oca) occitana. Gervais, P., Zoologie et Paléontologie françaises (2), p. 273, pl. 20, figs. 5, 6. Paris, 1859.

Pristiphoca occitana. Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 25. Brussels, 1877. (Part.)

''Dauphin?'' Deperet, C., Arch. Mus. d'Hist. Nat. Lyon, vol. 4, p. 272. 1887. (Molasse helvetienne.)

TYPE LOCALITY.—Shell marl of Romans, Department of Drôme, France. Middle Miocene.

? CETACEAN, gen. et sp.?

''Phocas.'' Vandelli, A. A., Hist. e Mem. d. Acad. Real. d. Sci. de Lisboa, vol. 11, pt. 1, pp. 291, 297, pl. 5, fig. 10. 1831.

''Phoque.'' Gervais, P., Zoologie et Paléontologie françaises (2), p. 274. Paris, 1859.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 25. Brussels, 1877.

TYPE LOCALITY.—In upper sedimentary deposits on the Cape of Espichel beyond the Tejo and at the site of Adica about four leagues from Lisbon, Portugal. ''Primeiro Terreno marinho no Calcareo grosseiro marinho.''

? PHOCID, gen. et sp.?

''Foca.'' Tozzeti, G. T., Relazioni d'alcuni Viaggi fatti in diverse parti della Toscane per osservare le produxioni naturali, vol. 10, p. 394, and vol. 12, p. 200. Firenze, 1768–69.

''Phoque.'' Cuvier, G., Recherches sur les ossemens fossiles (4), vol. 8, pt. 1, p. 453. Paris, 1836.—Blainville, H. M. D., Ostéographie ou description iconographique, vol. 2, p. 38. Paris, 1839–64.

TYPE LOCALITY.—Caverns on the sea coast near Pisa, Province of Tuscany, Italy. Upper Pliocene?

? PHOCID, gen. et sp.

''Loup marin.'' Boue, A., Journal de géologie, vol. 3, no. 9, pp. 30–31. Paris, 1831.

''Phoque.'' Blainville, H. M. D., Ostéographie ou description iconographique, vol. 2, p. 41. Paris, 1839–64.—Pictet, F. J., Traité de Paléontologie (2), vol. 1, p. 232. Paris, 1853.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 25. Brussels, 1877.

TYPE LOCALITY.—In a calcareous formation at Wollersdorf ''analogous to the 'crayeuse de Maestricht,' Germany.'' Upper Cretaceous?

? CETACEAN

Otaria leclercii. Delfortrie, E., Actes de la Societe Linneenne de Bordeaux (3), vol. 8, pp. 385–386, figs. 2a, 2b, 2c, 2d. 1872.—Gervais, P., Journal de Zoologie, vol. 1, p. 327, figs. 2a, 2b, 2c, 2d. Paris, 1872.—Van Beneden, P. J., Ann. Mus. Roy. Hist. Nat. de Belgique, vol. 1, pt. 1, p. 25. Brussels, 1877.—Allen, J. A., Misc. Publ. no. 12, U. S. Geol. and Geog. Surv. Terr., Dept. Interior, p. 218. Washington, D. C., 1880.—Toula, F., Beiträge z. Paläont. u. Geol. Osterreich-Ungarns, vol. 11, pp. 51, 55. Wien und Leipzig, 1898.—True, F. W., Prof. Paper no. 59, U. S. Geol. and Geog. Surv., Dept. Interior, p. 147. Washington, D. C., 1909.

(*Mesotaria*) *leclercii.* Roger, O., Bericht naturwiss. Vereins f. Schwaben und Neuburg (a. V.), vol. 32, p. 74. Augsburg, 1896.—Trouessart, E. L., Catalogus mammalium tam viventium quam fossilium, vol. 1, p. 378. Berlin, 1897.

Type locality.—Bone breccia of Saint-Medard-en-Jalle, near Bordeaux, France. Upper Oligocene.

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THE BRIONES FORMATION OF MIDDLE CALIFORNIA

BY
PARKER D. TRASK

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CONTENTS

INTRODUCTION AND ACKNOWLEDGMENTS

This paper presents the results of a study of the faunal and stratigraphic relations of the Briones formation to the adjacent formations in an effort to determine its position in the geologic scale. The results indicate: (1) that the Briones probably should be classified with the San Pablo group (Upper Miocene) rather than with the Monterey group (Lower and Middle Miocene); (2) that it is a minor cycle of deposition distinct from the Cierbo formation.[1]

Hitherto in its relationship to other strata, the Briones formation has occupied a more or less uncertain position. The term Briones was first used by Professor A. C. Lawson[2] in 1914 in the San Francisco Folio. It was applied to the "Scutella breweriana beds," which at that time were regarded as forming the upper faunal member of the Monterey group in the region east of San Francisco Bay. Dr. J. C. Merriam[3] in 1898 was the first person to indicate the faunal distinctness of the "Scutella breweriana beds." He included them, however, in the undifferentiated Miocene beneath the San Pablo. Very little detailed work has been done on the Briones since then. A few writers[4] have mentioned a faunal similarity between the Briones and the San Pablo, but they have included the Briones in the Monterey group. However, Clark[5] indicated that perhaps the Briones might have a closer relationship to the San Pablo than to the Monterey.

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1 The recognition of the Briones as a part of the San Pablo group causes the "Lower San Pablo" formation to become the middle member of the group. In order to overcome this ambiguity, Professor B. L. Clark, in his recent paper on the Marine Tertiary of the West Coast of the United States, in the Journal of Geology, volume 29, page 601 (1921), applies the name Cierbo formation to the "Lower San Pablo," and he uses the term Santa Margarita for the Upper San Pablo. He retains the name San Pablo for the entire group consisting of the Briones, Cierbo, and Santa Margarita.

In the present paper, unless otherwise stated, the term San Pablo refers to that part of the San Pablo group above the Briones, viz., the Lower San Pablo (Cierbo) and the Upper San Pablo (Santa Margarita). In other words it refers to the San Pablo group as understood previous to the application of the evidence here presented.

2 Lawson, A. C., San Francisco Folio, U. S. G. S. No. 193, p. 11, 1914.

3 Merriam, J. C., Distribution of the Neocene sea-urchins of Middle California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 2, p. 112, 1898.

4 Merriam, J. C., A note on the fauna of the Lower Miocene of California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 3, p. 378, 1904.

Weaver, C. E., The stratigraphy and palaeontology of the San Pablo formation of Middle California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 251, 1909.

Clark, B. L., Fauna of the San Pablo group of Middle California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, p. 436, 1915.

5 *Loc cit.*, p. 436.

Most of the field work for the present paper was done during the summer of 1919, but several days were spent in the field in the fall of 1920 and the spring of 1921. The paleontological evidence is based both on collections made during this field study, and on previous collections made by the University of California.

The writer is particularly indebted to Professor B. L. Clark, whose personal supervision, suggestions, and coöperation, both in the field work and determination of fauna, have made possible the results here presented.

Through the kindness of Professor James Perrin Smith, the writer has had access to the collections of the Briones at Leland Stanford Junior University. He is particularly indebted to Mr. Frederick P. Vickery of the Southern Branch of the University of California for much information concerning the nature of the southern extension of the Briones, and for assistance with the maps and paleontological collections of the Stanford Geological Survey.

The work of determining the fauna has been greatly facilitated by the excellent collections made by Professors J. C. Merriam and B. L. Clark.

Acknowledgment is also due Mr. E. L. Furlong of the Museum of Paleontology at the University of California for numerous suggestions and friendly criticisms.

AREAL DISTRIBUTION OF BRIONES FORMATION

The Briones formation is so far known only from a limited area near San Francisco Bay. It is particularly well developed in the western part of Contra Costa County, which has been the chief field of investigation.

The most easterly known exposure of the Briones is on the southwest flank of Mt. Diablo. Mr. Vickery informs the writer that he has observed the Briones extending to a point a few miles south of Mt. Hamilton. Twenty-five miles to the west in the Santa Cruz Quadrangle[6] and extending northerly along the San Francisco Peninsula, the Briones has not been reported as occurring between the Monterey and the Santa Margarita. Professor B. L. Clark has told me that he has observed the Briones as far north as Carneros Creek, just west of the city of Napa, some thirty-five miles north of San Francisco.

[6] Branner, J. C., Arnold, Ralph, and Newsome, J. J., Santa Cruz Folio, U. S. G. S. No. 163, 1909.

This limited known occurrence of the Briones deposits and the fact that in all other regions in California the Briones formation has not been recognized between the Monterey and the Santa Margarita, indicate that the Briones sea was probably an embayment of small extent.

DESCRIPTION OF THE FORMATION

The Briones formation shows a wide range in thickness. The minimum noted is on the south side of Mt. Diablo in the vicinity of Sycamore Creek, on the east side of the Walnut Creek syncline. Here the thickness is about 450 feet. Ten miles to the north along the strike the thickness of the formation has increased to over 1000 feet. Five miles to the west on the west side of this syncline, the thickness of the Briones averages about 1100 feet. On progressing northwesterly toward San Pablo Bay, the deposits gradually increase in thickness and attain a maximum of over 2300 feet.

One of the most typical exposures of the Briones formation is found on the southwest side of Mt. Diablo. Here the basal beds consist of some 75 to 150 feet of gray, fairly well indurated, medium-grained, slightly fossiliferous sandstones. Overlying these sandstones are about 75 feet of hard, massive, firmly cemented, coarse-grained sandstones, which in places are finely conglomeratic. These beds contain a great number of fossils and the shells are packed so closely together that they make veritable shell beds. The strata overlying these shell beds vary in thickness from 300 to 800 feet and consist of yellow, sandy shales alternating with fine-grained sandstones. Certain members are relatively resistant to erosion and appear as small longitudinal ridges on the sides of the hills. Near the top of the formation the deposits become more fine-grained and shaly in texture.

In the Contra Costa Hills and regions to the south, except in the territory near San Pablo Bay, the exposures of the Briones formation are very similar to those found on the southwest side of Mt. Diablo. The most striking features are the hard, massive, extremely fossiliferous, reef-like sandstones near the base of the formation, which, due to their resistant nature and generally high angle of dip, weather in bold relief.

In the northwestern portion of the Contra Costa Hills, progressing northward from Walnut Creek to San Pablo Bay, the Briones deposits gradually thicken, and become more fine-grained in texture. Even the coarse-grained reef-like beds, so prominent in other sections, gradually merge into soft fine-grained sandstones.

In the San Pablo Bay region, the Briones is composed of three lithologic members, two very similar sandstones and an intermediate shale. As a rule the sandstones are fine-grained, soft, yellow, more or less fossiliferous, and in places grade into sandy shales. The maximum thicknesses of the lower and upper sandstones are 1000 and 800 feet, respectively.

The middle member, which is a shale, attains a maximum thickness of 600 feet near San Pablo Bay. Lawson[7] has named it the Hercules shale member. It thins to the southwest, and six miles from the bay, it has a thickness of less than 200 feet. At this point the continuity of the section is broken by a fault, and the Hercules shale member has not been definitely recognized to the south.

The Hercules shale is composed of a yellow, unfossiliferous, bituminous shale, which, lithologically, appears similar to the shales of the Monterey group below.

As yet no differences in dip and strike have been noted between the Briones and the formations above and below. There is, however, a rather sharp change in lithology between it and the adjacent formations. As a general rule the upper part of the Monterey consists of a yellow shale (though in a few localities it is composed of a soft, yellow, fine-grained sandstone), while the base of the Briones is characterized by a gray, coarse-grained sandstone. The upper part of the Briones is usually composed of a soft, yellow, fine-grained sandstone or sandy shale, while the base of the San Pablo consists of a hard, gray, coarse-grained to finely conglomeratic sandstone.

On the southwest side of Mt. Diablo in Wall Point Cañon there is an irregular contact and a sharp change in lithology between the Monterey and the Briones. The upper Monterey is composed of a yellow shale, while the base of the Briones consists of a hard, gray, coarse-grained sandstone. *Astrodapsis brewerianus* (Rémond) has been found in the sandstone five centimeters above the contact, thus indicating the identity of these beds with the Briones. The contact is quite distinct and somewhat irregular. Erosional gutters, ten to fifteen centimeters in depth, are observed in the upper part of the Monterey shales. Cracks in the Monterey, a foot or more in depth, are found filled with the sandstone matrix from above. A layer of isolated pebbles, about two centimeters in diameter, occurs just above

[7] Lawson, A. C., San Francisco Folio, U. S. G. S. No. 193, p. 11, 1914.

the contact. There is no evidence of differences in dip and strike, as none of the beds of the Monterey appears to be truncated by the Briones. The lithologic change, irregular erosion line, isolated layer of pebbles above the contact, and the finding of *Astrodapsis brewerianus* (Rémond) just above the contact indicate that this is probably the contact between the Briones and the Monterey.

Similar irregular contacts have been found between the Monterey and the Briones in two other localities. One of these is on the northern end of Shell Ridge, some seven miles northwest along the strike of the contact mentioned above. The other is located in the northern part of the Concord Quadrangle, in a Santa Fé Railroad cut, one mile east of Muir Station, on the north end of the Pacheco syncline. In each of these two localities there is a sharp lithologic change, irregular contact line, and in the one on the north end of the Pacheco syncline, shale pebbles, three to five centimeters in diameter, very similar to the underlying Monterey shale, are found in the sandstone above the contact. Pholas borings are also found just beneath the contact. This contact is somewhat more irregular than the others—erosional gutters nearly a foot in depth being present.

On the southwest side of Mt. Diablo on the northern side of Sycamore Creek, there is an irregular contact between the Briones and the Lower San Pablo (Cierbo). Here a road cuts across the contact three times, and the break may be traced interruptedly for about one-half mile. There is a sharp change in lithology. The beds below the contact usually are composed of yellow, sandy shales, containing *Nassa whitneyi,* n. sp. The beds above the contact consist of hard, massive, finely conglomeratic sandstones. Numerous borings of the Pholadid type are found in the beds immediately below the contact. Cracks a foot or more in depth are found in the shale below, filled with the sandstone matrix from above. There is no appreciable difference in dip and strike. The sharp change in lithology, uneven contact, presence of Pholadid borings, and *Nassa whitneyi,* n. sp., found just below the contact, point to this being the line of demarcation between the Briones and the San Pablo.

Clark[8] has described another disconformity between the Briones and the San Pablo, which occurs about two miles to the north in Wall Point Cañon. This is very similar to the one mentioned above. There is a sharp change in lithology, irregular contact line, and borings of the Pholadid type are found in the beds just beneath the contact.

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[8] Clark, B. L., Fauna of the San Pablo group of Middle California, Univ. Calif. Publ. Bull. Dep. Geol., vol. 8, p. 408, 1915.

FAUNA

The Briones formation is here treated as a unit. Sufficient collections have not been made to warrant the determination of minor faunal zones, if any occur.

There are several forms which are regarded as characteristic of the Briones formation. The most characteristic is *Astrodapsis brewerianus* (Rémond), which is quite common. In fact, for several years previous to the application of the name Briones, the term "Scutella breweriana zone" was applied to these beds.

Other good markers are:

Astrodapsis brewerianus diabloensis Kew
Pecten ricei, n. sp.
Koilopleura sinuata (Gabb)
Trophon daviesi, n. sp.
Modiolus gabbi subconvexus, n. var.
Modiolus veronensis, n. sp.

The following species complete the list of those forms so far recognized only from the Briones. An asterisk indicates that the species is of relatively rare occurrence.

Siphonalia rodeoensis, n. sp.
*Antigona willisi, n. sp.
*Leda furlongi, n. sp.
*Pecten andersoni gonicostus, n. var.
Pecten tolmani Hall and Ambrose
*Pecten vickeryi, n. sp.
Spisula falcata brioniana, n. var.
Tivela merriami, n. sp.
*Venus brioniana, n. sp.
*Calliostoma obliquistriata, n. sp.
*Ficus rodeoensis English
*Oliva simondsi, n. sp.
*Sinum trigenarium, n. sp.

Pecten raymondi brionianus, n. var., is also very common, but it is not restricted to the Briones, for occasional specimens are found in the San Pablo. In the absence of other reliable markers, the finding of a preponderance of this variety may be taken as a fair indication of the Briones age of a formation.

Nassa whitneyi, n. sp., is also an abundant species in the Briones. As yet it has not been found in the San Pablo. Hence it may serve as an aid in distinguishing the Briones from the San Pablo (Cierbo and Santa Margarita). However, while this species has not definitely been recognized from beds of Monterey age, specimens have been found which indicate the possibility of this form extending into the Monterey. Further collecting and better material may show that such is the case.

In the San Pablo Bay region the Briones has been regarded as consisting of three lithologic members. The faunal similarity of the lower and upper sandstone members and the relatively non-persistent character of the middle shale member, indicate that these three members should be regarded as a single formation.

The following fauna has been recognized from the lower sandstone member of the Briones in the San Pablo Bay region:

Arca cf. trilineata Conrad
Chione panzana Anderson and Martin
Diplodonta harfordi Anderson
Diplodonta parilis (Conrad)
Diplodonta, sp.
Dosinia cf. merriami Clark
Leda cf. taphria Dall
Macoma andersoni Clark
Macoma cf. yoldiformis Carpenter
Marcia oregonensis (Conrad)
Modiolus cf. capax Conrad
Mya ovalis (Conrad)
Panope cf. generosa Gould
Pecten andersoni gonicostus, n. var.
Pecten raymondi brionianus, n. var.
Phacoides annulatus (Reeve)
Schizothaerus nuttallii (Conrad)
Siliqua lucida (Conrad)
Solen perrini Clark
Solen cf. sicarius Gould
Spisula albaria (Conrad)
Spisula catilliformis Conrad
Spisula falcata brioniana, n. var.
Tellina oregonensis Conrad
Yoldia cooperi Gabb
Calyptraea filosa (Gabb)
Ficus rodeoensis English
Ficus stanfordensis Arnold
Fusinus, sp.
Koilopleura sinuata (Gabb)
Nassa whitneyi, n. sp.
Natica kirkensis Clark
Natica pabloensis Clark
Siphonalia rodeoensis, n. sp.
Thais cf. lima (Martyn)
Turris, sp.

All these forms except the following have been found in the Briones formation in other localities:

Diplodonta, sp.
Leda cf. taphria Dall
Macoma andersoni Clark
Pecten andersoni gonicostus, n. var.
Ficus rodeoensis English
Fusinus, sp.
Thais cf. lima (Martyn)
Turris, sp.

Of these eight species, five are not accurately determinable, and one, *Macoma andersoni* Clark, is found in the San Pablo above. Only two determinable species are restricted to this lower sandstone, and only one specimen of each of these two species has so far been found.

All the species found in this lower sandstone which also occur in the Monterey group, have been found in the Briones formation in other regions.

The presence of the following forms, which are quite common in the Briones formation, and whose range is either limited to the Briones formation itself, or to the San Pablo group, shows the close faunal relationship between this sandstone and the Briones formation in general.

Pecten raymondi brionianus, n. var.	Ficus stanfordensis Arnold
Dosinia merriami Clark	Natica kirkensis Clark
Macoma andersoni Clark[9]	Natica pabloensis Clark
Nassa whitneyi, n. sp.[10]	Koilopleura sinuata (Gabb)

Hence, due to this close faunal similarity between this lower sandstone member and the Briones formation in general, and to the faunal distinctness between it and the Monterey group, it seems that this lower sandstone should be regarded as a part of the Briones formation.

COMPLETE LIST OF KNOWN SPECIES FROM THE BRIONES FORMATION WITH THEIR GEOLOGIC RANGE

	Oligocene	Monterey group	Briones	San Pablo	Etchegoin	Recent
ECHINODERMATA						
Astrodapsis brewerianus (Rémond)	....	....	×	....	....	....
Astrodapsis brewerianus diabloensis Kew	....	....	×	....	....	....
Ophiurites (Ophiuroglyphus?), sp.	....	....	×	....	....	....
BRYOZOA						
One species	....	....	×	....	....	....
ARTHROPODA						
Balanus, sp. *a*	....	....	×	....	....	....
Balanus, sp. *b*	....	....	×	....	....	....
Cancer?, sp.	....	....	×	....	....	....
PELECYPODA						
Antigona willisi, n. sp.	....	....	×	....	....	....
Arca trilineata Conrad	....	×	×	×	×	....
Cardium corbis (Martyn), n. var.?	....	....	×	....	....	....
Cardium quadrigenarium Conrad	....	×	×	×	×	×
Chione panzana Anderson and Martin	....	×	×	....	....	....
Diplodonta harfordi Anderson	....	....	×	×	×	....
Diplodonta parillis (Conrad)	....	....	×	×	×	....
Diplodonta, sp.	....	....	×	....	....	....
Dosinia arnoldi Clark	....	....	×	×	....	....
Dosinia merriami Clark	....	....	×	×	....	....
Dosinia merriami occidentalis Clark	....	....	×	×	....	....
Leda furlongi, n. sp.	....	....	×	....	....	....
Leda cf. taphria Dall	....	×	×	×	×	×

[9] *Macoma andersoni* Clark as yet has not been found in the Briones in other regions, but it is fairly common in the Upper San Pablo (Santa Margarita).

[10] *Nassa whitneyi,* n. sp., may possibly occur in the Monterey.

COMPLETE LIST OF KNOWN SPECIES FROM THE BRIONES FORMATION WITH THEIR GEOLOGIC RANGE—(*Continued*)

	Oligocene	Monterey group	Briones	San Pablo	Etchegoin	Recent
PELECYPODA—(*Continued*)						
Macoma andersoni Clark	....	....	×	×	....	....
Macoma nasuta (Conrad)	×?	×	×	×	×	×
Macoma cf. secta (Conrad)	....	×	×	×	×	×
Macoma cf. yoldiformis Carpenter	....	....	×	×	....	×
Marcia oregonensis (Conrad)	×	×	×	×	×	×
Metis alta (Conrad)	....	....	×	×	×	×
Modiolus cf. capax Conrad	....	....	×	×	×	×
Modiolus gabbi subconvexus, n. sp.	....	....	×	....	....	....
Modiolus veronensis, n. sp.	....	....	×	....	....	....
Mulinia cf. densata Conrad	....	....	×	×	×	....
Mulinia pabloensis Packard	....	....	×	×	....	....
Mya ovalis (Conrad)	....	....	×	×	×	....
Mytilus cf. perrini Clark	....	....	×	×	....	....
Mytilus cf. trampasensis Clark	....	....	×	×	....	....
Ostrea bourgeoisi Rémond	....	....	×	×	....	....
Pandora, sp.	....	....	×	....	....	....
Panope generosa Gould	....	×	×	×	×	×
Pecten andersoni gonicostus, n. var.	....	....	×	....	....	....
Pecten bilineatus Clark	....	....	×	×	....	....
Pecten crassicardo (Conrad)	....	....	×	×	....	....
Pecten raymondi Clark	....	....	×	×	....	....
Pecten raymondi brionianus, n. var.	....	....	×	×	....	....
Pecten ricei, n. sp.	....	....	×	....	....	....
Pecten tolmani Hall and Ambrose	....	....	×	....	....	....
Pecten vickeryi, n. sp.	....	....	×	....	....	....
Phacoides annulatus (Reeve)	....	....	×	×	×	×
Pitaria, sp.	....	....	×	....	....	....
Saxidomus nuttalli Conrad	....	×	×	×	×	×
Schizothaerus nuttallii (Conrad)	....	....	×	×	×	×
Siliqua lucida (Conrad)	....	....	×	×	×	×
Solen perrini Clark	....	×?	×	×	×	....
Solen sicarius Gould	....	....	×	×	×	×
Spisula albaria (Conrad)	....	×	×	×	×?	....
Spisula catilliformis Conrad	....	×	×	×	×	×
Spisula falcata brioniana, n. var.	....	....	×	....	....	....
Tellina oregonensis Conrad	×	×	×	....	....	....
Tivela diabloensis Clark	....	....	×	×	....	....
Tivela merriami, n. sp.	....	....	×	....	....	....
Venus brioniana, n. sp.	....	....	×	....	....	....
Venus martini Clark	....	....	×	×	....	....
Yoldia cooperi Gabb	....	....	×	×	×	×
Yoldia, sp.	....	....	×	....	....	....
Zirphaea dentata Gabb	....	....	×	×	....	....
GASTROPODA						
Actaeon, sp.	....	....	×	....	....	....
Acanthina perrini, n. sp.	....	....	×?	....	....	....

COMPLETE LIST OF KNOWN SPECIES FROM THE BRIONES FORMATION WITH THEIR GEOLOGIC RANGE—(*Concluded*)

	Oligocene	Monterey group	Briones	San Pablo	Etchegoin	Recent
GASTROPODA—(*Continued*)						
Astralium raymondi Clark	....	....	×	×	....	....
Calliostoma obliquistriata, n. sp.	....	....	×	....	....	....
Calyptraea filosa (Gabb)	....	×	×	×	×	....
Cancellaria cf. condoni Anderson	....	×	×	....	....	....
Cancellaria pabloensis Clark	....	....	×	×	....	....
Cancellaria cf. wynoothchensis Weaver	....	×	×	....	....	....
Cerithium, sp.	....	....	×	....	....	....
Chrysodomus cf. cierboensis Clark	....	....	×	×	....	....
Chrysodomus imperialis Dall	....	....	×	×	×	....
Crepidula praerupta Conrad	....	×	×	×	....	....
Ficus rodeoensis English	....	....	×	....	....	....
Ficus stanfordensis Arnold	....	....	×	×	....	....
Fissurella, sp.	....	....	×	....	....	....
Fusinus, sp.	....	....	×	....	....	....
Koilopleura sinuata (Gabb)	....	....	×	....	....	....
Nassa whitneyi, n. sp.	....	×?	×	....	....	....
Natica arnoldi Clark	....	....	×	×	....	....
Natica kirkensis Clark	....	....	×	×	....	....
Natica pabloensis Clark	....	....	×	×	....	....
Oliva simondsi, n. sp.	....	....	×	....	....	....
Olivella cf. pedroana (Conrad)	....	×	×	×	×	×
Sinum trigenarium, n. sp.	....	....	×	....	....	....
Siphonalia rodeoensis, n. sp.	....	....	×	....	....	....
Thais cf. lima Martyn	....	×	×	×	×	×
Trophon daviesi, n. sp.	....	....	×	....	....	....
Trophon gracilis clarki, n. nom.	....	....	×	×	....	....
Turris, sp. *a*	....	....	×	....	....	....
Turris, sp. *b*	....	....	×	....	....	....
SCAPHOPODA						
Dentalium, sp.	....	....	×	....	....	....
ELASMOBRANCHII						
Spine and teeth	....	....	×	....	....	....

STATISTICAL SUMMARY OF FAUNAL LIST

	Species
Echinodermata	3
Bryozoa	1
Pelecypoda	56
Gastropoda[11]	29
Scaphopoda	1
Arthropoda	3
Elasmobranchii	1
Total number of species	94

[11] *Acanthina perrini*, n. sp., is omitted from the summary as it is found in beds which are questionably correlated with the Briones.

Number of determinable species	64[12]
Number of species so far recognized only in the Briones	21 or 32.8 %
Number of species that extend into the San Pablo	41 or 64.0%
Number of species that extend into the Etchegoin (Pliocene)	19 or 29.7%
Number of Recent species occurring in the Briones	12 or 18.8%
Number of species that extend into the Monterey group (Vaqueros and Temblor)	12 or 18.8%
Number of species that extend into the Oligocene	2 or 3.1%
Number of species peculiar to the Briones and San Pablo	20 or 31.2%
Number of species peculiar to the Briones and the Monterey group	1 or 1.5%

RELATION OF THE BRIONES FAUNA TO THE MONTEREY FAUNA

A study of the known fauna of the Briones formation indicates that it has a much closer relationship to the San Pablo than to the Monterey. Twelve out of the sixty-four determinable species (18.8 per cent) extend into the Monterey, while forty-one species or 64 per cent occur in the San Pablo. Of the twelve species that extend into the Monterey, ten are known to occur in the San Pablo, one (*Tellina oregonensis* Conrad) occurs in the Oligocene, and only one (*Chione panzana* Anderson and Martin)[13] is peculiar to the Briones and the Monterey. Since only one (or possibly two) species out of a determinable fauna of sixty-four species is peculiar to these two formations, it appears that the Briones fauna is distinct from that of the Monterey.

RELATION OF THE BRIONES FAUNA TO THE SAN PABLO FAUNA

Of the forty-three known Briones species that extend into other formations forty-one occur in the San Pablo. Of these, twenty are peculiar to the Briones and to the San Pablo. They are:

Dosinia arnoldi Clark
Dosinia merriami Clark
Dosinia merriami occidentalis Clark
Macoma andersoni Clark
Mulinia pabloensis Packard
Ostrea bourgeoisi Rémond
Pecten bilineatus Clark
Pecten crassicardo (Conrad)
Pecten raymondi Clark
Pecten raymondi brionianus n. var.
Tivela diabloensis Clark
Venus martini Clark
Zirphaea dentata Gabb
Astralium raymondi Clark
Cancellaria pabloensis Clark
Ficus stanfordensis Arnold
Natica arnoldi Clark
Natica kirkensis Clark
Natica pabloensis Clark
Trophon gracilis clarki, nov. nom.

[12] The large number of indeterminable species is chiefly due to the generally poor preservation. A rather high percentage of the Briones fossils consists of casts or molds.

[13] *Nassa whitneyi*, n. sp., may possibly extend into the Monterey, but even if it did, there would then be only two species peculiar to these two formations.

A large number of the species peculiar to the Briones and the San Pablo are highly ornamented forms, or are of types which do not have long ranges, and which, if the Briones were a distinct period, probably would not extend into the San Pablo, such as the following:

Astralium raymondi Clark	Pecten raymondi Clark
Cancellaria pabloensis Clark	Pecten raymondi brionianus, n. var.
Trophon gracilis clarki, n. nom.	Pecten bilineatus Clark
Ficus stanfordensis Arnold	

In addition to these highly ornamented types, some forms are relatively common in the Briones which as yet have not been found in the San Pablo, but which are very closely related to some San Pablo species. These are:

Briones Form	San Pablo Homologue
Astrodapsis brewerianus diabloensis Kew	Astrodapsis cierboensis Kew; Astrodapsis tumidus Rémond
Modiolus gabbi subconvexus, n. var.	Modiolus gabbi Clark
Trophon daviesi, n. sp.	Trophon ponderosum Gabb

The general character or facies of the fauna of the Briones and the San Pablo appears to be very similar. A large number of species are numerically quite abundant in both formations:

Arca trilineata Conrad	Saxidomus nuttalli Conrad
Diplodonta parilis (Conrad)	Schizothaerus nuttallii (Conrad)
Dosinia arnoldi Clark	Siliqua lucida (Conrad)
Dosinia merriami Clark	Solen perrini Clark
Dosinia merriami occidentalis Clark	Solen sicarius Gould
Metis alta Conrad	Spisula albaria (Conrad)
Mulinia pabloensis Packard	Spisula catilliformis Conrad
Mya ovalis (Conrad)	Calyptraea filosa (Gabb)
Ostrea bourgeoisi Rémond	Crepidula praerupta Conrad
Pecten raymondi brionianus n. var. (San Pablo homologue, P. raymondi Clark)	Natica kirkensis Clark
	Natica pabloensis Clark

The above fossils are very common and constitute numerically over one-half of the specimens found in the Briones, yet they are also quite abundant in the San Pablo.

The lithologic sequence of the Briones and the San Pablo is very similar. Both possess massive, hard, fossiliferous sandstones near the base of the formation. The upper parts of both consist of alternating fine-grained sandstones and sandy shales. As yet, no differences in dip and strike have been observed between the Briones and the San Pablo.

Hence from the faunal similarity to the San Pablo, and the faunal distinctness from the Monterey, it is concluded that the Briones formation should be included in the San Pablo group rather than in the Monterey, or in a distinct group of its own.

That the Briones is a distinct formation from the Lower San Pablo (Cierbo) has already been shown by Merriam[14] on the basis of the sea-urchins. The Briones form, *Astrodapsis brewerianus* (Rémond) has not been found in the Lower San Pablo, and the Lower San Pablo form, *Scutella gabbi* (Rémond) has not been observed in the Briones.

The Briones has twenty-one species that have not been found in other formations; the Lower San Pablo has twenty-one species that are peculiar to it; and there are only five species which are restricted to these two formations. This indicates a faunal distinctness.

The following are the twenty-one species peculiar to the Briones:

Astrodapsis brewerianus (Rémond)
Astrodapsis brewerianus diabloensis Kew
Antigona willisi, n. sp.
Leda furlongi, n. sp.
Modiolus gabbi subconvexus n. var.
Modiolus veronensis, n. sp.
Pecten andersoni gonicostus, n. var.
Pecten ricei, n. sp.
Pecten tolmani Hall and Ambrose
Pecten vickeryi, n. sp.
Spisula falcata brioniana, n. var.
Tivela merriami, n. sp.
Venus brioniana, n. sp.
Calliostoma obliquistriata, n. sp.
Ficus rodeoensis English
Koilopleura sinuata (Gabb)
Nassa whitneyi, n. sp.
Oliva simondsi, n. sp.
Sinum trigenarium, n. sp.
Siphonalia rodeoensis, n. sp.
Trophon daviesi, n. sp.

The following are the twenty-one species peculiar to the Lower San Pablo[15] (Cierbo):

Asterias rémondii Gabb
Scutella pabloensis Kew
Pecten cierboensis Clark
Pecten crassiradiatus Clark
Pecten weaveri Clark
Pitaria behri Clark
Pitaria stalderi Clark
Sanguinolaria alata (Gabb)
Spisula abscissa (Gabb)
Tivela diabloensis angulatum Clark
Bursa carinata Clark
Calyptraea diabloensis Clark
Cerithiopsis turneri Clark
Chrysodomus cierboensis Clark
Chrysodomus pabloensis Clark
Columbella pittsburgensis Clark
Hemifusus dalli Clark
Littorina rémondii Gabb
Murex (Ocinebra) selbyensis Clark
Thais cierboensis Clark
Trophon dickersoni Clark

The following are the five species peculiar to the Briones and the Lower San Pablo:

Dosinia merriami Clark
Ostrea bourgeoisi Rémond
Tivela diabloensis Clark
Trophon gracilis clarki, n. nom.
Natica kirkensis Clark

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[14] Merriam, J. C., Distribution of the Neocene sea-urchins of Middle California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 2, p. 117, 1898.

[15] Clark, B. L., Fauna of the San Pablo group of Middle California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, pp. 417–423, 1915.

The geographic distribution of the Briones formation appears to be somewhat different from that of the Lower San Pablo, for on the north side of Mt. Diablo the Lower San Pablo is present, while the Briones is absent.

Hence from (1) the faunal distinctness of the two formations, (2) the different geographic distribution, and (3) the lithologic difference with erosion contacts, it is concluded that the Briones is a minor cycle of deposition distinct from the Lower San Pablo:

The San Pablo group would accordingly consist of three minor epochs, Briones, Lower San Pablo (Cierbo), and Upper San Pablo (Santa Margarita).

DESCRIPTION OF SPECIES

Subkingdom **MOLLUSCA**

Class PELECYPODA

Family LEDIDAE

Genus LEDA Schumacher

LEDA FURLONGI, n. sp.

Plate 1, figures 1*a* and 1*b*

Type.—No. 12362; *cotype*—No. 12363, Univ. Calif. Mus. Pal.

Shell small, subovate, moderately ventricose; beaks obscure, nearly central; slightly opisthogyrous; posterior dorsal edge gently concave; anterior dorsal edge nearly straight; anterior end regularly rounded; posterior end subacutely rostrate; lunule and escutcheon elongate, lanceolate, extending almost the entire length of the dorsal margins, and rather strongly pouting; surface sculptured with numerous fine regular concentric lines; hinge plate unknown.

Dimensions.—Type specimen U. C. no. 12362; length, 20.8 mm.; alt., 11.3 mm.; thickness of both valves, 8 mm. Cotype, U. C. no. 12363, length 16.1 mm.; alt., 8.6 mm.

Occurrence.—Briones formation, U. C. loc. 15.

Named in honor of Mr. E. L. Furlong of the Museum of Paleontology, University of California.

L. furlongi, n. sp., somewhat resembles *L. taphria* Dall,[16] but differs from the latter in being narrower, more elongate posteriorly, possessing finer concentric sculpturing, and the lunule and escutcheon being more strongly pouting. It differs from *L. ochsneri* Anderson and Martin[17] in being less acutely elongated posteriorly, the posterior dorsal slope being less concave, and the concentric ribs being finer.

[16] Dall, Nat. Hist. Soc. Brit. Columbia, Bull. no. 2, p. 7, pl. II, figs. 6–8, 1897.

[17] Anderson and Martin, Cal. Acad. Sci., ser. 4, vol. 4, p. 53, figs. 8*a*, 8*b*, 8*c*, 1914.

It differs from *L. whitmani* Dall[18] in that it possesses finer and more evenly distributed ribs over the entire surface, the posterior dorsal edge is less concave, and the shell appears much narrower.

Family Pectinidae

Genus PECTEN Müller

PECTEN (LYROPECTEN) RICEI, n. sp.

Plate 2, figures 1 and 2

Type.—No. 12364; *cotype*—No. 12365, Univ. Calif. Mus. Pal.

Shell medium in size; about as long as high, equilateral; apical angle about 89°; anterior and posterior dorsal margins strongly depressed; surface of left valve with fourteen low flat topped to broadly rounded ribs; interspaces flat, about equal in width to ribs, and possessing from three to four, almost invariably three, small riblets, which have a tendency to become bifurcated near the ventral margin.

Dimensions.—Type specimen U. C. no. 12364; alt., 63.7 mm.; width, about 53 mm.; apical angle, 89°. Cotype, U. C. no. 12365; alt., 72.3 mm.; width, 70.7 mm.; apical angle, 93°.

Occurrence.—Briones formation. Type from U. C. loc. 3535; cotype from loc. 3534.

Named in honor of Professor C. D. Rice, University of Texas.

PECTEN (LYROPECTEN) VICKERYI, n. sp.

Plate 4, figure 1

Type in Stanford University Paleontological Collection.

Shell large, slightly more wide than high; ears about one-half the width of the shell; dorsal margins strongly depressed and quite long, being about three-fourths the height of the shell; surface with sixteen prominent ribs; every third rib being higher and more strongly developed than the others; interspaces about as wide as ribs; both ribs and interspaces ornamented with numerous fine riblets; ears with five to six small ribs.

Dimensions.—Alt., 99 mm.; width about 106 mm.; apical angle, 100°.

Occurrence—Briones formation, vicinity of McGuire Peaks, Pleasanton Quadrangle.

Note.—Only one valve has been found. Type specimen possesses depression near ventral margin.

Named in honor of Mr. Frederick P. Vickery, Department of Geology, Southern Branch, University of California.

PECTEN (PECTEN) RAYMONDI BRIONIANUS, n. var.

Plate 1, figures 2 and 3

Type.—No. 12368; *cotype*—No. 12369, Univ. Calif. Mus. Pal.

Dimensions.—Type specimen U. C. no. 12368; alt., 37.3 mm.; width, 37.3 mm.; length of ears, 18.7 mm.; apical angle, 100°. Cotype, U. C. no. 12369; alt., 31.7 mm.; width, 32.7 mm.; apical angle, 100°.

Occurrence.—San Pablo group. Type and cotype from U. C. loc. no. 3532.

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[18] Dall, U. S. G. S. Prof. Paper 59, p. 103, pl. XIV, fig. 4, 1909.

An analysis of over one hundred specimens of the forms of *Pecten raymondi* Clark found in the Briones and the San Pablo formations shows that there are two end varieties with a gradual gradation between. The San Pablo forms, as a general rule, possess a relatively more convex left valve, and higher and stronger ribs which are relatively close together. This is the typical *P. raymondi* described by Clark.[19] The forms found in the Briones have only slightly convex valves, and the ribs are relatively low and widely separated. The name *P. raymondi brionianus* is suggested for this variety.

PECTEN (PECTEN) ANDERSONI GONICOSTUS, n. var.

Plate 1, figure 5

Type.—No. 12370, Univ. Calif. Mus. Pal.

Shell small to medium in size, subcircular, nearly equilateral; dorsal margins gently concave; anterior dorsal margin longer than posterior; ventral margins strongly arcuate; right valve gently convex, and possesses about seventeen subangular "V" shaped ribs; interspaces wider than ribs; hinge line about three-fifths width of shell; ears about equal in length; anterior ear with five ribs; posterior ear with four fine subangulate ridges, with interspaces wider than the ridges; byssal notch prominent.

Dimensions.—Type specimen U. C. no. 12370; alt., 29.7 mm.; width, 30.2 mm.; length of ears, 18 mm.; apical angle, 100°.

Occurrence.—Briones formation, U. C. loc. no. 1176.

This species resembles *P. andersoni* Arnold,[20] but it differs from the latter in that the right valve is less convex, the ribs are less prominent, the interspaces are wider, and the ears are shorter and broader.

Family Mytilidae

Genus MODIOLUS Lamarck

MODIOLUS GABBI SUBCONVEXUS, n. var.

Plate 3, figure 2

Type.—No. 12372, Univ. Calif. Mus. Pal.

Shell very similar to *M. gabbi* Clark,[21] but differs from the latter in that the umbonal ridge is less prominent; the shell is more convex, narrow, and tumid; the striations are slightly narrower and less prominent; and on the posterior slope the striations become much finer, closer together and more numerous.

Dimensions.—Type specimen U. C. no. 12372; alt., 56.8 mm.; greatest width, 20.6 mm.

Occurrence.—This is a common species in the Briones formation. Type from U. C. loc. no. 793.

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[19] Clark, B. L., Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, p. 450, pl. 46, figs. 1 and 2, pl. 47, figs. 1 and 2, 1915.

[20] Arnold, U. S. G. S. Prof. Paper 47, p. 82, pl. XXIV, figs. 5–8, 1906.

[21] Clark, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, p. 458, pl. 48, fig. 1, 1915.

MODIOLUS VERONENSIS, n. sp.

Plate 3, figure 4

Type.—No. 12373, Univ. Calif. Mus. Pal.

Shell small to medium in size, flat and elongate; anterior end extending only slightly beyond beak; posterior dorsal edge straight and not separated from the posterior end by any well defined angle; anterior dorsal edge slightly concave; base evenly rounded; surface smooth, except for concentric lines of growth.

Dimensions.—Type specimen U. C. no. 12373; length, 40.6 mm.; greatest width, 17.9 mm.

Occurrence.—Briones formation. Type specimen from U. C. loc. no. 3529.

Family CYRENIDAE

Genus CYRENA Lamarck

CYRENA (CORBICULA) DIABLOENSIS, n. sp.

Plate 3, figures 5*a* and 5*b*

Type.—No. 12374, Univ. Calif. Mus. Pal.

Shell medium in size, subcircular; beaks anterior to the middle of the shell, inconspicuous, and only slightly prosogyrous; dorsal margins straight and nearly equal; surface smooth except for fairly heavy, irregular lines of growth; hinge plate heavy; posterior cardinal not as heavy as two anterior cardinals; nymph plate fairly long for this genus, but not as wide or as prominent as is often the case with Cyrena.

Dimensions.—Type specimen U. C. no. 12374; alt., 37.6 mm.; width, 42.4 mm.

Occurrence.—Upper San Pablo formation, U. C. loc. no. 1949.

This species differs from *C. californica* Gabb,[22] found in the same horizon, in being more circular in outline, in having less conspicuous beaks, which are less prosogyrous, in having heavier teeth and more obsolete laterals, and in possessing a less prominent nymph plate.

Family CARDIIDAE

Genus CARDIUM Linné

CARDIUM CORBIS, n. var.?

Plate 5, figure 3

Specimen.—No. 12376, Univ. Calif. Mus. Pal.

Shell is very similar to *Cardium corbis* (Martyn),[23] but differs in having on the average three or four less ribs. The Briones form has 29 to 30 ribs, while the recent form (the typical *C. corbis*) has 33 to 34. The preservation on all the specimens found in the Briones as yet is very poor, and it is difficult to tell whether this is a new variety of *C. corbis* or not. However, the twenty-nine ribs appear to be quite constant on the seven specimens at hand.

Dimensions.—Specimen figured is U. C. no. 12376; alt., 34 mm.; width, 40 mm.

Occurrence.—Briones formation. Specimen figured from U. C. loc. no. 207.

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[22] Gabb, Calif. State Geol. Surv., Palaeontology of California, vol. 2, p. 26, fig. 45, 1869.

[23] Martyn, Univ. Conch., pl. XXVIII, fig. 2, 1784.

Family Veneridae

Genus VENUS Linné

VENUS BRIONIANA, n. sp.

Plate 5, figure 1

Type.—No. 12377, Univ. Calif. Mus. Pal.

Shell large, subcircular in outline, inequilateral, height about equal to width; anterior dorsal edge short, concave; posterior dorsal edge long and very gently convex; ventral margin strongly arcuate; surface of shell ornamented with numerous concentric undulations, on and between which are smaller incremental lines; hinge plate unknown.

Dimensions.—Type specimen U. C. no. 12377; alt., 88.5 mm.; width, 86. 5 mm.

Occurrence.—Briones formation, U. C. loc. no. 177.

This species resembles *V. conradiana* Anderson,[24] found in the Temblor formation (Monterey group) in the southern part of the state, but it differs from the latter in that it is more symmetrical in shape, less produced posteriorly, and it possesses a fuller anterior ventral margin.

Genus TIVELA Link

TIVELA MERRIAMI, n. sp.

Plate 6, figures 1*a* and 1*b*

Type.—No. 12378, Univ. Calif. Mus. Pal.

Shell medium in size, height almost equal to width, ventricose, line of greatest ventricosity anterior to middle of shell; surface with slight depression posterior to middle; beaks prominent, only slightly prosogyrous, and a little posterior to middle of shell; dorsal margins straight, subacutely depressed, with greatest depression near beaks; posterior dorsal margin longer than anterior and with a slight depression, which is coexistent with the depression posterior to the middle of the shell; ventral margin strongly arcuate anteriorly; surface smooth except for fine incremental lines; hinge plate heavy; right valve with three cardinals; anterior cardinal nearly obsolete and very close to the dorsal margin; middle and posterior cardinals about equal in size, the posterior being somewhat the longer; nymph plate heavy and longer than any of the cardinals; anterior clasper long, with inner crest considerably below the level of the dorsal margin. The species is quite distinct because of its ventricosity, rounded dorsal margins, and peculiar hinge.

Dimensions.—Type specimen U. C. no. 12378; alt., 62.3 mm.; width, 66.8 mm.

Occurrence.—Briones formation, U. C. loc. no. 3582. Known only by right valve.

Named in honor of Dr. J. C. Merriam.

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[24] Anderson, Proc. Cal. Acad, Sci., ser. 3, vol. 2, p. 195, pl. XIV, 1905.

Genus ANTIGONA Schumacher

ANTIGONA WILLISI, n. sp.

Plate 5, figures 2*a* and 2*b*

Type.—No. 12379, Univ. Calif. Mus. Pal.

Shell elongate, subovate; lunule large, well defined, and depressed; escutcheon elongate, depressed, and well developed in left valve and apparently absent in right; anterior dorsal margin gently concave and about three-fifths the length of the posterior, which is almost straight; posterior end subacutely rounded; anterior end produced and broadly rounded; surface of shell sculptured by regular undulations; near the beak and over a large part of the surface, undulations about equal in size to interspaces, but near ventral margin become much more closely crowded; undulations and interspaces marked with fine incremental lines; hinge unknown. The species is quite distinct because of its elongate form.

Dimensions.—Type specimen U. C. no. 12379; alt., 33.3 mm.; width, 42.7 mm.; greatest diameter, 22.8 mm.

Occurrence.—Briones formation, U. C. loc. no. 146.

Named in honor of Professor Bailey Willis, Stanford University.

Family Mactridae

Genus SPISULA Gray

SPISULA FALCATA BRIONIANA, n. var.

Plate 4, figures 2*a* and 2*b*

Type.—No. 12380, Univ. Calif. Mus. Pal.

Shell small to medium in size, subtrigonal, inequilateral, equivalve; beaks rather inconspicuous, incurved and only slightly prosogyrous; anterior dorsal edge long and straight; posterior dorsal edge straight to gently convex, and about two-thirds the length of the anterior dorsal edge; posterior end evenly rounded; anterior ventral end produced and subacutely rounded; surface smooth except for fine incremental lines; hinge plate short, resilifer shallow; cardinals small and fragile; laterals very short and close to laminae.

Dimensions.—Type specimen U. C. no. 12380; alt., 17.6 mm.; length, 24.0 mm.

Occurrence.—Briones formation. Type from U. C. loc. no. 3522.

This variety resembles *S. falcata* (Gould),[25] a recent species of the West Coast, but it differs from the latter in that it is higher in proportion to length; it possesses a more prominent umbonal ridge; it has a shorter hinge plate and shorter laterals; and the distance from the center of the hinge plate to the distal ends of the laterals is about one-half of what it is in *S. falcata.*

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[25] Gould, Proc. Brit. Soc. Nat. Hist., vol. III, p. 216, 1850.

Class GASTROPODA

Family Trochidae

Genus CALLIOSTOMA Swainson

CALLIOSTOMA OBLIQUISTRIATA, n. sp.

Plate 7, figures 1*a* and 1*b*

Type.—No. 12385, Univ. Calif. Mus. Pal.

Shell small, subconical; apex low; body whorl more than half height of shell; sutures depressed; sides of whorls convex; body whorl with about ten oblique ribs which are rounded and somewhat indistinctly nodose; ribs inclined at an angle of about 30° to the revolving lines; between base and the oblique nodes are two spiral ribs, the upper of which is the more prominent; lower spiral rib almost at base of whorl; surface also sculptured with numerous fine oblique riblets, inclined at an angle of 45° to the whorls; these are more pronounced between upper spiral rib and suture; base of body whorl flat, at right angles to the sides, and is ornamented with three revolving ribs; aperture not preserved.

Dimensions.—Type specimen U. C. no. 12385; alt., 6.6 mm.; greatest width, 10.2 mm.

Occurrence.—Briones formation, U. C. loc. no. 3575.

This species resembles *C. bicarinatum* Clark,[26] occurring in the Upper San Pablo, but it differs from the latter in that it possesses the prominent oblique striations on the sides of the whorls, a lower spire, less prominent nodes upon the upper part of the whorls, and it has three instead of four revolving ribs upon the base of the body whorl.

Family Naticidae

Genus SINUM Bolten

SINUM (SIGARETUS) TRIGENARIUM, n. sp.

Plate 7, figures 2*a* and 2*b*

Type.—No. 12386, Univ. Calif. Mus. Pal.

Shell medium in size; spire low; number of whorls to spire three; body whorl large and sculptured with about thirty revolving ribs, about one to the millimeter; aperture subovate, elongate posteriorly.

Dimensions.—Type specimen U. C. no. 12386; alt., 33.5 mm.; greatest width, 35.3 mm.; alt. of aperture, 29 mm.; maximum width of aperture, 17.8 mm.

Occurrence.—Briones formation, U. C. loc. no. 3576.

This species is similar to *S. scopulosum* (Conrad),[27] but it differs from the latter in that it possesses thirty spiral ribs on the body whorl,

[26] Clark, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, p. 481, pl. 65, figs. 14 and 19, 1915.

[27] Conrad, U. S. Expl. Exp. Geol., Appendix, p. 727, pl. 19, figs. 6 and 6*a*, 1849.

while *S. scopulosum* has forty-five. In comparing the number of ribs per 5 mm. on specimens of *S. trigenarium*, n. sp., and *S. scopulosum* of about the same size, five ribs per 5 mm. are found in the former and eight ribs per 5 mm. are found in the latter. Also the aperture of *S. trigenarium* is more elongate posteriorly.

Family NASSIDAE

Genus NASSA Lamarck

NASSA WHITNEYI, n. sp.

Plate 7, figures 3 and 6

Type.—No. 12387; *cotype*—No. 12388, Univ. Calif. Mus. Pal.

Shell medium sized; apical angle averages 53°; number of whorls to spire five; sutures deeply depressed; whorls convex, with a fairly well marked tabulation on the upper border; surface of body whorl ornamented with about 27 to 30 medium to coarse longitudinal ribs; surface also possesses 11 to 13 revolving ribs, which are more prominent and nearer together than the longitudinal ribs; interspaces between revolving ribs much smaller than width of ribs; the juncture of the two sets of ribs gives the surface a nodose aspect, but frequently due to the lesser prominence of the longitudinal ribs, the spiral lines become the more pronounced; on the spiral whorls only seven of the spiral ribs are seen; outer lip sometimes possesses a rope-like varix; canal short, reflexed, and separated from the posterior part of the body whorl by a deep, rounded depression; inner lip not preserved; columella appears to be smooth, but better preserved specimens may show plications.

Dimensions.—Type specimen U. C. no. 12387; alt., 14 mm.; greatest width, 9 mm. Cotype, U. C. no. 12388; alt., 13.5 mm.; greatest width, 7.8 mm.

Occurrence.—This is a very common species throughout the entire Briones formation. Type from U. C. loc. no. 3524; cotype from loc. no. 1176.

Named in honor of Professor F. L. Whitney, Professor of Paleontology at the University of Texas.

This species differs from *N. pabloensis* Clark[28] in that it is more convex and it possesses more numerous longitudinal and spiral ribs. It differs from *N. arnoldi* Anderson[29] in that it is larger and it possesses more numerous and less prominent ribs.

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[28] Clark, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, p. 493, pl. 65, figs. 8 and 9, 1915.

[29] Anderson, Proc. Cal. Acad. Sci., ser. 3, vol. 2, p. 204, pl. XVI, figs. 70 and 71, 1905.

Family Buccinidae

Genus SIPHONALIA Adams

SIPHONALIA RODEOENSIS, n. sp.

Plate 7, figures *4a* and *4b*

Type.—No. 12389, Univ. Calif. Mus. Pal.

Shell fusiform; spire of medium height; sutures moderately appressed; whorls subangulate above the middle and slope gently up to the suture; surface of whorls with about ten longitudinal ridges, which are more pronounced upon the spiral whorls, and are more prominent at the point of angulation of the whorls; shell sculptured with numerous spiral ribs, which tend to become obsolete on the body whorl; on the whorls of the spire there are three major revolving ribs alternating with two minor ribs; inner lip smooth; canal medium in length and gently reflexed; umbilicus subperforate.

Dimensions.—Type specimen U. C. no. 12389; alt., 30.5 mm.; greatest width, 17.8 mm.; alt. of aperture, 21.5 mm.

Occurrence.—Briones formation. Type from U. C. loc. no. 1177, on the north side of Rodeo Creek.

This species resembles *S. danvillensis* Clark,[30] found in the Upper San Pablo, but it differs from the latter in that the angulation on the whorls, particularly on those of the spire, is not so pronounced; the surface of the whorls above the point of angulation slopes upward toward the suture and is not depressed as in *S. danvillensis;* there are no spiral ribs above the angulation; and there is a pronounced alternating arrangement in size of the revolving ribs on the spiral whorls.

Family Muricidae

Genus TROPHON Montfort

TROPHON DAVIESI, n. sp.

Plate 7, figures *5a and 5b*

Type.—No. 12391, Univ. Calif. Mus. Pal.

Shell medium in size; spire about one-third height of shell; suture slightly appressed; body whorls five, with a flat, somewhat upward sloping tabulation; body whorl large, with depression about midway from angulation to base of whorl; outer lip not preserved; inner lip incrusted; canal moderately long and recurved; umbilicus subperforate.

Dimensions.—Type specimen U. C. no. 12391; alt., 42 mm.; greatest width, 29 mm.; alt. of aperture, 28 mm.

Occurrence.—Briones formation. Type from U. C. loc no. 1354.

Named in honor of my mother, Kate Davies Trask and my uncle, Dr. M. J. Davies.

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30 Clark, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, p. 497, pl. 67, fig. 6, 1915.

This species differs from *T. ponderosum* Gabb[31] in that it possesses a longer body whorl, longer canal, and a depression of the body whorl near the base.

T. daviesi, n. sp., resembles *T. carisaensis* (Anderson)[32] in possessing the depression on the lower part of the body whorl, but in the latter the depression is much more strongly developed and takes the form of a groove. *T. daviesi* further differs from *T. carisaensis* in that it is less solid, more slender, and less prominently nodose.

TROPHON GRACILIS CLARKI, n. nom.

Plate 6, figures 2, 3, and 4

Trophon gracilis pabloensis. Clark, B. L., Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, p. 498, pl. 66, figs. 6 and 7, 1915.

Type.—No. 11625; *cotype*—No. 11626; Briones *cotype*—No. 12390.

"Shell medium-sized; spire rather high; apex acute; number of whorls to spire five or six; body whorl large; sutures obscurely appressed. Whorls angulated, with the narrow surface above the angulation sloping up gently to the suture. Surface of shell crossed by ten or eleven prominent lamella-like varices which are flexed forward and produced on the angle into upright, fairly prominent spines; on the upper whorls of the spire the varices become prominent ridges. Spiral ribbing lacking; outer lip sharp; inner lip smooth and incrusted; canal broken on all specimens that the writer so far has obtained."

Dimensions.—Clark's type, U. C. no. 11625; alt., unknown; max. width, 32 mm. Clark's cotype, U. C. no. 11626; alt., unknown; max. width, 26 mm. Author's cotype, U. C. no. 12390; alt., 53.7 mm.; max. width, 30 mm.; alt. aperture, 33.6 mm.

Occurrence.—Clark's type and cotype are from the Lower San Pablo, U. C. loc. no. 409. The writer's cotype is from the Briones, U. C. loc. no. 177.

Clark in this paper described two varieties of different species of the genus *Trophon,* to both of which he ascribes the name "pabloensis," n. var. Hence to avoid duplication of terms, this variety has been renamed in honor of Professor Clark.

In one of the specimens in the Briones the canal has been preserved and the following may be added to Clark's description: Aperture elongate; canal moderately long and recurved; umbilicus subperforate.

This canal is very similar to that of *Trophon gracilis* (Perry),[33] and hence further shows the relationship of this variety to that species; but the differences noted by Clark in his description seem to be sufficient to warrant making this form a distinct variety.

31 Gabb, *op. cit.,* vol. 2, p. 2, pl. 1, fig. 3, 1869.

32 Anderson, *op. cit.,* p. 206, pl. XVII, figs. 90 and 91, 1905.

33 Perry, Conch., pl. IX, fig. 4.

Note.—In the specimens found in the Briones formation the varices are not so pronounced as those from the Lower San Pablo; but the Briones forms appear to be somewhat eroded, and since they are similar to the Lower San Pablo forms in other respects, they are ascribed to the Lower San Pablo species.

Family THAISIDAE

Genus ACANTHINA Fischer de Waldheim

ACANTHINA PERRINI, n. sp.

Plate 8, figures 1*a* and 1*b*

Type in Stanford University Paleontological Collection.

Shell small to medium in size; whorls four; body whorl about two-thirds the height of the shell; sutures appressed; whorls with a prominent angulation, which on the body whorl is a little above the middle; on the whorls of spire angulation comes just above the suture; surface posterior to angulation slopes upward at an angle of about 45°; whorls with about eleven nodes on line of angulation, which are more prominent on the posterior whorls of the spire, where the nodes might be classed as longitudinal ribs; these nodes tend to become obsolete upon the body whorl; surface smooth except where lines of growth form depression on lower part of shell, which is characteristic of this genus; canal short, recurved; inner lip smooth; outer lip not preserved.

Dimensions.—Type specimen alt., 32.5 mm.; max. width, 26.3 mm.; alt. of aperture, 21.3 mm.

Occurrence.—Briones formation?. About six miles south of Livermore. Type in Stanford University collection.

Named in honor of Professor James Perrin Smith, Stanford University.

This species is quite distinct because of its low spire and broad body whorl.

Genus KOILOPLEURA, n. gen.

Plate 8, figures 2, 3*a*, 3*b*, 4*a*, and 4*b*

Type.—No. 11900; *Cotype.*—No. 12393, Univ. Calif. Mus. Pal.

Shell solid, elongate, medium spire; sutures deeply impressed, bordered by a raised tabulation; lower part of body whorl with prominent angulation, below which the shell rapidly narrows to form the canal; surface of shell between angulations markedly concave; outer lip with spine, causing pronounced narrow depression on lower part of body whorl below lower angulation; canal moderately long, rather wide, very deep, and curved posteriorly; umbilicus pronounced and subperforate.

Dimensions.—Genotype specimen U. C. no. 11900; alt., 35 mm.; greatest width, 20 mm.; alt. of aperture, 27 mm. Cotype, U. C. no. 12393; alt., 49 mm.; greatest width, 24 mm.; alt. of aperture, 27 mm.

Occurrence.—Briones formation (Upper Miocene). Type from U. C. loc. no. 1354; cotype from loc. no. 1455.

This fossil has hitherto been regarded as belonging to the genus *Agasoma* Gabb.[34] English[35] in his description of the genus *Agasoma* stated that there were two sections of that genus, but he did not give them separate names. He stated: "The first section includes only *A. sinuatum* Gabb, with the narrow mouth opening; narrow, deep, medium length, recurved canal; and the pronounced angulation of the body whorl. The second includes the other species with evenly rounded, ventricose body whorl, and shallow wide canal." This second section is the typical *Agasoma* described by Gabb.

In view of the spine on the outer lip; depression on lower part of body whorl; pronounced subperforate umbilicus; and canal similar to *Acanthina* Fischer de Waldheim,[36] it appears that this form shows a closer relationship to *Acanthina* than to *Agasoma.* It differs from *Acanthina,* however, in possessing a deeply channeled suture, a pronounced collar; and two angulations on the body whorl with the pronounced concavity between. Hence, due to these differences from *Acanthina* it is regarded as a new genus. Since it shows a closer relationship to *Acanthina* than to any other genus it is placed in the *Thaisidae* family.

The word "Koilopleura" is derived from *κοῖλος*, concave, *πλευρά*, side.

Genus KOILOPLEURA, n. gen.

KOILOPLEURA SINUATA (Gabb)

Clavella sinuatum. Gabb,[37] Calif. State Geol. Surv., Paleontology of California, vol. 2, p. 5, 1869.

Agasoma sinuatum. Gabb, Calif. State Geol. Surv., Paleontology of Calif., vol. 2, p. 46, pl. 1, fig. 7, 1869.

Agasoma sinuatum Gabb. English, Univ. Calif. Publ. Bull. Dept. Geol., vol 8, p. 250, pl. 25, figs. 5 and 6, 1914.

Type.—No. 11994; *cotype*—No. 11995, Univ. Calif. Mus. Pal.

An examination of Gabb's types, which are quite small specimens, shows that what Gabb has taken for the convex portion in the middle of the body whorl is the rounded lower angulation which becomes so prominent in the older specimens. Between the two angulations there is the same pronounced concavity seen in the larger specimens.

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[34] Gabb, Pal. of Calif., vol. 2, p. 46, 1869.

[35] English, W. A., The Agasoma-like Gastropods of the California Tertiary, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, p. 245, 1914.

[36] Fischer de Waldheim, Mus. Demid, 1806.

[37] Shell elongated, rather slender; spire low, convex; whorls four; suture deeply channeled, bordered by a thickened rim; body whorl convex in the middle, broadly grooved above, and excavated below; aperture long and narrow; columbella sinuous, slightly incrusted; outer lip simple; canal slightly recurved.

Family Olividae

Genus OLIVA Brugiére

OLIVA SIMONDSI, n. sp.

Plate 8, figures 5*a* and 5*b*

Type.—No. 12394, Univ. Calif. Mus. Pal.

Shell medium sized, solid, coniform; spire one-third height of shell; whorls five, smooth and flat; pillar with two strong plications, with a smaller one between; callous extends half the distance from posterior to anterior end of aperture, and extends around to the posterior canal; outer lip not preserved.

Dimensions.—Type specimen U. C. no. 12394; alt., 36.8 mm.; greatest width, 23 mm.; alt. of aperture, 30.3 mm.

Occurrence.—Briones formation, U. C. loc. no. 171.

Named in honor of Professor F. W. Simonds, University of Texas.

This species is very close to *O. peruviana coniformis* Philippi[38] in shape, but it differs from the latter in that it possesses a small plication between the larger two, while in *O. peruviana coniformis* the smaller plication is posterior to the two larger.

KEY TO LOCALITIES

Locality	Millimeters east*	Millimeters south*	Quadrangle	Formation
15	147	155	Concord	Briones
146	68	264	Mt. Diablo	Briones
171	222	29	Concord	Briones
177	208	9	Concord	Briones
409	342	353	Mare Island	Lower San Pablo
1176	35	427	Carquinez	Briones
1177	27	411	Carquinez	Briones
1354	One mile southeast of Muir Station.		Concord	Briones
1455	54	256	Mt. Diablo	Briones
1492	80	275	Mt. Diablo	San Pablo
1942	321	193	Concord	San Pablo
1949	325	196	Concord	San Pablo
3522	283	210	Concord	Briones
3524	281	223	Concord	Briones
3529	170	223	Pleasanton	Briones
3532	78 feet south loc. 3529.		Pleasanton	Briones
3534	33 feet south loc. 3529.		Pleasanton	Briones
3535	58 feet south loc. 3529.		Pleasanton	Briones
3575	24	225	Mt. Diablo	Briones
3576	Near San Pablo Bay.		Mare Island	Briones
3581	216	378	Pleasanton	Briones
3582	218	377	Pleasanton	Briones

* Measurements in these two columns refer to distances in millimeters on the map, east and south, respectively, from northwest corners of the topographic sheets.

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[38] Philippi, Abb. u. Beschr., xix, 1, figs. 5–7, 1842–1851.

EXPLANATION OF PLATE 1

Fig. 1*a*. *Leda furlongi*, n. sp. × 2. Dorsal view. Type.—No. 12362, Univ. Calif. Mus. Pal., loc. 15. Briones.

Fig 1*b*. *Leda furlongi*, n. sp. × 2. Right valve of type.

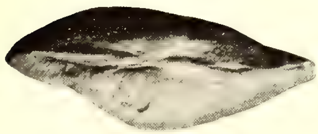
Fig. 2. *Pecten raymondi brionianus*, n. var. × 1. Left valve. Type.—No. 12368, Univ. Calif. Mus. Pal., loc. 3532. Briones.

Fig. 3. *Pecten raymondi brionianus*, n. var. × 1. Left valve. Cotype.—No. 12369, Univ. Calif. Mus. Pal., loc. 3532. Briones.

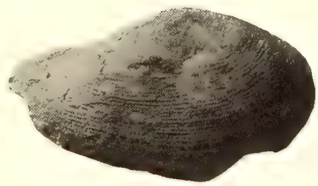
Fig. 4. *Pecten raymondi* Clark. × 1. Right valve. Type.—No. 11581, Univ. Calif. Mus. Pal., loc. 1492. San Pablo.

Fig. 5. *Pecten andersoni gonicostus*, n. var. × 1. Right valve. Type.—No. 12370, Univ. Calif. Mus. Pal., loc. 1176. Briones.

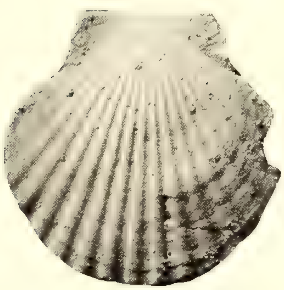
Fig. 6. *Pecten raymondi* Clark. × 1. A very large specimen of the convex left valve. No. 12371, Univ. Calif. Mus. Pal., loc. 1942. Upper San Pablo.



1*a*



1*b*



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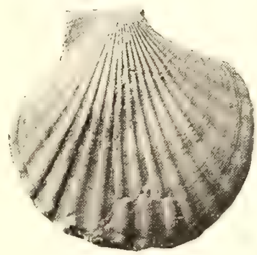

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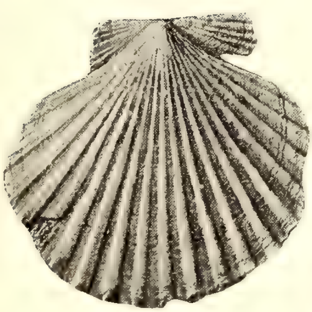

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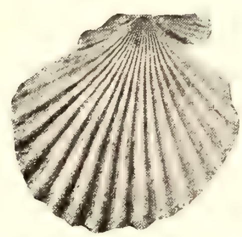

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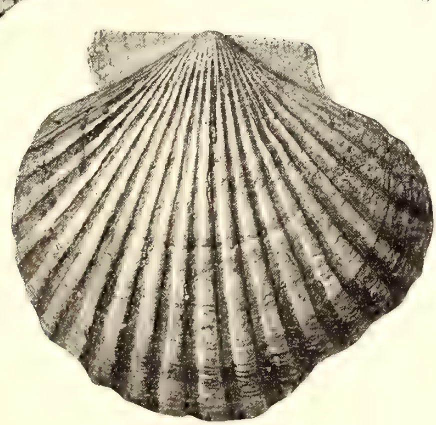


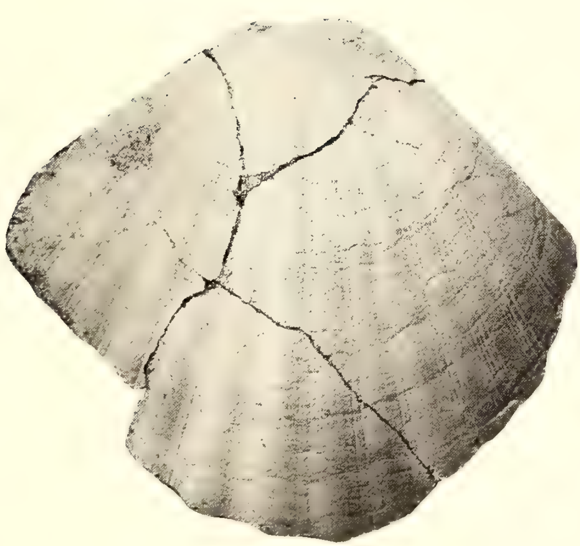
6

EXPLANATION OF PLATE 2

Fig. 1. *Pecten ricei*, n. sp. × 1. Left valve. Type.—No. 12364, Univ. Calif. Mus. Pal., loc. 3535. Briones.

Fig. 2. *Pecten ricei*, n. sp. × 1. Right valve. Cotype.—No. 12365, Univ. Calif. Mus. Pal., loc. 3534. Briones.

1



2

EXPLANATION OF PLATE 3

Fig. 1. *Pecten tolmani* Hall and Ambrose, × 1, showing convex left valve. This species has never before been figured. It was first described by Hall and Ambrose in Nautilus, vol. xxx, p. 82, 1916. Type is in Stanford University Paleontological Collection. Specimen figured is No. 12367, Univ. Calif. Mus. Pal., loc. 3581. Briones.

Fig. 2. *Modiolus gabbi subconvexus*, n. var. × 1. Type.—No. 12372, Univ. Calif. Mus. Pal., loc. 793. Briones.

Fig. 3. *Pecten tolmani* Hall and Ambrose, × 1, showing flat right valve. Specimen figured is no. 12366, Univ. Calif. Mus. Pal., loc. 3581. Briones.

Fig. 4. *Modiolus veronensis*, n. sp. × 1. Type.—No. 12373, Univ. Calif. Mus. Pal., loc. 3529. Briones.

Fig. 5*a*. *Cyrena diabloensis*, n. sp. × 1. Exterior view. Type.—No. 12374, Univ. Calif. Mus. Pal., loc. 1949. San Pablo.

Fig. 5*b*. *Cyrena diabloensis*, n. sp., × 1, showing dentition. Type.


1


2


3


4


5a


5b

EXPLANATION OF PLATE 4

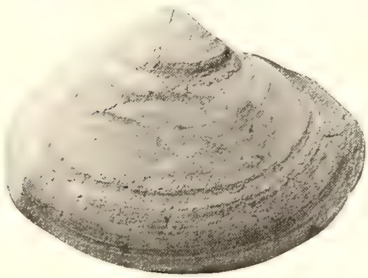
Fig. 1. *Pecten vickeryi*, n. sp. × 1. Left valve. Type in Stanford University Paleontological Collection. Briones.

Fig. 2*a*. *Spisula falcata brioniana*, n. var. × 2. Right valve, showing dentition. Type.—No. 12380, Univ. Calif. Mus. Pal., loc. 3522. Briones.

Fig. 2*b*. *Spisula falcata brioniana*, n. var. × 2. Exterior view. Type.

1

2a



2b

EXPLANATION OF PLATE 5

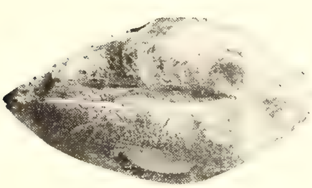
Fig. 1. *Venus brioniana,* n. sp. × 1. Right valve. Type.—No. 12377, Univ. Calif. Mus. Pal., loc. 177. Briones.

Fig. 2*a*. *Antigona willisi,* n. sp. × 1. Dorsal view. Type.—No. 12379, Univ. Calif. Mus. Pal., loc. 146. Briones.

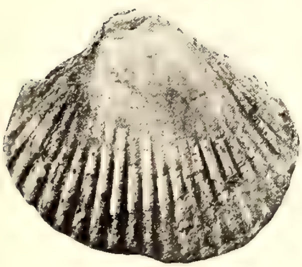
Fig. 2*b*. *Antigona willisi,* n. sp. × 1. Right valve of type.

Fig. 3. *Cardium corbis* (Martin), n. var.? × 1. Left valve. Specimen figured is no. 12376, Univ. Calif. Mus. Pal., loc. 207. Briones.

1



2a



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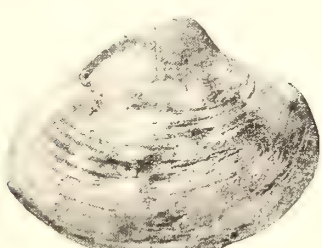


2b

EXPLANATION OF PLATE 6

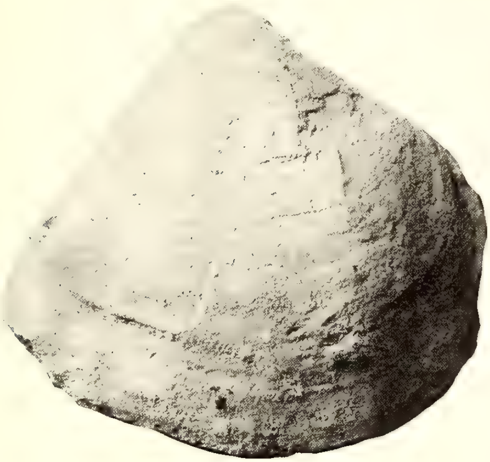
Fig. 1*a*. *Tivela merriami*, n. sp. × 1. Right valve, exterior view. Type.—No. 12378, Univ. Calif. Mus. Pal., loc. 3582. Briones.

Fig. 1*b*. *Tivela merriami*, n. sp. × 1. Right valve of type, showing dentition.

Fig. 2. *Trophon gracilis clarki*, n. nom. Type.—No. 11625, Univ. Calif. Mus. Pal., loc. 409. Lower San Pablo (Cierbo).

Fig. 3. *Trophon gracilis clarki*, n. nom. Cotype—No. 12390, Univ. Calif. Mus. Pal., loc. 177. Briones.

Fig. 4. *Trophon gracilis clarki*, n. nom. Cotype.—No. 11626, Univ. Calif. Mus. Pal., loc. 409. Lower San Pablo.



1*a*

2

3

1*b*

4

EXPLANATION OF PLATE 7

Fig. 1*a*. *Calliostoma obliquistriata*, n. sp. × 2. Type.—No. 12385, Univ. Calif. Mus. Pal., loc. 3575. Briones.

Fig. 1*b*. *Calliostoma obliquistriata*, n. sp. × 2. Type.

Fig. 2*a*. *Sinum trigenarium*, n. sp. × 1. Type.—No. 12386, Univ. Calif. Mus. Pal., loc. 3576. Briones.

Fig. 2*b*. *Sinum trigenarium*, n. sp. × 1. Type.

Fig. 3. *Nassa whitneyi*, n. sp. × 1. Type.—No. 12387, Univ. Calif. Mus. Pal., loc. 3524. Briones.

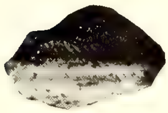
Fig. 4*a*. *Siphonalia rodeoensis*, n. sp. × 1. Type.—No. 12389, Univ. Calif. Mus. Pal., loc. 1177.

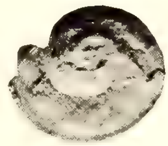
Fig. 4*b*. *Siphonalia rodeoensis*, n. sp. × 1. Type.

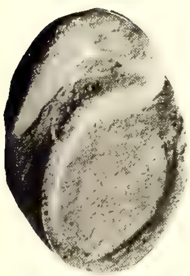
Fig. 5*a*. *Trophon daviesi*, n. sp. × 1. Type.—No. 12391, Univ. Calif. Mus. Pal., loc. 1354. Briones.

Fig. 5*b*. *Trophon daviesi*, n. sp. × 1. Type.

Fig. 6. *Nassa whitneyi*, n. sp. × 3 (approximately). Shows varix on outer lip. Cotype.—No. 12388, Univ. Calif. Mus. Pal., loc. 1176. Briones.


1a


1b


2a


3


2b


4a


4b


5a


6


5b

EXPLANATION OF PLATE 8

Fig. 1*a*. *Acanthina perrini*, n. sp. × 1. Type in Stanford University Paleontological Collection.

Fig. 1*b*. *Acanthina perrini*, n. sp. × 1. Type.

Fig. 2. *Koilopleura sinuata* (Gabb). × 1. Specimen figured is No. 11901, Univ. Calif. Mus. Pal. Briones.

Fig. 3*a*. *Koilopleura sinuata* (Gabb). × 1. Genotype.—No. 11900, Univ. Calif. Mus. Pal., loc. 1354. Briones.

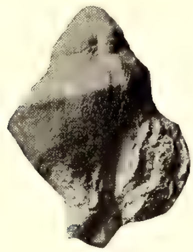
Fig. 3*b*. *Koliopleura sinuata* (Gabb). × 1. This shows the narrow depression on lower part of body whorl and the spine on the outer lip. Genotype.

Fig. 4*a*. *Koilopleura sinuata* (Gabb). × 1. Cotype of genus.—No. 12393, Univ. Calif. Mus. Pal., loc. 1455. Briones.

Fig. 4*b*. *Koilopleura sinuata* (Gabb). × 1. Cotype of genus.

Fig. 5*a*. *Oliva simondsi*, n. sp. × 1. Type.—No. 12394, Univ. Calif. Mus. Pal., loc. 171. Briones.

Fig 5*b*. *Oliva simondsi*, n. sp. × 1. Type.



1*a*

1*b*

2

3*a*

3*b*

4*a*

4*b*

5*a*

5*b*

UNIVERSITY OF CALIFORNIA PUBLICATIONS
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GEOLOGY OF THE CUYAMACA REGION OF CALIFORNIA

WITH SPECIAL REFERENCE TO THE ORIGIN OF THE NICKELIFEROUS PYRRHOTITE

BY
F. S. HUDSON

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CONTENTS

INTRODUCTION

This report on the geology of the Cuyamaca region is the result of three months' field work carried on in the summers of 1917, 1918, and 1919. During the first season the Friday Mine and the immediately adjacent country were the particular objects of study. In the following seasons the general geologic investigation of the area was carried on.

A complete report on the geology of the region would contain a chapter on the gold quartz veins. But time was not available for more than a cursory examination of the mines of the Julian and Banner districts, and nothing was learned that would add to the knowledge already available in the literature.[1]

In the study of the geology of the Friday Mine particular attention was given to the ultimate origin of the deposit. For this reason the secondary minerals of the ore receive only brief notice here. Secondary sulphides are present in small amount, but their development has probably added little or nothing to the valuable metal content of the ore. Time was not available for a complete investigation along this line.

The writer was assisted in the field by Mr. W. E. Inman in 1917 and is indebted to him not only for this work but for access to the results of his study of the Friday Mine ores. Thanks are due to Mr. G. H. Alvey for assistance in geologic mapping in 1918. To Messrs. W. E. Sterne and Beecher Sterne, the principal owners of the Friday Mine, the writer is grateful for the privilege of examining the property. Without the assistance of Mr. C. M. Sterne the detailed investigation of the mine would have been impossible. The writer is especially indebted to Professor G. D. Louderback, at whose suggestion this work was begun and to whose encouragement and helpful criticism the completion of the report is largely due, and to Professor A. C. Lawson, who has pointed out fruitful lines of investigation.

[1] See the various annual reports of the State Mineralogist, particularly the reports for 1888, 1889, 1890, 1892, and 1914.

GEOGRAPHY

The term ''Cuyamaca Mountains'' applies to three prominent peaks, lying along a north-south line, within the main mountain range of San Diego County. The highest of these peaks, South or Cuyamaca Peak, is the loftiest mountain in San Diego County, rising to 6515 feet above sea level. The other peaks, Middle and North peaks, have elevations of about 5800 and 6000 feet respectively.

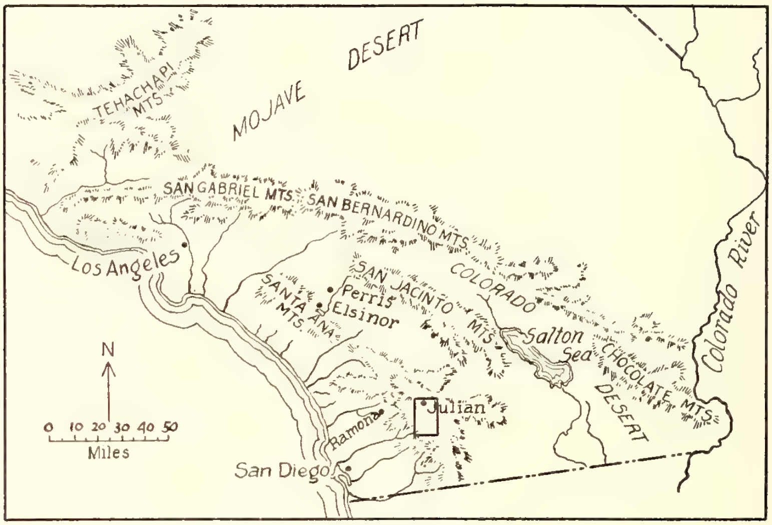


Fig. 1. Index Map.

The term ''Cuyamaca Region'' is applied to the area of the Cuyamaca Mountains, together with those portions of the surrounding country which stand at considerable elevation, yet do not belong to other mountain groups, such as Volcan Mountain to the north and Laguna Mountain to the southeast. The area mapped includes about eighty square miles, lying in the southeastern portion of the Ramona Quadrangle and the northeastern portion of the Cuyamaca Quadrangle of the U. S. Geological Survey.

The town of Julian, in the northern part of the area studied, lies sixty miles by road northeast of San Diego City. In past years it was the principal town of the Julian gold mining district. Its present importance is as a trade center for the farmers of the neighboring mountain valleys and as a stage station on one of the routes between San Diego and the Imperial Valley.

Pine Hills, a summer resort situated four miles southwest of Julian, and Descanso, lying several miles south of the southern limit of the map, are the only other settlements of importance in the district.

Friday Mine, which is the subject of a chapter of this report, is situated four miles southeast of Julian, on the road from that town to Cuyamaca Reservoir.

The roads from Julian to Pine Hills, and to Descanso, by way of Cuyamaca Reservoir, have been rebuilt since the publication of the U. S. Geological Survey sheets. They do not in general follow the old routes. Certain stretches of these roads are shown on the map, while in those places where the writer did not take the time to obtain accurate data a blank space has been left. The road from Pine Hills to Cuyamaca Reservoir, recently built, has been plotted in.

Relief.—The most striking topographic features of the region are the Cuyamaca Mountains, whose three peaks form a ridge, rising from the broad upland of the Peninsular Range. When viewed from the east, this ridge is seen to rise with steep slopes to heights of from 5100 to 6500 feet from a region of fairly low relief which stretches from the vicinity of Stonewall Peak to the north and within which lies the open valley now occupied in part by Cuyamaca Reservoir. On their west flanks the mountains have steeper slopes, particularly South Peak, which drops off 2500 feet from the summit in a horizontal distance of one and one-quarter miles.

The main divide of the region, separating the drainage to the Pacific Ocean from that to the Colorado Desert, lies in a ridge several miles to the east of the Cuyamaca Mountains. This ridge has an elevation of from 4500 to 5500 feet along its crest. Within the limits of the map it runs from the vicinity of Julian, southeastward, passing immediately east of Rattlesnake Valley. Where it bounds the region of low relief north and east of Cuyamaca Reservoir this ridge rises but a few hundred feet above the gently rolling country to the west, while to the east is a region of deep cañons and rugged peaks. To the northwest, in the vicinity of Julian, the contrast between the type of topography on either side of the divide is almost as striking. Here, on the west side, are the open valleys of Coleman and Cedar creeks and the rolling land near Julian, while on the east are the steep slopes down to Banner and Chariot cañons. The gently rolling summit lands do not, however, all lie on the Pacific side of the divide, as the headwaters of the Banner Cañon stream, which runs to Salton sink, reach into a part of the country of low relief near Julian.

Climate and vegetation.—In common with the greater part of California, San Diego County has a summer dry season and a winter wet season. In the mountainous portion of the county, however, there are frequent local thunder showers during the summer.

The Cuyamaca region receives probably more rainfall than any other part of the county. At Cuyamaca Dam and at Pine Hills Hotel the records show an annual precipitation of about 40 inches. A portion of this is in the form of snow. In the winter of 1917–18 there were 18 inches of snowfall at the dam, an amount said to be less than usual. At the east end of the reservoir the average rainfall is not much over 20 inches and farther east the precipitation rapidly decreases, the climate as a matter of fact becoming that of the desert.

The vegetation of the region is an index of the distribution of the rainfall. The Cuyamaca Peaks are covered with a dense growth of pines, cedars, and chaparral. On the gentler slopes around Julian, Pine Hills, Cuyamaca Reservoir, and Green Valley there is a more open growth of pines, with oaks and in places dense stands of chaparral. At the east end of the reservoir the vegetation is scanty and the divide between the Pacific and desert drainages in certain stretches is almost barren, in other stretches it has a chaparral cover with scattered trees. To the east of Banner and Chariot cañons the country gradually takes on the appearance of the desert, many of the rugged slopes being almost barren of vegetation.

Physiographic problems.—The Cuyamaca region is but a small part of a large physiographic province about which little is known. It is impossible to work out the physiographic history of such a small area without extensive observations over the larger area. Lacking this knowledge of the region as a whole, it is thought best not to present any conclusions based on the meager data at hand. Attention is called, however, to certain physiographic features which will need explanation in any future investigation of the physiography of the region. These features are:

(1) The alluviated summit valleys; (2) the attack of the streams on the alluvial filling of these valleys; (3) highest mountains situated to the west of the main water parting; (4) highest mountains composed of rocks yielding easily to chemical agencies; lower country carved from formations resistant to chemical decay; (5) the deep cañon of Boulder Creek cut through the highest mountain range; (6) the unimportant elevation of the main water parting above the adjacent summit valleys; (7) contrast in physiographic features on either side of the main divide.

GEOLOGY

Summary Statement

The rocks exposed at the surface over a large part of the mountainous region of San Diego County are quartz-bearing plutonic rocks, varying from quartz diorite to true granite in composition. The relation of these rocks to the older rocks which they have intruded shows that the intrusion was of batholithic nature. Most of the cover has been stripped from this batholith, the older rocks being found as remnants, surrounded by granite. These older rocks are schists, the result of metamorphism of shales and sandstones, with subordinate layers of lava.

In the Cuyamaca region the schists are present in more than their usual proportion and the complex of schist and granitic rock, here generally a quartz diorite, often gneissic, has been intruded by younger igneous rocks. The younger intrusives are of two distinct types, acidic and basic. The acidic rock is a true granite. It occupies an oval area in the region of Rattlesnake Valley. The basic rock varies from basic diorite to ultra basic types, but the predominant varieties are gabbro and norite. These basic rocks occupy a considerable area which includes the three peaks of the Cuyamaca Mountains, and they are also found in several small outlying areas. The younger intrusives solidified at moderate depths in the earth's crust. The granite mass is apparently a laccolith, while the main mass of basic rock may be termed a chonolith. Dikes of basic composition cut the gabbro-norite mass and pegmatite is found in intrusive relationship to all the rocks mentioned above. Dikes of soda aplite occur cutting both quartz diorite and schist.

The schist series is of uncertain age; it may be Triassic or late Paleozoic, or may include rocks of both ages. The quartz-diorite batholith was developed in post-Triassic time and is probably equivalent to the post-Mariposa intrusions of the Sierra Nevada. The younger intrusives are without much doubt pre-Cretaceous and followed closely on the batholithic intrusion.

Along the summit of the Cuyamaca Mountains there are several prominent open valleys with flat or gently rolling surfaces. Evidence afforded by stream cuts into the surface of the valleys shows that they are underlain by considerable thicknesses of bedded, unconsolidated, sandy alluvium. A mile southwest of the Friday Mine recent stream cutting exposes twenty feet of alluvium, and in Pine Valley, several miles to the east, there is at least fifteen feet. Similar material underlies Green Valley and the small valley northeast of Wynola.

The present-day streams, both those flowing to the Pacific Ocean and to the Salton Sea, are engaged in removing this alluvium. They have cut channels with flat, gravel-strewn floors and steep walls to a depth of ten to twenty-five feet.

The valley now occupied by Cuyamaca Reservoir is probably also underlain by alluvium and small patches of bedded alluvium can be seen at various places along even the narrowest of the cañons to the west of the summit valleys.

The alluvium of Pine Valley carries frequent thin layers of decomposed vegetable material, separated by layers of fairly clean sand. It is therefore thought that most of these unconsolidated bedded deposits were accumulated in meadows, which from time to time had their grass cover buried under layers of sand.

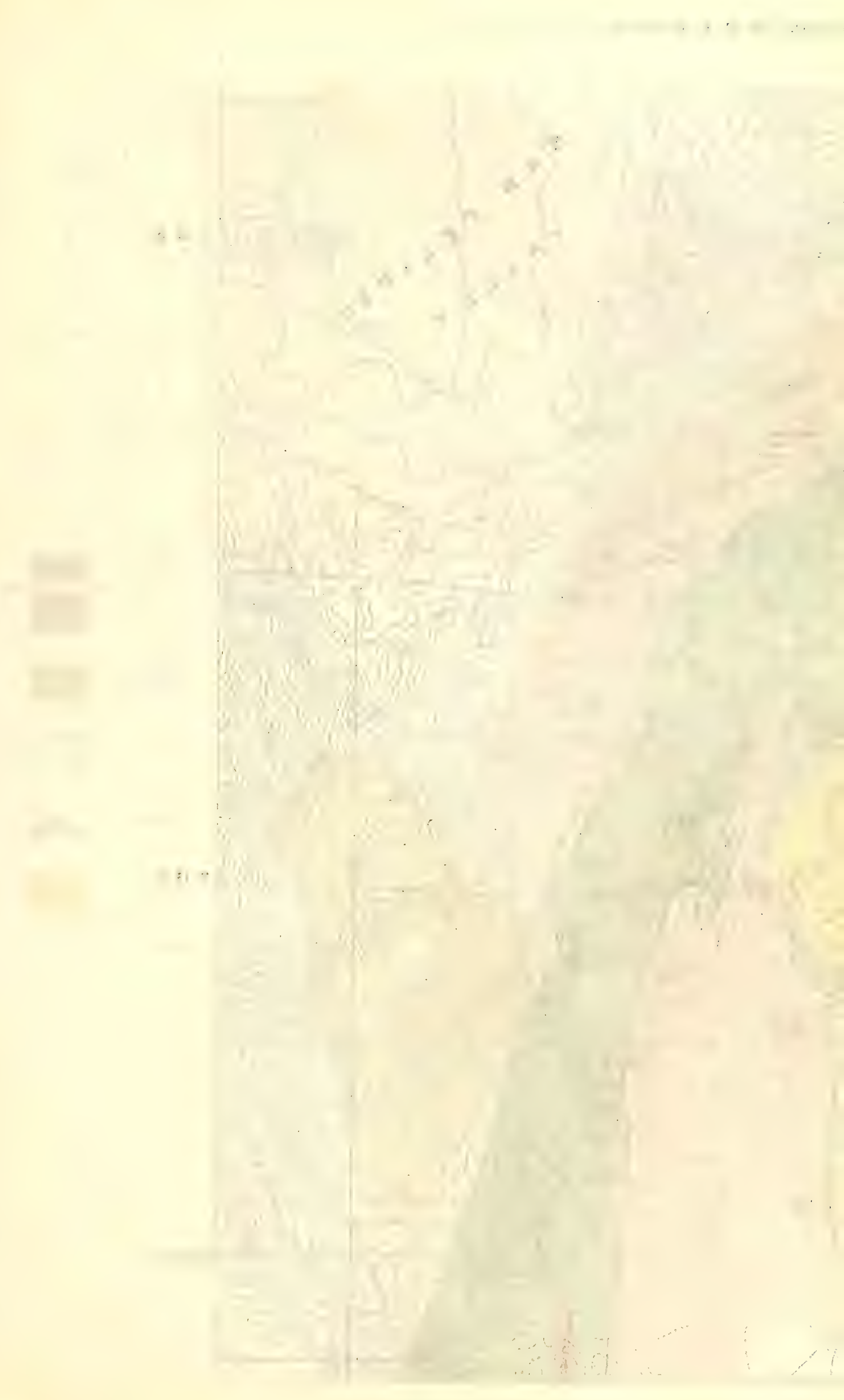
The Julian Schist Series

Bodies of schistose rock inclosed in granite are of frequent occurrence in the mountains of San Diego County and have also been described from Lower California. Such schists are particularly abundant in the Cuyamaca region and form the country rock for most of the gold quartz veins of the Julian and neighboring mining districts.

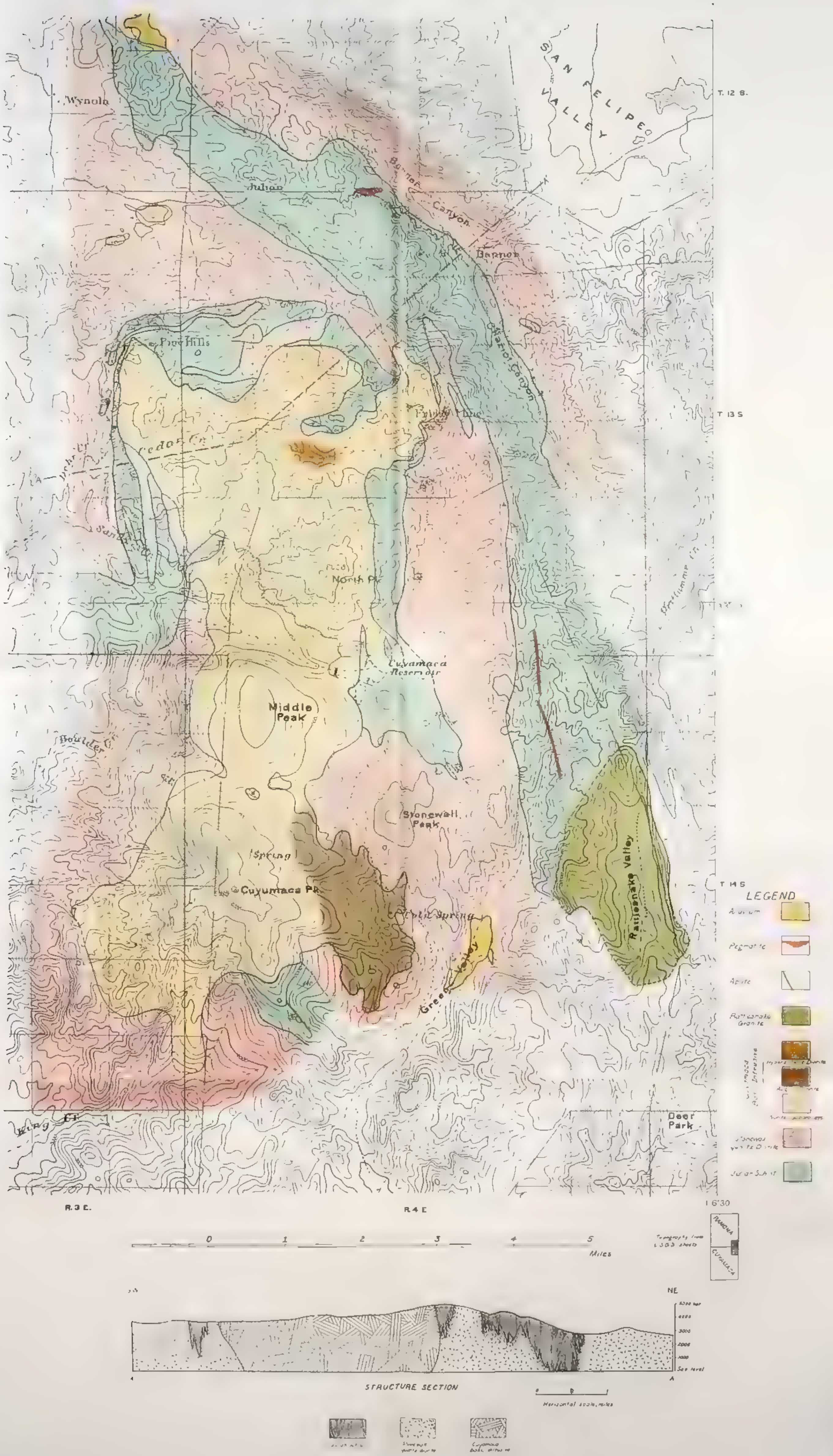
The most prominent body of schist in the region extends without a break from north of Wynola, through Julian, to the region of Rattlesnake Valley, a distance of over twelve miles. Its width varies from three-quarters of a mile to a mile and a half. This belt of schist will hereafter be termed the main Julian schist body.

Numerous smaller masses of schist outcrop to the southwest of the main body and several outlying masses are found on its northeast side.

Fissile quartz-mica-schist.—The central portion of the main body of the Julian schist, extending from three miles northwest of the town of Julian, southeastward to the limits of the area mapped, is a fine-grained, fissile quartz-mica schist. A typical specimen of this rock has fine-grained, blue-gray layers of quartz and sericite about one-sixteenth inch in thickness, with coarser layers of quartz and biotite. The quartz-sericite layers have flakes of biotite which are generally not oriented parallel to the schistosity.



GEOLOGICAL MAP OF THE CUYAMACA REGION, BY F. S. HUDSON



Quartzite.—Beds of bluish, dense, fine-grained quartzite, often with some biotite, are rather common within the schist series. Their thickness varies generally from a few inches to ten feet, but several beds of much greater thickness were noted. The north-south ridge east and northeast of Cuyamaca Reservoir, which divides the drainage to the Pacific Ocean from that through Oriflamme Cañon to the Salton Sea, is determined by the presence of a layer of quartzite varying from 50 to 100 feet in thickness. This bed can be traced without interruption for almost two miles. The quartzite beds, if mapped, would probably furnish the key to the original structure of the schist body.

Amphibolite schist.—Layers of amphibolite schist were found within the schist series in the southwest quarter of section 9, township 13 south, range 4 east, and in the northwest quarter of section 8, of the same township. The rocks are distinctly schistose and are composed of a fine-grained aggregate of basic plagioclase and green hornblende.

Actinolite schist was found on the dump of the Helvetia Mine, in the northwest quarter of section 4, near Julian, and a considerable body of similar rock lies within the schist two miles southeast of Cuyamaca Reservoir, on the road to Rattlesnake Valley.

Paragneiss and coarse schist.—Along the western edge of the main schist body, extending from the vicinity of Julian to at least as far south as the latitude of Stonewall Peak, there is a zone of paragneisses and coarse schists varying in width from less than one-quarter to over three-quarters of a mile. Similar rocks were found at certain localities along the northeast margin of the main body of schist, and also along the contacts of many of the smaller schist masses which are inclosed in quartz diorite. The rocks of these border zones are invariably much coarser in texture than is the fissile schist described above. The micaceous varieties generally have poor or irregular fissility, being gnarled or contorted. Included within the gnarly schists and gneisses are short lenses, with blunt ends, of gray and gray-blue dense quartzose rock. These are generally but a few inches thick and less than one foot in length.

Of the more interesting types of paragneiss and schist a few are selected for brief description. Sillimanite-quartz-mica-gneiss was collected a short distance east of the quartz diorite, one mile northeast of the Cuyamaca Reservoir. It contains quartz, muscovite, oligoclase, biotite, tourmaline, and sillimanite. Medium grained layers, an inch or more in thickness and composed of the two micas, quartz, feldspar, and tourmaline, alternate with coarser grained layers, up to one inch thick, of biotite and sillimanite. The sillimanite is in prisms, generally about 4 mm. in diameter and as much as 1 cm. in length. The tourmaline is pleochroic in brown colors, thus differing from that found in the pegmatite of the Friday Mine, whose colors, under the microscope, are steel-blue and gray-blue.

Sillimanite gneiss much like the above, except that it carries no tourmaline, was found as far as one-quarter mile from the nearest quartz-diorite outcrop along the line between sections 9 and 10, and in the northeast quarter of the northwest quarter of section 10, township 13 south, range 4 east. Along the western margin of that part of the main schist belt lying southeast of Cuyamaca Reservoir sillimanite gneiss was found at least one-half mile from the nearest outcrop of granitic rock.

A typical specimen of andalusite-bearing gneiss, collected about three-quarters of a mile east of the quartz-diorite contact, in the main schist body east of Cuyamaca Reservoir, is composed of quartz, biotite, labradorite, and andalusite. The biotite is for the most part segregated in thin layers, which are much contorted. The andalusite is in prismatic crystals, pink in color.

A specimen from the main schist body two miles southeast of Julian has the same mineral composition, except that the feldspar is oligoclase. This specimen also has much of the biotite segregated in thin layers, separated by granular layers, up to 3 mm. in width, poor in biotite. There is no contortion, however, the rock being evenly banded, though not fissile.

A third specimen, from a point on the Julian-Banner road, one-half mile east of Julian, is a fine-grained quartz-mica schist, carrying crystals of andalusite.

The three rocks seem to be the result of successively less severe degrees of metamorphism of the same kind of original material.

Injection gneiss.—The sillimanite gneisses and many of the andalusite gneisses seem to be made up in part of material of igneous or pegmatitic nature. They might be classed under injection gneisses. But injection gneisses in which no sillimanite or andalusite occurs, and in which the igneous material varies from small amounts up to nearly the whole of the rock, are found along all the contacts between schist and quartz-diorite gneiss.

An excellent place to study injection gneiss is on the Julian-Banner road, two miles east of Julian. For a distance of about one hundred yards southwest of the igneous contact the fissile schist is coarser than usual and carries knots of muscovite up to 4 mm. in diameter. For a distance of twenty yards from the granitic rock the schist is so permeated with igneous material as to form an injection gneiss. The igneous rock here is a gneissoid granodiorite, composed of orthoclase, oligoclase, quartz, and biotite. The injection gneiss consists of regular layers of pegmatitic material, from 1 mm. to 10 mm. in thickness, separated by very thin layers of muscovite and biotite. The pegmatitic layers carry tourmaline, quartz, and feldspar. There is a gradual transition from schist carrying little or no injected matter to gneissoid granodiorite, carrying a few shreds of what appears to be schist. Contacts of this nature are to be found at almost all places where granitic rock meets schist.

The presence of tourmaline in these rocks is, however, not the general rule. As an example of the more common type, the mineral composition of an injection gneiss from the contact immediately west of Julian may be cited. The rock here is composed of fine-grained layers of albite, quartz, muscovite, and biotite, alternating with coarser layers of quartz, muscovite, albite, and andesine.

Many of the injection gneisses, especially those found along the southwest contact of the main schist body, carry blunt lenses of quartzose rock, like those found within the sillimanite gneisses. These lenses have the appearance of fragments of once continuous layers that have been rounded by rolling or kneading.

Some of these lenses are moderately fine-grained paragneiss having the appearance of hornfels. They invariably contain considerable quartz and generally carry either pyroxene or basic plagioclase or both. Biotite is generally lacking or is in very small amount. Those specimens carrying the most biotite are the only ones having any suggestion of schistose structure, but there is sometimes a layering either on a megascopic or a microscopic scale, due to the distribution and varying grain of the minerals.

Other lenses consist of rock carrying from 75 to 80 per cent of quartz, 15 per cent or more of pyroxene, the balance consisting of basic plagioclase (basic labradorite to bytownite), biotite, graphite, magnetite, titanite, apatite, and rutile. The pyroxene in three of the specimens was diopside, while in another sample it proved to be augite. The rock has a mosaic texture. The pyroxene often shows sieve textures. The crystalloblastic order is (1) biotite, (2) pyroxene, (3) quartz and plagioclase.

One of the quartz-pyroxene rocks carries a small amount of green hornblende. Examples of quartz-amphibole rocks, carrying no pyroxene, were found at two localities, and differ in no way from the quartz-pyroxene rocks save in the substitution of green hornblende for diopside. The hornblende of these rocks is a green-brown variety. The pleochioism is $\mathfrak{a}$ = colorless to faint green, $\mathfrak{b}$ = brown, $\mathfrak{c}$ = green, absorption: $\mathfrak{b} > \mathfrak{c} > \mathfrak{a}$.

One of the dense quartzose lenses, occurring in sillimanite gneiss, is composed of about 85 per cent quartz, the balance being basic plagioclase with a small amount of biotite.

The writer has been unable to find any reference to rocks similar to these lenses in American geologic literature. Harker and Marr have described the metamorphic effect of the Shap granite on the Lower Coldwell grit in Westmoreland. The unaltered rock is composed of subangular grains of quartz and feldspar, with some interstitial dusty matter like kaolin, and little patches of finely granular calcite. A specimen of the metamorphosed rock, from 600 yards from the granite contact, has a vitreous appearance and is made up of quartz, feldspar, and lime augite, the contacts of the minerals being "sutural."[2]

Rosenbusch has described a number of quartz-pyroxene rocks from Alsace and southern Germany. They are classed in his para-pyroxene gneiss group, within which there is a wide range of mineralogic composition.[3]

With regard to the structure of these rocks he states:[4] "While the ortho-pyroxene-gneisses are usually distinctly schistose, this is very often not the case with the para-pyroxene-gneisses and their structure is typically hornfels-like."

A typical section through the schist series.—The following is a section from the northeast edge of the main schist mass, immediately west of Banner, southwestward to the Julian-Cuyamaca road:

	Gneissoid granodiorite.
60 feet	Injection gneiss.
300 feet	1. Quartz-two-mica schist with knots of muscovite. Coarser near the igneous contact, grades into next member away from contact.
700 feet	2. Medium grained quartz-mica schist, with quartzite layers.
400 feet	3. Medium grained quartz-two-mica schist. Large muscovite flakes at high angle to schistosity. "Rolled" lenses of quartz-pyroxene rock.

[2] Harker, A., and Marr, J. E., Quart. Jour. Geol. Soc., vol. 47, 1904, p. 321.

[3] Rosenbusch, H., Elemente der Gesteinslehre, 1910, pp. 617–619.

[4] *Ibid.*, p. 618.

1500 feet	4*a*. Fissile, evenly banded, quartz-muscovite schist. Weathered surfaces resemble slate. Contains no quartzite.
40 feet	4*b*. Quartzite.
360 feet	4*c*. Fissile, fine-grained schist.
150 feet	4*d*. Quartzite, in part thin-bedded.
200 feet	4*e*. Fissile, fine-grained schist.
20 feet	4*f*. Quartzite, thin-bedded.
3000+ feet	5. Evenly banded, coarse quartz-mica schist, containing a few quartzite layers and some injected material. In part carries andalusite.
	Injection gneiss.
	Gneissoid quartz diorite.

About one-half mile to the southeast practically the same sequence of rocks is present, save that here member 5 of the above section is represented by an equal or greater thickness of coarse, generally gnarly, quartz-mica-sillimanite gneiss and other paragneisses, with lenses of dense quartz-pyroxene rock.

Origin of the schist series.—The fissile schists composed chiefly of quartz and two micas and banded with numerous quartzite layers can hardly have had any other than a sedimentary origin. The layers of quartzite are essentially parallel to the schistosity, showing that the schistosity in general conforms to the original bedding. Whether there is isoclinal folding or not cannot be said. These rocks are thought to have resulted from the metamorphism of a series of shales and fine-grained, clayey sandstones, with beds of nearly pure quartz sandstone.

The amphibolite and actinolite schists, on the other hand, if we may judge from their mineral composition and mode of occurrence, are probably derived from andesitic or basaltic lavas.

The sillimanite gneiss, andalusite gneiss, and other paragneisses as deduced from their mineral composition differ in no way chemically from the fissile schists, leaving out of account, of course, the igneous or pegmatitic injected matter. The presence of quartzitic lenses and alternating layers of varying mineral composition proves their sedimentary origin, and they are therefore thought to have been derived from the same types of sediments as were the fissile schists.

The contorted or gnarly character of many of these rocks is probably due to a second schistosity imposed on an earlier. In support of this interpretation is an example from the coarse quartz-mica schist, number 5 of the section given on this page. The rock is an evenly banded, medium grained quartz-mica schist in which the schistosity is parallel to the original bedding. The banding strikes E–W and dips vertically. There is another set of planes in the rock which curve so as to be inclined at a high angle to the even banding and then merge into it. Along these curving planes are layers of coarse muscovite flakes. This rock probably represents an intermediate stage between the fissile schists and the gnarly textured gneisses.

Conclusions.—The Julian schists are the product of metamorphism of a series of shales, fine clayey sandstones, and nearly pure quartz sandstones, with subordinate layers of basic volcanic rock. In the less metamorphosed portions the schistosity is parallel to the original bedding of the rock. In the intensely metamorphosed portions there is evidence of two directions of schistosity, the earlier conforming to the original bedding, the later at a varying angle to it. The rocks exhibiting the double schistosity are characterized by peculiar minerals generally ascribed to contact metamorphic action, i.e., sillimanite and andalusite.

The intrusive quartz diorite is without doubt responsible for these contact minerals. There seems some reason, therefore, to attribute the later schistosity to the action of the intrusion. The earlier schistosity is attributed to a time earlier than the intrusion. Further evidence that the rocks were schistose before the intrusion of the quartz diorite is found in the extensive development of *lit par lit* injection gneisses and the total absence of hornfels along the contacts.

Age of the Julian schists.—The earliest ideas that are of any value in this discussion are those of Fairbanks.[5] In a paper on the geology of San Diego, Orange, and San Bernardino counties he reports finding fossils in limestone, inclosed in black shale and sandstone, four miles up a cañon which comes from the northeast and enters Silverado Cañon near its mouth. This seems to refer to Ladd Cañon, south of Sugarloaf Peak in the Santa Ana Mountains. (Shown on Corona Quadrangle map, U. S. G. S.) These fossils were sent to the National Museum and pronounced Carboniferous.[6] Fairbanks concluded that the metamorphic rocks of the Santa Ana Mountains were equivalent to the crystalline schists of the Julian gold belt. He continues:

> This is a belt of schists which runs through the heart of the Peninsula range, from the Mexican line through the Santa Ana Mountains. . . . . I believe that there is no question but what the metamorphic rocks of the Santa Ana range are equivalent in age to a large part of those in San Diego county. Although none but Carboniferous fossils were found, it is probable that the Metamorphic Series contains rocks much older as well as younger.[7]

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[5] Fairbanks, H. W., California State Mineralogist, Report (XI), 1893.

[6] *Ibid.*, p. 115.

[7] *Ibid.*, p. 118.

J. P. Smith, in his paper on "The comparative stratigraphy of the marine Trias of western America," says:

Dr. H. W. Fairbanks has discovered in the Santa Ana Range, Orange County, California, some fossiliferous limestones with pelecypods resembling *Daonella* and a trachyostracan ammonite not generically identifiable. These beds probably represent the Lower Trias, but the fossils are too scanty for a definite opinion to be based on them.[8]

The results of the work of W. C. Mendenhall have been published in the "Index to the Stratigraphy of North America."[9] He reports that the axis of the Santa Ana Mountains

is made up of a series of dark-gray or black slates with minor amounts of interbedded brown sandstones, the whole sparingly intruded by a series of medium acid dikes and overlain unconformably by remnants of the associated effusives whose aspect is generally that of andesites or slightly more acidic rocks.

The slates exhibit varying degrees of metamorphism. They usually have a well-developed cleavage, which, however, is generally not sufficiently perfect to obscure the original bedding planes. In general they resemble the Mariposa slate of central California, although as a rule they are less extensively altered. . . . .

Both the sediments and the associated effusives have been intruded and slightly altered by great masses of granitic rocks, and this three fold series after a long time interval, represented by an extensive physical unconformity, has been at least partly buried under Cretaceous conglomerates and shales of Chico aspect. . . . .

The determination of the age of the slates is based on small collections made in Ladd Canyon, on the south slope of the range, and near the mouth of Bedford Canyon, on its north slope. . . . .

Dr. Stanton decided, in the case of the Bedford Cañon collection, that the fossils are clearly Triassic. No mention is made of the determination of the Ladd Cañon collection, but presumably it also indicated a Triassic age.

Quoting Mendenhall further:

The Triassic beds probably extend considerably beyond the area in the Santa Ana Mountains where they have been carefully examined. Similar beds are known to occur in Railroad Canyon between Elsinor and Perris. . . . .

Merrill in a recent publication applied the name "Julian Group" to the crystalline schists of San Diego County. He says:

The metamorphic formations are mica schists, slates, quartzites and limestone, the first being especially well exposed near Julian and the latter occurring in small areas at several points. These metamorphic rocks, from their structural position and lithologic characters, may be regarded as probably equivalent to the Calaveras group described in the Mother Lode Folio of the U. S. Geological Survey and will be here designated as the Julian group. Their exact age is uncertain.[10]

[8] Smith, J. P., Proc. Calif. Acad. Sci., ser. 3, vol. 1, 1904, p. 352.

[9] Willis, Bailey, U. S. Geol. Surv. Prof. Paper, 71, pp. 505–506, 1912.

[10] Merrill, F. J. H., "Geology and mineral resources of San Diego and Imperial counties," Calif. State Min. Bur., 1914, p. 12.

A fossil was found by Mr. D. D. Bailey of Julian in the small area of metamorphic rock that lies in the granite about a mile southeast of Banner. This was submitted by Mr. H. L. Huston of San Francisco to Dr. J. P. Smith, who pronounced it "a slender ammonite that is without much doubt Triassic."[11]

The fossil is an imprint of an ammonite on the surface of an angular pebble of dark gray, quartzitic rock. It was found as float. The writer in company with Mr. Bailey visited the locality where this was found. The rocks of the vicinity are non-fissile, quartz-two-mica schists, sillimanite gneiss and blue-gray quartzite. Several hours' search was not rewarded by the finding of any fossils, but considerable rock similar in appearance to the matrix of the fossil specimen was seen.

Correlation based on lithologic character.—The conclusion has already been presented that the Julian schists were originally a series of shales, fine clayey sandstones, and pure quartz sandstones. The beds of the Santa Ana Mountains, as described by Mendenhall, would, if subjected to further metamorphism, yield schists much like those at Julian.

The writer has examined the metamorphic rocks along Railroad Cañon, north of Elsinore in Riverside County, which were referred by Mendenhall to the Triassic on the basis of their lithologic similarity with the rocks of the Santa Ana Mountains. The prevailing rocks are dark slates and gray quartzites. Both a white and an impure facies of quartzite was seen and some of the slates are rather sandy. Within this series at one horizon occur gray cherts interbedded with green shales. Lenses of fine-grained quartz-rhodonite-rhodochrosite rock are found lying parallel to the bedding within this sequence of chert layers.

Similar occurrences of manganese minerals in chert lenses inclosed in small masses of metamorphic rocks which are in turn surrounded by granite are found a short distance northeast of Deer Park, and between Campo and Jacumba, in San Diego County. In these lenses metamorphism has been more severe so that rhodochrosite is lacking and manganese garnet occurs in addition to rhodonite. Moreover, the inclosing rocks are quartz-mica schists similar in appearance to the Julian schist. If these manganese-bearing cherts really belong to the Julian schist series, it is seen that there is a remarkable similarity between that series and the Railroad Cañon rocks. Practically the only difference is in the degree of metamorphism.

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[11] Oral communication.

The Stonewall Quartz Diorite

The most widespread rocks of the mountainous portion of San Diego County are of plutonic type, varying from intermediate to acidic in chemical composition. Three specimens determined by Dr. A. S. Eakle from quarries near the towns of Lakeside, Foster, Santee, and Grossmont, at the western edge of the mountains, proved to be granites, while a fourth was granodiorite.[12] Farther to the northeast quartz diorite is the prevailing rock. It has been described by Calkins, as follows:

> The dominant rock about Ramona, as well as westward to the foot of the mountain range, is one that would commonly be called a biotite granite. Its color is gray with a tinge of olive-green; its texture is moderately coarse. Feldspar is its most abundant mineral, but quartz is also abundant, and small flakes of black mica occur in moderate quantity. Microscopic study shows that the rock is not a typical granite, inasmuch as the alkali feldspar is very subordinate to the soda-lime feldspar.[13]

Excepting a mass of true granite which will be described in a later chapter as the Rattlesnake granite, the granitic rocks of the Cuyamaca region are low or lacking in alkali feldspar and are to be classed as granodiorites and quartz diorites. In mineral composition they are much like the rock described by Calkins, and might well be correlated with it and termed the Ramona quartz diorite. However, as there may possibly have been more than one period of irruption of magmas of this nature, that of the Cuyamaca region will be termed the Stonewall quartz diorite, after the peak of that name composed of this rock.

Petrographic description.—These rocks are medium to coarse-grained aggregates of quartz, plagioclase, biotite, and rarely orthoclase. The plagioclase varies from albite to andesine, and in one specimen, from a dark segregation, it is labradorite. Green hornblende occurs in the dark segregations. Orthoclase is present in only three out of fourteen specimens examined, and in these makes up less than 10 per cent of the rock.

In part of the area mapped the quartz diorite is distinctly gneissoid, in other localities, as in the neighborhood of Stonewall Peak, the gneissoid character is barely discernible or completely lacking. This

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[12] Mines and mineral resources of Imperial and San Diego counties, Calif. State Miner., Rept., 1913–1914, p. 43.

[13] Calkins, F. C., Molybdenite and nickel ore in San Diego County, California, U. S. Geol. Surv., Bull. 640, 1916, p. 74.

gneissoid structure is generally best developed in the vicinity of contacts of the quartz diorite with the schist and is lacking at a distance from schist bodies. For instance, immediately east of the schist body south of the Friday Mine the rock is distinctly foliate. To the east of this point the gneissic structure becomes less prominent until one mile to the east, on approaching the main schist body, the rock again becomes quite gneissoid. The same change occurs on going west from the west boundary of the main schist belt north of Wynola. Again, the irruptive rock in the vicinity of the schist mass south of Cuyamaca Reservoir is gneissoid, while in rock of the same composition in Stonewall Peak and along the basic intrusive contact to the southwest the foliate structure is nearly or completely lacking.

The strike of the gneissoid structure is always essentially parallel to that of the neighboring schist. The dip of the foliation in the intrusive rock often conforms to the dip of the schist. It is inferred that the gneissic structure is parallel to the walls of the schist bodies. An inspection of the map will show that some of the schist bodies have curving courses, notably those in the vicinity of Pine Hills. The structure of gneiss and schist conforms even in these cases. It is therefore concluded that the gneissoid structure is not the result of the dynamic metamorphism of solid rock, but that it represents the flow lines of a partially consolidated magma.

Age of the quartz diorite.—The intrusive nature of the contacts of the quartz diorite and the Julian schist is evident from the occurrence of injection gneisses, paragneisses, and contact minerals along the contact. The Cuyamaca Basic Intrusive cuts across the structures of schist and quartz diorite gneiss and is undoubtedly younger than either.

To the northwest of the Cuyamaca region, in the Santa Ana Range, and to the south, in the mountains of Lower California, Cretaceous rocks rest upon the eroded surface of great granitic masses. No instances of post-Cretaceous granite are known in California. We can then with reasonable assurance say that the quartz diorite is pre-Cretaceous. From Mendenhall's work in the Santa Ana Mountains we know that at least part of the granite of the Peninsular Range is post-Triassic. This leads to the conclusion that the Stonewall quartz diorite is pre-Cretaceous and post-Triassic, probably corresponding in age to the post-Mariposa granitic masses of the Sierra Nevada.

Type of intrusion.—The wide zone on the west side of the main belt of Julian schist, in which injected material and contact minerals are found, makes it probable that the intrusive contact dips at a low angle to the east beneath the schist body. The contact zone on the east side of the schist belt, while narrower than that on the west, is still so wide that it appears likely that the contact here also dips toward the schist. It is thus probable that the schist masses wedge out downward. The widespread occurrence of quartz diorite in the Cuyamaca and Ramona regions suggests that we have to deal with a great batholithic mass.

The Cuyamaca Basic Intrusive

The main basic intrusive mass of the Cuyamaca Mountains, together with the smaller outlying masses, presents many petrographical variations, but the rocks of which it is composed, with a few exceptions, may be grouped as gabbros, norites, and basic diorites. These rocks are of medium to fine grain, specimens having their largest mineral grains over 5 mm. in size being rare. In general the rocks have a maximum grain of from 1.5 to 4.0 mm. Despite the fine grain, the rocks never exhibit diabasic structure, and the porphyritic habit is exceptional.

The rocks of the mass have been classified as diorites on the one hand and norites and gabbros on the other hand, according as their plagioclase feldspar contains more or less than 50 per cent of albite molecule. No attempt was made to mark off the norites from the gabbros during the field work. Even had the discrimination been possible in the field, the complex intermingling of the two types and the heavy soil cover would have rendered their separate mapping impracticable. It can, however, be said that norites are more abundant than gabbros in the immediate vicinity of the Friday mine, and also in the embayment in sections 16 and 17, township 13 south, range 4 east, and in the outlying area to the northwest of that embayment. Gabbro predominates over norite in the region west of Middle Peak and Cuyamaca Peak. As a result of microscopic study two areas of diorite have been roughly delineated. One of these, lying along Cedar Creek, two miles north of North Peak, is predominantly hypersthene diorite, but augite diorite and brown-hornblende norite are also present. The other area of diorite occupies the lobe of the basic intrusive mass that extends east, on the east flank of Cuyamaca Peak. It is characterized by augite diorite.

Constituent minerals.—The various rock types are mixtures of a limited number of minerals, in varying proportions.

The feldspars range from oligoclase to anorthite. Under the microscope they are seen to be almost invariably twinned according to the albite law. Combinations of albite and carlsbad or albite and pericline twinning are frequent.

The hypersthene, to the unaided eye, has rather light colors, including pale brown and pinkish tints. These colors would indicate enstatite, but microscopic examination shows the mineral to have always a negative sign. The pleochroism is buff to pink for the fast ray, very pale green for the slow ray. In many of the thin sections examined a mineral was seen having all the properties of hypersthene except that it seemed to show oblique extinction. A more careful examination showed that this was not oblique extinction, but symmetrical extinction, in which one of the two sets of cleavage lines was poorly developed. There is no reason then to regard this mineral as other than hypersthene. It is possible that "a pleochroic augite precisely like the hypersthene, but with a distinct extinction angle," described by Coleman[13] from the Sudbury norites, is of the same nature.

The augite appears black in the hand specimen. Under the microscope it shows a maximum extinction angle of 55°, is colorless to pale buff, and frequently is filled with an opaque dust.

The brown hornblende appears black to the unaided eye. Its microscopic properties are as follows: Pleochroic: $\mathfrak{a}$ = colorless, faint green, but generally pale buff; $\mathfrak{b}$, $\mathfrak{c}$ = dark shades of brown; absorption, $\mathfrak{b} > \mathfrak{c} > \mathfrak{a}$. The sign is negative, the extinction angle 28°, the maximum birefringence .026.

In hand specimens entirely unaffected by weathering, the olivine appears colorless or very faint green, and is transparent. With increasing weathering the olivine becomes yellowish and finally red. In thin section the olivine is colorless or very faint green. Its sign is negative.

The green hornblende appears dark green megascopically. Under the microscope it shows the following colors: $\mathfrak{a}$ = greenish yellow or pale buff; $\mathfrak{b}$ = dark brown-green, dark green or light brown-green; $\mathfrak{c}$ = dark green to pale yellow green; absorption, $\mathfrak{b} > \mathfrak{c} > \mathfrak{a}$. The maximum extinction angle is 30°, the sign negative.

Besides these essential minerals there are certain minor constituents. Apatite needles are found in almost all the rocks. Green spinel, pleonaste, is frequently present, associated with the magnetite. No picotite or chromite was noted. Every specimen of basic rock examined contained either pyrrhotite or magnetite or both. The biotite,

[13] Coleman, A. P., Rept. Bur. Mines Ont., vol. 14, pt. III, 1905, pp. 115–116.

found in certain of the border facies, differs in no way in its optical properties from that of the gneisses. Its pleochroism is yellow to almost colorless, parallel to the principal axis, deep brown to black, parallel to the cleavage. The quartz seems to be identical with that of the more siliceous rocks.

Description of typical rocks.—Fifteen types of basic igneous rocks have been recognized in this region. In order to give an idea of the mineralogic composition and texture of these rocks a detailed petrographic description of ten specimens, typical of as many varieties of rock, will be presented. The five varieties not described—augite diorite, brown-hornblende gabbro, gabbro-norite, olivine gabbro-norite, and quartz gabbro-norite—differ not at all in texture from the types described. As their names indicate, their discrimination from the other types depends either on some minor, though characteristic, constituent, or on a difference in the relative proportion of common constituents, or on a difference in the kind of plagioclase.

Norite (no. 151, pl. 9, fig. 1), from the small area of basic rock one and one-half miles east of Pine Hills.

This rock has the following composition:

Anorthite	40%
Hypersthene	31%
Augite	25%
Brown Hornblende	2%
Pyrrhotite	2%

The maximum size of grain is 2.3 mm., the average about 0.5 mm.

The plagioclase and pyroxenes have mutually interfering, irregular boundaries, made up of a series of curves. There is little tendency toward euhedral outline on the part of any of the constituents.

The brown hornblende occurs both as rims on the hypersthene individuals, lying between the hypersthene and the feldspar, and as separate patches within the hypersthene. In both cases it is clear and compact. An individual of brown hornblende, shown in plate 9, figure 2, at one place has irregular, branching arms between several feldspar grains. Optically it is one individual throughout.

The pyrrhotite occurs in grains up to 0.8 mm. in diameter. These grains are frequently quite irregular in outline, having two or more branches from their main body. However, many of the sulphide grains have extremely simple form, being circular or slightly oval in section. The most irregular grains invariably are found filling spaces at the meeting of several silicate individuals, quite like the hornblende, mentioned above. The grains with circular and oval sections, on the other hand, are always completely inclosed within a single silicate individual, generally a pyroxene.

The pyrrhotite occurs most commonly at the edges of pyroxenes, extending thence into feldspar. Sometimes the pyrrhotite is separated from the pyroxene by brown hornblende. This, however, is not the result of any reaction between the ore mineral and the pyroxene, but is part of an ordinary hornblende "rim" which on either side of the grain of ore lies between the pyroxene and feldspar.

Olivine norite (no. 190, pl. 9, fig. 3), from summit of hill south of Pine Hills.

The mineral composition is as follows:

Bytownite	54%
Hypersthene	24%
Augite	4%
Olivine	16%
Pyrrhotite	2%

The average grain is 0.7 mm., the maximum 2.0 mm.

Both hypersthene and augite are in some instances molded against crystallographic boundaries of the feldspar. Some of the pyroxenes are then probably later than part of the feldspar. There is, however, little tendency to diabasic texture, most of the constituents meeting in curving contacts.

The olivine occurs in nearly equant grains with irregular rounded outlines. These grains are found both within the pyroxene and the feldspar. In the latter situation a kelyphitic zone separates the olivine from the feldspar. These zones, as in specimen no. 70, are composed of compact amphibole within and a fibrous mineral without.

The olivine appears to be the earliest silicate. Its crystallization was followed by that of the feldspar and pyroxene, whose periods overlapped, so that most of the pyroxene is later than at least part of the feldspar.

The pyrrhotite is found in association with all the silicate minerals. Its grains have not very complex outlines, those entirely inclosed in single olivines having particularly simple, circular sections.

Gabbro (no. 202), from a cañon running northwest from Cuyamaca Peak, at 5000 feet elevation.

The mineral composition of this rock is as follows:

Bytownite	46%
Olivine	7%
Hypersthene	13%
Augite	27%
Green Hornblende	4%
Magnetite	3%
Pyrrhotite	0.37%
Spinel	Very small amount

The average grain is 0.5 mm., the maximum 1.5 mm.

The augite occurs in large individuals with irregular rounded outline. In some cases branching masses extend out from the main mass of an individual, the whole being an optically continuous body. This is illustrated by plate 9, figure 4. The augite frequently includes grains of feldspar poikilitically.

The hypersthene, like the augite, shows ophitic texture, but the external outline of its individuals are much more regular. Both pyroxenes generally have mutually interfering, curving boundaries against the feldspar, but in a few cases the hypersthene is molded against crystallographic planes of the feldspar. Apparently all of the pyroxene crystallized after at least a portion of the feldspar.

Compact, light green hornblende forms rims on the augite, sometimes so extensive as to leave very little augite. The hornblende and augite appear to be crystallographically continuous.

The pyrrhotite occurs in grains up to 0.2 mm. in diameter. The largest grains are within, or in contact with, pyroxenes, but much of the pyrrhotite is entirely inclosed in feldspar. Most of the grains have rounded irregular outlines, in no case, however, so irregular as that of the augite mentioned above. On the other hand, there are several sulphide grains, entirely enclosed in single feldspars which have almost perfectly circular outlines.

The spinel occurs in minute, irregular grains. The magnetite generally shows irregular forms, with rounded outlines, much like those of pyrrhotite. The relations between the spinel and magnetite, shown in plate 9, figure 5, point to a close genetic connection.

Olivine gabbro (no. 130), from point about one mile north of North Peak. On road northeast of sawmill.

The mineral composition is as follows:

Bytownite	50%
Olivine	21%
Augite	19%
Brown hornblende	9%
Pyrrhotite	1%

The average grain is 0.4 mm., the maximum 1.0 mm.

All the constituents show mutually interfering, curving outlines.

Many of the olivine grains are rimmed with hypersthene, in just the same way that the augite individuals are rimmed with brown hornblende. The hypersthene rims often show optical continuity for more than one-quarter the circumference of the olivine grains, in one case for more than one-half the circumference. The brown hornblende sometimes makes up over one-half of a crystallographically continuous, compound individual with augite.

The pyrrhotite occurs within the mineral individuals, rather than at the contacts of dissimilar minerals. The pyroxenes contain more pyrrhotite than does the olivine, the feldspar least of all. When entirely inclosed in individual minerals the pyrrhotite shows extremely simple outlines, circular or oval.

Brown-hornblende norite (no. 108), from north center of northwest quarter of section 20, township 13 south, range 4 east.

The mineral composition is as follows:

Labradorite	46%
Hypersthene	20%
Brown Hornblende	25%
Augite	6%
Magnetite	2.4%
Pyrrhotite	0.6%

The average grain is 0.3 mm., the maximum 0.8 mm.

The hypersthene, augite and plagioclase have mutually interfering, curving boundaries. The brown hornblende is seen as euhedral sections, entirely enclosed in feldspar, and also occurs in completely anhedral fashion, molded against crystallographic planes of the feldspar. It is generally found implanted on the ends of hypersthene individuals.

Some of the hornblende then seems to have crystallized before at least part of the plagioclase, while some is apparently later than all the plagioclase.

The pyrrhotite is found generally at the boundaries between pyroxenes and feldspars, and the grains in such situations have rather complicated outlines. The few grains of ore that occur within single silicate individuals (in this rock, within feldspars) have simple circular or oval outlines.

Periodotite (no. 60), from east wall of north cross-cut, 170-foot level, Friday Mine.

The mineral composition is as follows:

Olivine	73%
Augite	14%
Brown hornblende	10%
Pyrrhotite	3%

Average grain is 1.2 mm.

The olivine occurs in equant or slightly elongated grains, meeting in irregular curving contacts. The augite is in large very irregular individuals including the olivine poikilitically.

Pyrrhotite occurs in irregular masses, in part at the meeting point of three or more olivine grains, in part within single olivine grains. No sulphides occur in the augite or hornblende.

Troctolite (no. 70), from point eight feet north of body of massive ore, 170-foot level, Friday Mine.

The mineral composition is as follows:

Bytownite	56%
Olivine	36%
Pyrrhotite	0.6%
Minerals of kelyphitic zones	7.0%

No euhedral tendency is exhibited by either olivine or feldspar. The olivine occurs in part as separate, rounded grains, surrounded by feldspar, and also as strings of coalescing grains which give the rock a banded appearance (see pl. 9, fig. 6, and pl. 10, fig. 1). The olivine crystallized before the feldspar.

The olivine grains are separated from the inclosing feldspars by rims or zones. These are of three kinds: (1) compact, faint brown or green, hornblende. These are clear and often optically continuous for a considerable fraction of the circumference of the olivine grain. (2) Aggregates of green fibers, set at right angles to the periphery of the olivine. The fibers show inclined extinction and are probably a fibrous amphibole. (3) Compound zones, composed of compact hornblende within and fibrous mineral without. Green spinel, pleonaste, occurs in sharply angular grains in these zones.

Pyrrhotite is associated with both the feldspars and olivines. Where lying entirely within single crystals its outlines are relatively simple.

Hypersthene diorite (no. 124), from area of hypersthene diorite, two miles north of North Peak.

The mineral composition is as follows:

Andesine	70%
Hypersthene	9%
Green Hornblende	19%
Magnetite	1.7%

The average grain is 0.3 mm., the maximum 2.5 mm.

There is little tendency toward euhedral outline on the part of any of the constituents. They meet in curving lines, as is shown in plate 10, figure 2.

The green hornblende is not fibrous but compact. It appears to have been formed at the expense of the hypersthene by alteration working inward from the edges; that is, by change of the edges of a preëxistent pyroxene body, and not as rims implanted on the edges by outward growth.

Magnetite is found in all the silicates as rounded grains. Its outlines are simpler than those generally shown by pyrrhotite.

Quartz norite (no. 114), from point one hundred yards north of contact in northwest quarter of southwest quarter, section 21, township 13 south, range 4 east.

The mineral composition is as follows:

Labradorite and Bytownite	52%
Hypersthene	22%
Quartz	20%
Biotite	4%
Magnetite	1.3%
Pyrrhotite	0.4%

The average grain is 0.5 mm., the maximum 1.6 mm.

The hypersthene and feldspar occur as an aggregate of anhedral grains with curving contacts. The quartz is sometimes molded against crystallographic faces of feldspar, or the two minerals meet along irregular curving boundaries. The biotite occurs as ragged grains and is penetrated along cleavages by the feldspars. It is possible that the biotite represents grains picked up by the norite from the wall rock, granite or schist, and that these grains were never melted or dissolved by the norite.

Most of the pyrrhotite occurs as very irregular masses, occupying the space at the meeting place of three or more feldspar individuals.

Quartz gabbro (no. 180b), two hundred yards northeast of locality of specimen 151 in small area of basic rock east of Pine Hills.

The mineral composition is as follows:

Labradorite	31%
Hypersthene	10%
Hornblende	20%
Augite	13%
Biotite	19%
Quartz	4%
Magnetite	3%

Average grain is 1.0 mm., maximum 2.0 mm.

The textural relations of the feldspar, pyroxenes, hornblende, and biotite are quite like those of specimen 114, and need no further comment.

The quartz occurs in irregular veinlike masses, which are optically continuous and may reach 5 mm. in length. Its boundaries against the various inclosing minerals are such as would be produced if the quartz had corroded the pyroxenes or feldspars. The contacts of the quartz against several of the bounding plagioclase crystals and also against individuals inclosed in the quartz are straight lines. One set of these lines is the trace of the 010 plane of the plagioclase. The other set does not seem to be related to any crystallographic properties of the feldspars, but on the other hand often corresponds exactly with the *c* axis of the quartz. These quartz masses, together with the bounding and included feldspars, have then the properties of a pegmatitic intergrowth.

Effect of marginal chilling.—Norites with distinct porphyritic texture were found at three localities in the north half of section 21, township 13 south, range 4 east. Two of these occurrences are within one hundred yards of the eastern and western margins of the intrusive mass. They are, however, known to occur as dikes, cutting the even-grained norites. At the third locality the structural relationship of the porphyry to the normal norite could not be made out; but, as the locality is situated over three hundred yards from the margin of the basic intrusive, it is probable that this rock also is from a dike.

The gabbro on the west flank of Cuyamaca Peak is distinctly porphyritic for a distance of one-quarter mile from its west margin. In no case, however, does the ground mass become as fine in grain as are many of the even-grained rocks from the central portions of the basic intrusive mass. The very width of the zone of porphyritic texture makes it improbable that it is caused by marginal chilling.

It is concluded that, for those portions of the intrusive mass mapped as norites and gabbros, there are no marginal chilling effects. The following observations of the average grain of rocks, other than dike rocks, of the norite, gabbro, and closely related types bear out this conclusion: In 6 rocks occurring within 50 yards of the margin, 2 of them immediately at the contact, the average grain was 0.6 mm.; in 8 rocks from Friday Mine it was 0.6 mm., and in 17 rocks, more than one-quarter mile from the margin, including those from Friday Mine, it was 0.56 mm. At two points on the contact of the diorite east of Cuyamaca Peak with the gneissoid quartz diorite, the diorite at the contact is finer grained than that a few feet distant. This decrease of grain without doubt is due to the cooling effect of the wall rock.

Assimilation of wall rock.—Five specimens of quartz norites and quartz gabbros were collected, representing four or five small areas of these rocks. Three of the specimens were collected from points within 25 yards of the contacts of gabbro or norite against quartz-mica schist. The two other samples were found at distances of 100 and 200 yards from the nearest schist. There can be little doubt that these rocks are ordinary norites and gabbros that have acquired their quartz and biotite from the schist. At the contact of basic diorite against gneissoid quartz diorite, two miles southeast of Cuyamaca Peak, there is conclusive evidence of the assimilation of wall rock by the basic intrusive. The contact, which is well exposed in the bed of a stream, strikes north 75° west and dips 40° to 60° north. Viewed as a whole, the contact is an even surface, sharply separating the basic rock, which lies above, from the quartz diorite below. The strike of the contact corresponds to that of the gneissoid structure in the quartz diorite, but the latter dips at a steeper angle, 70°, though in the same direction.

When viewed in detail, the contact is in places straight and sharp, but in other places the light and dark rocks penetrate one another in complicated fashion. Starting at the contact, the basic rock becomes gradually coarser till a point about ten feet away is reached, after which there is no change. The light colored rock for an inch or two on the quartz diorite side of the contact is finer grained than is the main mass of the gneissoid rock.

The diorite is composed of andesine, augite, biotite, and magnetite. The quartz diorite is made up of quartz, oligoclase, and biotite. A thin section, cut across the contact of the two rocks, shows that the quartz diorite has been penetrated by veinlike masses whose greatest width is at the contact and which wedge out within 5 or 10 mm. The minerals of these veinlets are augite, plagioclase, and quartz. The minerals of the veinlets have the same size of grain as those of the diorite. This shows that the fine-grained selvedge of the quartz-diorite gneiss is the result of the permeation of that rock by dioritic material. The biotite of the diorite is most abundant and, in largest individuals, near the contact.

Ten feet from the contact there is a small amount of biotite in the diorite, as there is also at 100 feet distance. The rock at 100 feet distance is more basic than that at the contact, the two rocks containing 45 and 60 per cent of andesine feldspar respectively.

Similar relations are found at the contact of augite diorite and gneissoid granodiorite between Cuyamaca and Stonewall peaks. The mineral compositions of three specimens taken from the diorite at various distances from the contact illustrate the case:

Distance from contact	Plagioclase Kind	Plagioclase Amt.	Augite	Green hornblende	Biotite	Quartz	Magnetite	Apatite
1 in.	Albite and oligoclase	55		8	13	24	0.5	
30 ft.	Andesine	62		33	×		4	1
1500 ft.	Andesine	67	12	20	×		1	

× minute quantity.

The granodiorite contains both orthoclase and oligoclase feldspars. The lack of orthoclase in the basic rock near the contact suggests that the potash feldspar has been altered to albite.

Texture and grain.—Measurements were made, by means of the microscope with micrometer eyepiece, of the average and maximum diameter of grain in all thin sections studied. The method employed in determining the size of grains was to measure the longest diameter of all the grains met with in several traverses across the thin section. The average of these diameters was taken as the "average grain," the maximum as the "maximum grain." Care was taken to exclude cataclastic grains, which as a matter of fact are rarely found. Feldspar twins were measured as one grain. Where pyroxene was found partially altered to green hornblende the whole area was considered as one grain. Where isolated areas of ferromagnesian minerals appeared to be parts of a poikilitic individual the diameter was taken to be that of the entire area occupied by those grains with parallel optical orientation.

The average size of grains of the basic rocks, excepting the dike rocks, was found to vary from 0.3 mm. to 1.2 mm. The average of all cases is 0.57 mm. The maximum size of grain, as observed in thin section, varies from 0.8 mm. to 13.0 mm., the average maximum of all cases being 2.6 mm.

Viewed in the hand specimen the rocks would be termed medium to fine-grained. Even in those of finest grain, however, many of the constituent minerals can be distinguished with the hand lens, and often there are large luster mottled pyroxenes, in general less than 1 cm. in size, but sometimes reaching 5 or 10 cm.

The results of grain measurements under the microscope were surprising, as the impression was gained from examination of the hand specimens that the rocks were in general of medium grain, and that some were even moderately coarse. The reason for this is to be found in the mode of occurrence of the feldspar. In most of the rocks the plagioclase shows little tendency to tabular or prismatic form, but occurs in aggregates of small anhedral grains, set together with smoothly curving boundaries.

Iddings gives the following classification of the grain of rocks: "Coarse-grained, average crystals greater than 5 mm. in diameter; medium-grained, crystals between 1 and 5 mm.; fine-grained, crystals less than 1 mm."[15] According to this scheme, the rocks of the Cuyamaca basic intrusion are for the most part fine-grained.

[15] Iddings, J. P., Igneous rocks, vol. 1 (1909), p. 192.

For comparison a few gabbros and norites from various European localities were studied, with the following results:

Number of specimen	74	77	78	79	81
Krantz-Rosenbusch Coll.					
Average grain	4.3 mm.	1.3	1.5	1.5	1.2
Maximum grain	10.0 mm.	3.2	4.0	4.0	6.0

No. 74, Norite, Hitteroe, Norway. In the hand specimen appears medium, verging on coarse-grained.

No. 77, Olivine gabbro, Oberkainsbach. Medium-grained in hand specimen.

No. 78, Olivine gabbro (Hyperite), Risor, Norway, appears medium-grained, verging on coarse.

No. 79, Olivine norite, Radantal, Harz Mountains, appears medium-grained.

No. 81, Troctolite, Radantal, Harz Mountains, appears medium-grained in hand specimen.

The rocks of the Cuyamaca mass are of finer grain than any of the type rocks considered above. On the other hand, an inspection of the micro-drawings of typical norites given by Harker[16] gives one the impression that the average grain of his specimens varies from 0.7 to 1.2 mm. This is about the same as many of the Cuyamaca rocks.

Despite their relatively fine grain the Cuyamaca rocks rarely exhibit porphyritic textures. While in all the specimens the largest grains are considerably larger than those of average size, there is a graded series of sizes, from slightly below the average to the maximum.

Diabasic texture was found nowhere in these rocks. A slight tendency to automorphic outline of the feldspars, seen in several of the specimens, probably corresponds to hyperitic texture. Large luster mottled crystals of pyroxene or brown hornblende are of frequent occurrence. The included mineral grains have rounded outline and the boundaries of the host mineral against the surrounding minerals are very ragged. The typical ophitic texture is rarely seen.

In general the rocks have the texture typical of gabbros, in that the minerals all have but slight tendency to euhedral outline.

Petrographic summary.—The rocks of the basic intrusive mass are fine to medium-grained rocks, belonging in general to the gabbro, norite, and diorite families. Their textures are those typical of gabbros, there being little or no tendency to diabasic structure. Extremely fine-grained and porphyritic textures are only locally developed along the margins of the mass. There is good evidence that the basic intrusive rocks made way for themselves in places by the assimilation of wall rock.

Of the silicate minerals, olivine was clearly the first to crystallize. Perhaps all the olivine crystallized before any of the other silicates. The period of crystallization of the pyroxenes runs parallel to that of the plagioclase and overlaps at either end, so that some of the pyroxene separated both before and after the plagioclase. The brown hornblende is believed to be a primary mineral of the rocks. Its period of formation was later than that of much of the pyroxene; yet apparently a portion of it separated before part of the plagioclase.

The order of crystallization is:

Olivine

Pyroxenes

Plagioclase

Brown Hornblende

[16] Harker, A., Petrology for students, 1908, p. 87.

The ore minerals, magnetite, pleonaste, and pyrrhotite, are believed to be primary constituents of these rocks. A detailed discussion of the evidence on this point will be given in the chapter on the Friday Mine.

Rock alteration.—About one-third of the rocks examined contain more or less green hornblende. In many cases this mineral is clearly of secondary origin, formed at the expense of augite or hypersthene. The green hornblende differs in occurrence from the brown variety in that euhedral cross-sections are never seen. The green hornblende is often seen as large, optically continuous, individuals with no remnant of the pyroxene from which it is probably derived. Again it occurs in aggregates of smaller individuals, with or without residual masses of pyroxene. In either case the hornblende is charged with magnetite, sometimes as dust, sometimes in irregular masses occupying a coniderable portion of the hornblende body. This magnetite is clearly of secondary origin, a by-product of the alteration of pyroxene to hornblende. Its occurrence, as a dust, is quite different from that of the primary magnetite, such as that described in specimens nos. 124 and 202. The alteration of pyroxene to green hornblende probably involves the addition of no material except water. The source of the water in this region may very well have been the pegmatite intrusions. Some evidence bearing on this point is given in the section on pegmatites.

Two specimens from the Cuyamaca basic intrusive mass were found to contain very small amounts of chlorite. A sample of norite from the area of basic rock east of Descanso contains chlorite and calcite.

A specimen of olivine gabbro from the north flank of North Peak contains fibrous serpentine developed at the edges of the olivine grains. The only other occurrence of this mineral noted in the district was a minute amount in one specimen from the Friday Mine.

The greater part of the areas of basic rocks is mantled by a brown to red soil containing boulders of fresh rock. This soil is sometimes underlain by material which represents an intermediate stage of weathering. It is rock decomposed in place with preservation of texture. Green blotches, representing original hornblende or pyroxene, lie in a light gray or yellow, friable matrix which represents the plagioclase. In such material the boulders of fresh rock, noted above as occurring in the red soil, can be seen in every stage of their formation from joint-bounded blocks. The rounding takes place by decomposition of the edges of blocks. No attempt has been made to determine the constituent minerals of the weathered products.

Relation between the different rock types.—The complexity with which the different basic rock types are intermingled has been mentioned in a previous section. These complex relationships not only obtain throughout the main mass of the basic intrusion but also in many of the outlying masses. The small mass, three-quarters of a mile east of Pine Hills, contains typical gabbro and typical norite, both varying in grain from medium to coarse. The larger mass, to the northeast, contains norite, olivine norite, and quartz norite. None of the natural exposures studied exhibit contacts between the different types of basic rocks. Our last resort to obtain evidence on this point is in the underground workings of the Friday Mine. Here it was impossible to find contacts marking off the norites, olivine norites, gabbros, olivine gabbros, augite diorite, brown-hornblende norites, and troctolites from one another. This statement refers to the massive rocks, and does not apply of course to the very fine-grained, brown-hornblende gabbros and brown-hornblende norites which occur in sharply bounded narrow dikes.

The hypersthene diorites and augite diorites have a finer grain than that of the general run of the norites and gabbros. Thus the average grain of three rocks from the hypersthene diorite mass is 0.3 mm., that of two rocks from the augite diorite mass is 0.4 mm. The granularity of these rocks is thus less than that of the norites and gabbros of the main intrusive mass, whose average grain is about 0.58 mm. It should be pointed out in this connection, however, that the average grain of four outlying stocks and dikes of gabbro and norite, all being less than one hundred yards in diameter, is 0.5 mm. The cooling effect of schist and granite walls had little, if any, influence on the grain of these rocks. There is no reason to believe that the norite or gabbro which surrounds the hypersthene diorite would have any greater cooling effect. Therefore, it is concluded, the finer grain of the diorites has no bearing on the question of their age with respect to the norites, gabbros, and other rocks of the basic intrusion. It is more likely that fineness of grain varies with the chemical composition of the rock.

The main basic intrusive mass, as also the small outlying masses, are intrusive complexes of various basic igneous rocks, the rock types merging one into the other by gradual changes in the proportions of their constituent minerals. Any theory to explain the heterogeneity of the main mass must also account for the variation in the outlying masses.

Form and type of intrusion.—The observed localities at which the actual contact of basic rock against the schist or the quartz diorite is laid bare are three in number. At these places the contact plane conforms essentially to the structure of the invaded rock. The mapping suggests that for perhaps a fifth of the periphery of the basic intrusive mass the contact conforms approximately to the foliation of the gneissoid quartz diorite and schist. However, along the greater portion of the border of the mass the basic rock cuts across the preexistent structures. In most cases where there is any degree of parallelism between the strike of the schist or gneiss and the direction of the contact of the main Cuyamaca intrusive, the dip of the invaded rocks is toward the intrusive at high angles, varying from sixty or seventy to ninety degrees.

There is no evidence of any metamorphism exercised by the basic magma on the schist or quartz diorite. This is to be expected, as the older rocks had a high degree of stability before the invasion of the basic rock.

Several small masses of schist occur within the basic intrusive area and two fairly large granite masses were found in the saddle between Cuyamaca and Middle peaks. These occurrences suggest that the basic magma made way for itself, at least in part, by the stoping of wall rock.

From evidence presented in a previous section there can be no doubt but that the basic magma enlarged its chamber, to a slight extent at least, by the assimilation of wall rock. It is doubtful if this action was on a considerable scale for the reason that such basic rocks as olivine gabbro and olivine norite are not only found in the central portions of the mass but are rather common along certain stretches of its periphery.

A complex intermingling of different rock types was found not only in the main mass of the basic rock but also in several of the smaller outlying masses. No definite contact planes were found between the different types of rock. It seems probable then that the heterogeneity of the Cuyamaca Basic Intrusive is due largely to differentiation in place.

The relatively fine grain of the rocks and the lack of contact action on the wall rocks suggest that the magma solidified at moderate depth.

It is believed that the structures of the wall rocks had much their present attitude before the intrusion of the basic masses. The form of the main intrusive body must then be an irregular mass elongated north and south and vertically. According to the usage of many geologists, this mass might be termed a laccolith. According to the classification proposed by Daly,[17] it would be a chonolith.

Age of the intrusion.—The Cuyamaca basic igneous mass is younger than the schists and quartz diorite. The evidence for this is: (1) it generally cuts across the structure of schist and quartz diorite; (2) the invaded rocks are schistose, while the intrusive is massive and only exceptionally shows flow banding; (3) dikes, small laccoliths, and plugs of gabbro and norite cut the quartz diorite and schist.

It has been shown that the Stonewall quartz diorite is probably of post-Triassic, pre-Cretaceous age. The basic intrusives are thus post-Triassic. It was concluded that the Cuyamaca igneous mass cooled at intermediate depths. If the Cuyamaca area represents the site of an ancient volcano, it might be possible to find remnants of its effusive rocks, which by their relation to sedimentary rocks would give a clue to the age of this intrusion.

Volcanic rocks of probable early Tertiary age are exposed in a belt along the western edge of the mountains of San Diego County. Determinations of specimens of these rocks by E. S. Larsen, quoted in a recent paper by Ellis, class them as quartz latites.[18] It can hardly be supposed that quartz latites were erupted by a volcano whose eroded neck contains only basic rocks. Andesitic lavas underlie Miocene sediments in Coyote Mountain, in Imperial County.[19] No accurate description of these rocks is available. It does not seem at all likely, however, that andesites could have been erupted in any quantity from the hypothetical Cuyamaca volcano. Late Tertiary or Quaternary basalts occur in northwestern San Diego County. These might conceivably have come from a ''gabbro-norite volcano,'' but their recency argues against their assignment to the Cuyamaca igneous period. The question of the exact age of the Cuyamaca intrusive must remain an open one. The writer's opinion, however, is that the intrusion occurred in pre-Cretaceous time, following closely on the development of the quartz diorite batholith.

The Rattlesnake Granite

A mass of granitic rock outcrops in the region of Rattlesnake Valley from five to six miles east of Cuyamaca Peak. Its area is roughly lenticular, with rounded ends. The greatest extent is north-

[17] Daly, R. A., Igneous rocks and their origin (New York, 1914), p. 84.
[18] Ellis, A. S., U. S. Geol. Surv., W. S. P., 446, 1919, pp. 72–73.
[19] Merrill, F. J. H., *op. cit.*, p. 12.

south, a distance of three miles. It is a true granite, varying from an alaskite to a biotite-hornblende granite. Orthoclase predominates over plagioclase in all specimens examined. It is coarser in grain than the gneissoid quartz diorite and granodiorite, and is only exceptionally gneissoid. At the south end of the area there is a marginal development of alaskite porphyry.

Schist and quartzite inclusions, quite common in the quartz diorite near Rattlesnake Valley, are entirely lacking in the Rattlesnake granite. The contacts of the granite against the schist and gneissoid quartz diorite generally cut across the structure of these rocks. At the north end of the mass the structure seems to indicate that the granite forced the schist apart to make room for itself. The walls of the granite mass dip steeply away from its center in some places, at others the dip is toward the center at somewhat lower angles.

Effect of the intrusion on wall rocks.—The contacts of the Rattlesnake granite were studied carefully at but two localities, its northern and southern extremities. At the northern end the granite is intrusive into fissile quartz-mica schists. The only evidence of metamorphism is the presence of large muscovite flakes for some distance from the granite, and a small amount of coarse contorted schist at the immediate contact. The varying strikes of the schist indicate that the granite made way for itself to some extent by forcing apart the wall rocks. At the southern end of the granite mass, potash-rich granitic material has been injected along the schistose planes.

It is evident that the Rattlesnake granite is an injected body of distinctly later age than the gneiss and schist which it intrudes. But its relation in time to the Cuyamaca basic intrusive is indeterminate.

Assuming that the date of the two intrusions was essentially the same, the hypothesis is advanced that the gabbro-norite complex and the granite of the Rattlesnake mass are complementary differentiates of a single magma of intermediate composition. The exposed area of the granite is small compared to that of the basic intrusive, but this may have no bearing on the relative volume of the two rocks at the time of their intrusion. It is interesting to note in this connection that the world average chemical composition of quartz diorites, the prevailing igneous rock of this region, is almost the exact mean of the compositions of gabbro-norite and granite.

Basic Dikes

Dikes of dark, dense, very fine-grained rock cut the various massive basic rocks exposed in the workings of the Friday Mine. Similar dikes cut the massive sulphide ore. All these rocks are brown-hornblende gabbros and brown-hornblende norites. Their textures differ in no way from that of the coarser, larger masses of the same composition, save in size of grain. All of them carry pyrrhotite in the same manner as the coarser rocks. Dikes of fine-grained norite and norite porphyry were also found at the surface in the neighborhood of the mine. These dikes represent the last activity of the basic intrusion. The fact that they cut the massive sulphide body is evidence of prime importance in the matter of the origin of the ore.

Pegmatite

Pegmatite cuts all the rocks of the region. It was not observed in intrusive contact with the massive sulphide body of the Friday Mine, but it does cut the fine-grained dikes which intrude the ore.

In an outcrop of gneissoid quartz diorite at the junction of the creeks in the northwest quarter of section 12, township 13 south, range 3 east, certain narrow pegmatite veins are contorted, though conforming to the schistosity of the gneiss. Other veins are perfectly straight and cut across the schistosity. At another locality southeast of the Friday Mine similar facts were observed. There the later veins, the straight ones, carry tourmaline, which is absent from the contorted veins. Sufficient time was not available for further inquiry. The observations suggest, however, that there are two ages of pegmatites, the first related to the quartz diorite intrusion, the second to that of the Rattlesnake granite.

The pegmatite occurs as large, irregular lenses, and dikes of all sizes cutting all the older rocks. It is especially abundant in certain portions of the Rattlesnake granite. In the schist it occurs in the forms mentioned above, and also impregnates the schist as a *lit par lit* injection, in the same manner as granitic material.

Petrography of the pegmatites.—A specimen of very coarse pegmatite from near the center of a large irregular mass exposed in the lower level of the Friday Mine is composed of quartz, abnormal orthoclase, microcline, albite-oligoclase, oligoclase, and black tourmaline.

A specimen from a six-inch vein in the large schist body on the lower level of the mine is made up of acidic andesine, labradorite, quartz, and tourmaline.

A suite of specimens was collected to illustrate the intrusion of gabbro by a narrow pegmatite dike at a locality in the end of the west branch of the north cross-cut, lower level of the Friday Mine. The basic rock near the pegmatite is a partially uralitized augite gabbro. Its plagioclase is labradorite, Ab_{35} An_{65}. The basic rock immediately adjacent to the pegmatite is composed of bytownite, green hornblende, and intrusive quartz. There is no augite whatever. The immediately adjacent pegmatite is composed of quartz and andesine feldspar, Ab_{65} An_{35}, while the pegmatite a short distance farther from the contact has the same constituents with the addition of a small amount of biotite and labradorite.

It is noteworthy that the feldspars of the pegmatite from the center of the large mass include considerable amounts of potash-bearing varieties, while the pegmatites of the narrow dikes have only soda-lime feldspars. This suggests that through material derived from the basic wall rocks a synthetic soda-lime pegmatite has been produced.

The tourmaline of the pegmatites examined has a pleochroism of deep steel blue and light blue-gray. The crystals are frequently fractured, the cracks being filled by feldspar and quartz. It is clear that the tourmaline was the first constituent to crystallize.

It is suggested that the alteration of the pyroxene of the gabbro to green hornblende has been brought about by material supplied during the intrusion of the pegmatite. Water was probably the chief, perhaps the only, chemical agent. It may be that the formation of the green hornblende in all the basic rocks dates from the intrusion of the pegmatites.

Aplite

A dike of aplite, varying from six to ten feet in thickness, intrudes the schist body southeast and east of Cuyamaca Reservoir. It is continuous for about two miles, its strike conforming essentially to that of the schist. Locally it is offset, for distances of a few inches to a few feet, and at one place it is offset for several hundred feet. These offsets do not appear to be the result of faulting later than the intrusion of the dike, but seem to result from the fact that the fracture which the dike filled was not continuous. Another aplite dike, with somewhat sinuous outcrop, cuts the quartz diorite gneiss one mile west-northwest of Julian.

A microscopic examination of a sample from the first mentioned dike proves it to be a soda aplite, composed of phenocrysts of albite, oligoclase, and quartz in a ground mass of quartz, plagioclase, sericite, and perhaps a little orthoclase. The quartz and feldspars are set together as a mosaic of mutually interfering grains. The feldspars show no tendency to elongation except to a slight degree in the phenocrysts.

Geologic Structure

The dominant agencies that have determined the structure of this region are (1) compression and (2) igneous intrusion. Bodies of schistose rocks lie within the great mass of quartz diorite in positions determined while the quartz diorite magma was still molten. Without doubt the sediments now represented by the schist series were folded prior to the development of the batholith. The quartzite layers of the schist series, if mapped in detail, would probably furnish the key to this folded structure.

Cutting across the fabric of the schist-quartz diorite complex are the two great igneous masses of the Cuyamaca and Rattlesnake intrusions and smaller masses related to the Cuyamaca Basic Intrusive.

The detailed mapping of this region has not shown the existence of any important faults. The "Preliminary geologic map of San Diego County, California,"[20] by A. J. Ellis, shows one major fault zone and two "lines of topographic expression which suggest the presence of faults" in the Cuyamaca region. The major fault runs along the southwest flank of Agua Tibia Mountain, determines the southwest boundary of the flat intermountain valley on the Valle de San José grant, determines a line of topographic depression through Banner Cañon, passes directly through Banner and thence southeastward. The physiographic evidence for this fault seems good. The writer has nothing to add from his study of the Cuyamaca region. In the area studied this supposed fault is entirely within granite.

There is good reason to doubt the existence of the other two faults indicated by Ellis. One of these is supposed to follow the courses of Green Valley and Chariot Cañon, leaving that cañon so as to pass three-quarters of a mile east of Banner, and continuing on to the north along the western edge of San Felipe Valley. While this fault may exist along the edge of San Felipe Valley, it is surely not present to the south for the reason that a prominent dike in the upper end of Green Valley crosses the supposed fault without offset. The physiographic features that probably led to the mapping of the third fault, in the region west of the Cuyamaca Mountains, can be explained as due to differential erosion.

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[20] U. S. G. S., Water Supply Paper 446, pl. 3.

Minor faulting, like that seen in the Friday Mine and described in the chapter on that mine, is probably widespread throughout the region.

THE FRIDAY MINE ORE BODY

The Friday Mine is situated immediately south of the road between Cuyamaca Reservoir and Julian, at a point four miles southeast of that town. It lies half a mile southwest of the divide between drainage to the Pacific Ocean and that to the Colorado Desert. The elevation at the mine is about 4700 feet above sea level. It is situated in an embayment of the main area of the Cuyamaca Basic Intrusive.

Discovery and Development

The original location of the Friday claim was made on an outcrop of gossan lying 55 feet northwest of the shaft now in use. The shaft there sunk was abandoned, apparently because ore was not found, and a new one started in gabbroic rock. At 50 feet depth it entered a body of schist which dips south at an angle of 75°. At 127 feet depth the lower side of the schist body was reached and a drift was run to the northeast along the contact of schist and basic intrusive rock. The drift entered sulphide ore at 50 feet from the shaft and was continued to the northeast, reaching the southwest or footwall side of the ore body at a point 85 feet from the shaft. From this point the footwall of the ore body was followed for 20 feet, and then a northwest crosscut was driven to the northern limit of ore, where a winze was sunk 16 feet on the contact. A working to the northeast from the junction of crosscut and main drift failed to find any ore. At a later date an incline was put down from the bottom of the shaft, along the schist body, to a point 45 feet measured vertically below the first level. Drifting along the footwall of the schist on this lower level failed to disclose any ore. After considerable blind work the downward continuation of the ore was found, as a thin wedge, almost immediately beneath the winze on the upper level.

General Geologic Description

The underground workings of the Friday Mine penetrate five distinct formations, the most abundant being the Cuyamaca Basic Intrusive, which here is predominantly a norite, but includes gabbro and peridotite facies. Included in the basic rock are several bodies of schist, which differ in no way from the typical rock of the Julian schist series. A body of massive sulphide ore lies, for the most part, entirely within the igneous rock, but on the upper level of the mine it is also in contact with the schist. Narrow dikes of fine-grained, hornblende-gabbro and hornblende-norite cut both the massive gabbroic rock and the sulphide ore body. Pegmatite occurs as large irregular bodies and dikes of various thicknesses, which cut not only the massive gabbroic rock but also the dikes of fine-grained basic rock.

The rocks of the mine.—The main body of schist is a tabular mass, striking northeast and dipping south at an angle of 75°. Along the upper level it has a fairly uniform thickness of 12 feet, but in the lower level its width varies from 1 to 12 feet. This rock differs in no way petrographically from the quartz-mica schist of the main Julian schist body, and is assigned to that formation. The contacts of the schist against the inclosing igneous rock are smooth planes along which a small amount of gouge is developed. That the schist body owes its present position essentially to faulting is, however, doubtful. Some movement along contacts is to be expected where two rocks of such dissimilar physical properties as schist and norite meet. The schist bodies are thought to be fragments torn from some larger body of the same rock by the basic intrusive magma.

The Cuyamaca Basic Intrusive is represented in the Friday Mine by norites, gabbros, olivine gabbros, olivine norites, brown-hornblende gabbros, peridotites, troctolites, and augite diorite. Norite is by far the most abundant of these types, making up at least one-half of the mass of basic rock exposed here. Peridotite and troctolite are quite rare, as is also augite diorite. With the exception of the augite diorite all the rocks carry pyrrhotite, the amount varying from a trace up to 3.0 per cent. Magnetite is rare. These rocks differ in no way from the basic rocks found elsewhere within the mass of the Cuyamaca basic intrusive.

The massive ore body.—The ore body is an irregular mass the greatest horizontal section of which probably lies between the two levels of the mine. On the upper level its greatest measurement is along a north-south line, a distance of forty feet. The width here varies from five to twenty-five feet. On the lower level the ore body is twelve feet long and only a few feet wide and wedges out before reaching the floor of the working.

The ore consists of sulphides, of which pyrrhotite and chalcopyrite may be distinguished with the unaided eye, together with various silicate minerals. Above the upper level the ore has been completely oxidized, the residue consisting of limonite and the silicate minerals of the gangue. In a zone along the contact between completely oxidized and partially oxidized ore, sulphates and arsenates of nickel and cobalt are present, including erythrite (hydrous cobalt arsenate, "cobalt bloom") and morenosite (hydrous nickel sulphate). Below the completely oxidized material on the upper level the sulphides have been decomposed along fracture planes and there is a slight amount of oxidation even in the ore of the lower level.

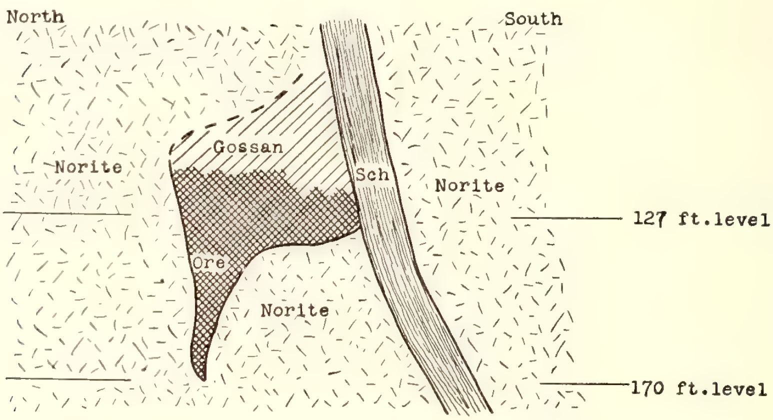

Fig. 2. Vertical section through the Friday Mine ore body.
Scale: 1 inch = 30 feet.

Basic dikes.—Narrow dikes of fine-grained hornblende gabbro and hornblende norite cut the massive gabbroic rocks at several localities. Near the bottom of the winze on the upper level one of these dikes cuts the sulphide ore. All the dikes show marked similarity among themselves, both in mineral composition and grain. They probably represent a late stage of the activity of the Cuyamaca Basic Intrusive magma. The fact that the ore is cut by a dike of this type is evidence of a close relationship between ore formation and magmatic processes.

Pegmatite.—A narrow dike of pegmatite cuts gabbroic rock 77 feet east of the shaft on the upper level. On the lower level the pegmatite is much more abundant. It occurs as narrow dikes cutting the basic igneous rocks at several places, and also as a large irregular mass, cutting both norite and schist, at a point near the junction of the east-west drift and the north cross-cut. At the latter place the pegmatite is particularly coarse, carrying feldspars several inches in diameter and tourmalines up to 6 inches in length. The pegmatite found particularly easy entrance along the contacts between the schist and basic intrusive and also along planes of schistosity within the schist. Much of the schist on the lower level is so saturated with pegmatitic material that it may be called injection gneiss.

Calkins has reported that the massive ore body "is cut by a thin dike of pegmatite containing conspicuous crystals of common black tourmaline."[21] The writer was unable to find the locality at which this phenomenon was observed, and believes that the ore has been stoped out there. However, pegmatite was seen cutting a dike of the fine-grained brown-hornblende norite. As these basic dikes are known to be younger than the ore, the later age of the pegmatite also is established, and Calkins' observation confirmed indirectly.

The boundaries of the ore.—With the exception of one boundary plane exposed on the upper level where the ore body is in contact with schist, the sulphide body is completely inclosed in the rocks of the basic intrusive mass. The shape of the ore body (see fig. 2) indicates that the contact between ore and schist is a fault. This contact is a smooth plane along which a small amount of limonite-stained gouge has been developed. Most of the contacts between ore and gabbroic rock are sheared, but a portion of the southern boundary plane, exposed in the upper level of the mine, is not affected by shearing and shows a gradation between coarsely crystalline pyrrhotite, carrying relatively small amounts of silicate minerals, and norite, carrying disseminated particles of sulphides which differ in no way from the sulphides found in the basic rocks in other parts of the Cuyamaca region.

MINERALS OF THE MASSIVE ORE

Pyrrhotite.—This is the predominant mineral of the ore body. It occurs in individuals without crystal outline, but with well developed parting planes. The extent of these planes shows that the pyrrhotite is coarsely crystalline, some individuals being over one and a half inches in diameter; but the average is less than one-half inch. The parting planes show a dull gray color, but fresh surfaces obtained by breaking the mineral across the parting have a conchoidal fracture and a metallic white to bronze color. In polished surfaces of the ore the pyrrhotite is readily determined from its prominent basal parting, as shown in plate 10, figures 5 and 6, and plate 11B, figure 1, and its pinkish color.

Magnetite.—Euhedral octahedrons of magnetite are found imbedded in the pyrrhotite.

Chalcopyrite.—Grains of chalcopyrite up to one-eighth inch in diameter may be seen. It also occurs in smaller grains and minute veinlike masses. On polished surfaces chalcopyrite is identified by its brilliant luster, freedom from cracks and cleavages, and its characteristic yellow color.

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[21] Calkins, F. C., U. S. Geol. Surv., Bull. 640, 1916, p. 81.

Polydymite.—The nickel-bearing mineral of the massive ore can be seen only on polished surfaces. It is white in color, takes a fair polish, and is 5.0 to 5.5 in hardness. This mineral has good cleavages in three directions, which have been interpreted as cubic. See plate 10, figures 5 and 6.

Following are the results of michochemical tests of this mineral:

HNO_3 dilute—slight, dull brown stain, rubs to clean smooth surface.

HNO_3 conc.—strong effervescence, dark brown stain. Rubs to gray roughened surface.

HCl, both dilute and concentrated—acid turns yellow.

Aq Reg.—strong effervescence, light brown stain, rubs clean. Acid turns green.

$FeCl_3$—no effect.

NH_4OH—no effect.

KCN—slight brown stain, rubs clean.

This mineral does not correspond exactly in its chemical reactions to any of the minerals listed in Murdoch's tables.[22] Chloanthite, gersdorfite, and polydymite are suggested by the determinative tables, the description of gersdorfite perhaps corresponding closest to the Friday Mine mineral. However, blowpipe analysis of isolated fragments of the pure mineral and also of the whole ore show no trace of arsenic, giving strong tests for nickel and sulphur, with no cobalt.

It is concluded that this mineral is either polydymite or a closely allied and hitherto undescribed species.

Brown Hornblende.—This mineral, differing in no way in optical properties from that found in the gabbros and norites, is to be found in samples of the least altered ore. It occurs in euhedral and subhedral forms, inclosed within single pyrrhotite crystals or in the spaces at the meeting point of several crystals. The brown hornblende of the ore has a much greater tendency toward euhedral outline than does that of the norites and gabbros. This is well shown in plate 10, figures 3 and 4.

Compact Green Hornblende.—This mineral is much like the brown variety in its mode of occurrence. It is pleochroic in green and blue-green colors.

Augite.—A small amount of colorless pyroxene with positive sign was identified in the ore from the lower mine level. Some of the more altered ore from the upper level shows under the microscope six and eight sided masses composed of granular calcite. These are thought to be pseudomorphs of the carbonate after augite.

Chlorite.—Green clinochlore occurs in greater or lesser amount in all the ore. It is found replacing the hornblende and also as minute veinlets traversing both the silicates and ore minerals. Plate 10, figure 3 illustrates the partial replacement of brown hornblende by chlorite.

An inspection of thin sections and polished surfaces leaves no doubt that the chlorite in both its modes of occurrence was introduced at a distinctly later time than that of the formation of the sulphides and hornblende. In the completely oxidized gossan the chlorite is found in hexagonal tablets with good crystalline outline. These may attain a diameter of one-half inch. In the partially oxidized ore chlorite occurs in a similar way, but in the fresh ore it is found only in small individuals replacing the hornblende and in the minute veinlets cutting the ore minerals. This evidence suggests that the chloritic type of

[22] Murdoch, Joseph, Microscopical determination of the opaque minerals (New York, 1916).

alteration was effected by meteoric waters and that the place favorable for the growth of chlorite was in the sulphide ore not far beneath the oxidized zone.

Actinolite.—The partially oxidized ore contains a considerable amount of a fibrous, green amphibole. Its optical properties are: $c \wedge \mathfrak{c} = 19°$, optical sign, negative. $\alpha = 1.62+$, $\beta = 1.630$, $\gamma = 1.647$. Colorless in thin section. This is probably actinolite, though its indices of refraction are higher than those listed in the tables. It is closely associated with the chlorite, flakes of the latter mineral being inclosed in the amphibole. In the completely oxidized ore the actinolite is white and dull, probably the result of leaching. It is thought that the actinolite is a secondary mineral formed by the same agencies as was the chlorite, since it increases in amount as the degree of oxidation increases, and is known to form at the expense of brown hornblende. (See pl. 10, fig. 3.)

Calcite.—White carbonate, identified as calcite, occurs as minute veinlets traversing both sulphides and silicates. The relation of the calcite to the hornblende in some specimens suggests that it may replace that mineral (see fig. 18) and certain masses of granular calcite are interpreted as complete replacements of amphiboles and augite by the carbonate.

Interrelations of Minerals

If the calcite masses which show six and eight sided sections are correctly interpreted as pseudomorphs after augite, it follows that the augite possessed idiomorphic outlines. The compact green hornblende generally occurs in stout prisms with rounded terminations. It approaches closer to euhedral form than does the amphibole of the norites and gabbros. The brown hornblende is found sometimes in even more perfect crystals. In general it may be said that the primary silicates usually have several of their bounding planes determined by crystallographic faces, the other bounding planes being smooth curves. There is little tendency for the hornblendes to be penetrated along their cleavages by the sulphides.

The sulphides make up from 75 to 90 per cent of the ore. As pyrrhotite is the prevalent sulphide, it may be said that this mineral determines the texture of the ore. It occurs in grains ranging from a few millimeters to several centimeters in diameter. In either the polished surface or the hand specimen the grains may be distinguished one from the other by the diverse orientation of the basal partings in the different grains. The boundaries are never crystallographic planes, but are made up of smooth curves, much like the boundaries between the silicate minerals of the gabbros and the norites. The texture of the ore further resembles that of the gabbros and norites in that the grains of pyrrhotite are on the whole equant.

Chalcopyrite is found in general as small irregular masses occupying the space where several large grains of pyrrhotite meet. Its contacts against the pyrrhotite are smooth, clean-cut curves. It sometimes occurs in somewhat elongated masses, which might be interpreted as *veins,* but the chalcopyrite shows no tendency to follow the parting of the pyrrhotite; and the highest magnification fails to show communicating channels between adjacent chalcopyrite masses.

The polydymite (?) is frequently intimately associated with the chalcopyrite and has much the same textural relations to the pyrrhotite as has the chalcopyrite. It is found in equant grains with rounded outlines and as irregular masses which may send off several branching apophyses between the adjacent pyrrhotite grains. These apophyses terminate as blunt wedges. They do not in all cases confine themselves to the space between two pyrrhotite grains, but extend into single individuals of pyrrhotite, in no case, however, showing any tendency to follow the parting planes. In one case the parting planes were seen to curve on approaching one of the apophyses of polydymite (?).

The examination of numerous polished surfaces failed to show a single case where either polydymite (?) or chalcopyrite occurred without pyrrhotite. Furthermore, masses of the nickel or copper mineral, that might be interpreted as veins cutting the pyrrhotite, stop abruptly on reaching the bounding planes between silicates and sulphides. This relation is shown in plate 11, figure 1. In some instances it appears as though the chalcopyrite had been mobile after the polydymite had ceased to form. In other instances the reverse relation is shown. It is probable that the copper and nickel minerals were formed at very nearly the same time. Both chalcopyrite and polydymite (?) were apparently mobile after the solidification of the pyrrhotite.

The Disseminated Sulphides of the Cuyamaca Basic Intrusion

A study of thin sections showed that the pyrrhotite occurs in two ways, (1) as irregular grains occupying the space where several silicate individuals meet, (2) as grains with simple oval or circular section, entirely inclosed in single silicate crystals (pl. 11, fig. 2). The most irregularly bounded grains of pyrrhotite are no more complex in their outline than are many augite and brown hornblende grains. While in some of the rocks examined the pyrrhotite occurs for the most part in association with the ferromagnesian minerals, yet in none of the rocks is it restricted to this position and in many of them the pyrrhotite shows no preference for any one silicate species.

A study of polished surfaces of norites and gabbros has modified only slightly the ideas as to textural relationships gained from the study of thin sections, excepting that it was found that the pyrrhotite occasionally occurs in veinlike masses, as illustrated in plate 11, figures 3 and 4. As such minute veinlets of sulphide were found at only two places in the nine polished surfaces studied, this phenomenon must be considered exceptional. The typical textural relations of ores to silicates in the basic rocks are shown by plate 11, figures 5 and 6, and plate 12, figures 1–5.

Pyrrhotite is readily identified in hand specimens of the rocks by its white to bronzy color, high metallic luster, and conchoidal fracture. In the polished surfaces it appears white to pinkish and the traces of parting planes permit it to be readily distinguished from the other sulphides.

Chalcopyrite sometimes occurs in large enough masses to be made out by the hand lens, but the greater amount is found in such minute individuals that the examination of polished surfaces with the microscope is necessary to differentiate it from the pyrrhotite in which it is invariably imbedded.

A white mineral, with hardness intermediate between pyrrhotite and chalcopyrite, is found in many of the rocks. It takes a high polish, shows no cleavage or crystal outlines. Michrochemical tests made of this mineral are as follows:

HNO_3 dilute—rich yellow-brown stain, no effervescence. Rubs off readily to untarnished surface.

HNO_3 conc.—similar action, but slight brownish stain persists after considerable rubbing.

HCl, both dilute and conc.—no effect.

Aq Reg.—no effect.

Samples of pentlandite from Sudbury gave similar reactions, but differ from the Cuyamaca mineral in having a yellow color in comparison with pyrrhotite. Enough material for blowpipe analysis or quantitative tests could not be isolated, but the evidence given above seems enough to justify the conclusion that the mineral is either pentlandite or else some very closely allied species.

Relationships between the sulphide minerals.—The pentlandite and chalcopyrite never occur except as portions of a compound grain with pyrrhotite. No matter what the shape of the pentlandite or chalcopyrite grain imbedded in the pyrrhotite may be, the exterior boundary of the whole sulphide mass is always made up of smooth curves, differing in no way from the boundaries of pyrrhotite grains that carry no nickel or copper. The chalcopyrite and pentlandite generally occur in one of three ways: (1) as grains, whose contacts against the pyrrhotite are irregular, sometimes serrated, curves; (2) as regular forms which show on the polished surfaces as lath sections with blunt ends; or (3) as forms which show as narrow wedges on the polished surfaces. The last two may be expressions of essentially the same form.

There are no veins of pentlandite or chalcopyrite in the pyrrhotite and there is no relation whatever of the nickel and copper minerals to the parting planes of the pyrrhotite. The pentlandite and chalcopyrite often occur together and then may form a compound grain with a common exterior boundary against the pyrrhotite, similar to the boundary of a compound grain of the three sulphides against the silicates. Almost invariably the nickel and copper minerals are found at the edge of pyrrhotite grains. An exception to the rule are minute tufts of pentlandite which were found in one specimen along a veinlet of calcite within the pyrrhotite. As the calcite is known to be secondary, these tufts are thought to be secondary pentlandite.

As a further proof that the nickel mineral occurs only in pyrrhotite the results of a series of qualitative tests for nickel with dimethylglyoxime may be cited. Three basic rocks that were known to contain no pyrrhotite did not carry enough nickel to give the faintest reaction with this delicate test. On the other hand, some of the pyrrhotite-bearing rocks, including three from the immediate vicinity of the ore body, do not carry nickel, showing that some of the pyrrhotite is not nickeliferous.

Relation of sulphides to rock alteration.—Chlorite is of rare occurrence, but in those few specimens in which it was identified it is clearly of later age than the ore minerals. Secondary green hornblende is much more common than chlorite. The textural relations show that to a large extent at least it also is later than the sulphides. As further evidence of this the following statistics may be cited:

Of 9 gabbros with green hornblende, 6 carry pyrrhotite, 3 have no pyrrhotite. Of 16 gabbros, both with and without green hornblende, including the 9 rocks above, 11 carry pyrrhotite, 5 have no pyrrhotite. The ratio of gabbros carrying sulphides to those without sulphides is the same for all gabbros as for those carrying green hornblende. Furthermore, none of the gabbros and norites with over 1 per cent sulphide was found to contain any green hornblende.

Relation of sulphides to total composition of rocks.—All of the rocks of the Cuyamaca Basic Intrusion carry either magnetite or pyrrhotite. Some of the rocks carry both ore minerals; but in general it may be said that a rock with considerable pyrrhotite will have little or no magnetite, and those rocks with considerable magnetite will have little or no pyrrhotite. There thus seems to be some kind of a reciprocal relationship between the two minerals. The most basic rocks are those in which the disseminated sulphides are most likely to be found. As most of these basic rocks carry either augite or hypersthene, it might be thought that the presence of these pyroxenes favored

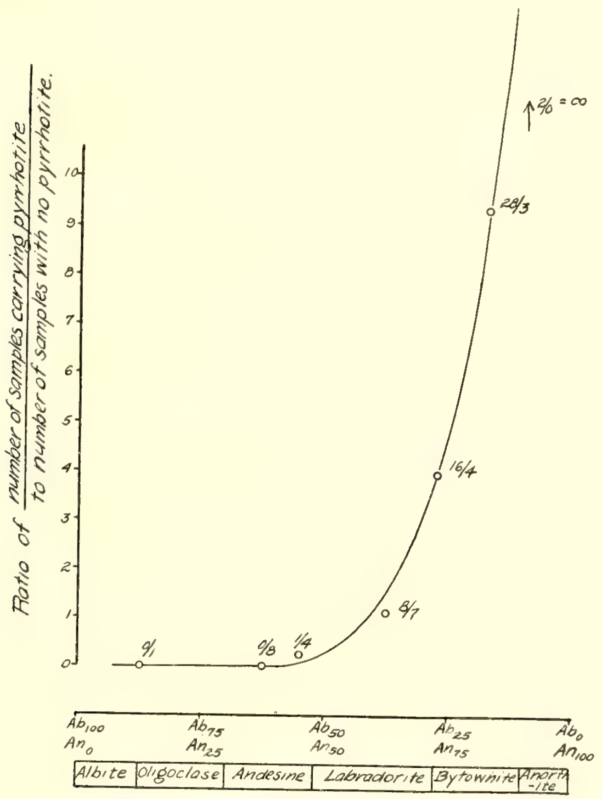

Fig. 3. Graph showing relationship between (1) the chances of finding pyrrhotite in the various rocks of the Cuyamaca Basic Intrusion, and (2) the kind of plagioclase characterizing the various rocks.

the development of the sulphides. This, however, is not the case, as none of the hypersthene diorites or augite diorites carries any pyrrhotite. The kind of plagioclase is the determining factor for the presence or absence of pyrrhotite. The more basic the plagioclase the more likely is the rock to carry pyrrhotite. As the feldspar generally makes up well over half the rock, it may be said that the presence of pyrrhotite is conditioned by the total composition of the rock. Figure 3 is a curve representing the chances of finding pyrrhotite in the gabbros, norites, diorites, etc., that are characterized by the different feldspars of the soda-lime series. It is plotted from the results of study of 82 specimens that are thought to represent fairly well the total composition of the Cuyamaca Basic Intrusive mass. Dike rocks are excluded.

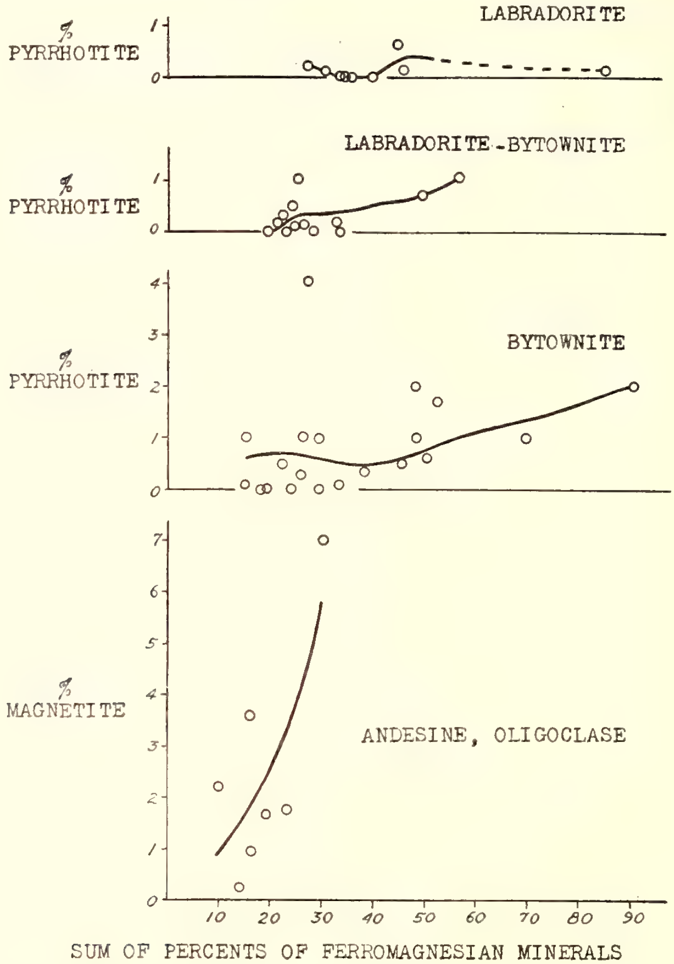

Fig. 4. Graphs showing the relation existing between the amount of ore minerals and the amount of ferro-magnesian minerals, in rocks of the Cuyamaca Basic Intrusion characterized by four different plagioclase feldspars.

Within each set of rocks characterized by a single type of plagioclase there is a rough direct relationship between the amount of ore minerals and the sum of the amounts of the ferromagnesian silicates. Figure 4 shows this relationship. The sum of the ferromagnesian minerals for each rock was obtained by the addition of the products of the percentage of each mineral by an appropriate factor, the factors being chosen to bring the percentage of each mineral to the same proportion with respect to (MgO, FeO)SiO_2. The factors are: olivine, 1.4; hypersthene, 1.0; augite, 0.5; green hornblende, 0.5; brown hornblende, 0.66. The curves for the labradorite-bytownite and bytownite rocks show a direct proportion between the amount of sulphide and the sum of the amounts of ferromagnesian minerals. The curve for

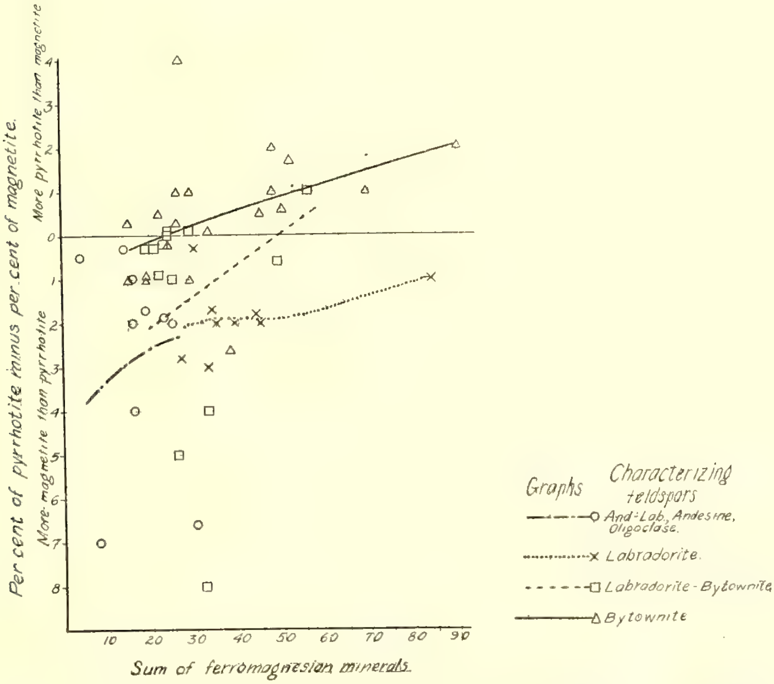

Fig. 5. The four curves represent the relations between the ores and the ferromagnesian silicates for four different groups of the basic intrusive rocks, characterized by four different plagioclase feldspars. The sum of the ferromagnesian minerals for each rock was obtained by addition of the products of the percentage of each mineral in the rock by an appropriate factor. These factors were used so as to make the various sums proportioned with respect to (MgO, FeO)SiO_2. These factors are: olivine, 1.4; hypersthene, 1.0; augite, 0.5; green hornblende, 0.5; brown hornblende, 0.66.

the labradorite rocks is without character and proves nothing. The curve for the soda-rich plagioclase rocks suggests a relationship between the amount of magnetite and that of the ferromagnesian minerals, but not enough samples of these rocks were examined to make this a good case.

The recognition of a reciprocal relationship between the amount of pyrrhotite and the amount of magnetite in the basic rocks has led to the idea of plotting the quotient of magnetite by pyrrhotite against various figures representative of the composition of the silicate portions of the rocks. The graphs obtained were extremely irregular and seemed to condemn the theory. Later it was discovered that by plotting the difference between the percentages of pyrrhotite and magnetite against the sum of the ferromagnesian minerals irregular graphs could be obtained, which when ''averaged'' became smooth curves. These curves (fig. 5) show that the difference between the amount of sulphides and that of magnetite, in rocks characterized by any particular plagioclase, stands in direct ratio with the sum of the per cents of the ferromagnesian minerals.

The origin of the disseminated sulphides.—From the standpoint of the textural relations of the three sulphides, considered as a unit, toward the silicate minerals which inclose them, it is almost inconceivable that the pyrrhotite, with its attendant nickel and copper minerals, could have been introduced into the rocks after the consolidation of the silicates. The reasons for this conclusion are: (1) lack of veins; (2) sulphides do not occur along cleavages of silicates; (3) contrast between the simple spherical or ovoid grains inclosed in single silicate crystals and the irregular grains with ramifying apophyses that occur at the meeting place of several silicate crystals; (4) irregular grains are no more complex in outline than many of the brown hornblende and augite individuals; (5) the sulphides do not replace the silicates. This is shown by (*a*) textural relations, (*b*) lack of preference for association of sulphides with any one silicate or group of silicates, and (*c*) the occurrence of sulphides bears no relationship to rock alteration.

With the exception of the minute tufts of pentlandite which were found along calcite veinlets within the pyrrhotite, the pentlandite and chalcopyrite could not have been introduced from without after the solidification of the pyrrhotite. This is shown by: (1) the absence of veins of pentlandite or chalcopyrite in either silicates or pyrrhotite; (2) the independence of particles of pentlandite or chalcopyrite of the parting planes of the pyrrhotite; (3) occurrence of nickel or copper mineral only as a part of a compound grain with pyrrhotite.

Conclusions.—The sulphide minerals are essential constituents of the igneous rocks in which they are found. The lack of crystalline outlines on the part of the pyrrhotite and the ramifying apophyses of the more irregular individuals show that the sulphide was the last constituent of the rock to solidify. The simple, round forms of those pyrrhotite grains that are inclosed in single crystals of silicates are also taken as proof that the sulphides existed as drops of liquid during the crystallization of the silicates which now inclose them.

There is a lack of evidence as to the relative time of formation of the three sulphides. They perhaps solidified simultaneously in their present form, or, what is more likely, by analogy with certain metallurgical products,[23] we may conceive of the sulphides solidifying as a homogeneous matte, which later became unstable, due to decrease of temperature, pressure, or both, and broke down to the mixture of three minerals as we now see them.

Relation of the Massive Ore Body to the Enclosing Rocks

The average composition of the Cuyamaca Basic Intrusion, leaving out of account the rocks of the Friday Mine, is approximately that of a gabbro-norite, whose plagioclase is a labradorite, carrying 38 per cent albite molecule. If, further, the diorites are eliminated from the calculation, for the reason that they may represent later intrusions and not differentiates in place, the approximate average composition of the mass is that of a gabbro-norite with a labradorite-bytownite (29 per cent albite molecule) as its feldspar. The average rock of the Friday Mine is an olivine norite, whose feldspar is bytownite (24 per cent albite molecule). It is evident, then, that the rocks adjacent to the massive ore body are more basic than is the average of the rocks from other portions of the intrusive mass.

Of eighteen basic rocks collected from the Friday Mine workings, only one, an augite diorite, lacks pyrrhotite. More than one-third of the rocks from other localities, excepting the rocks of the two diorite areas, carry no sulphide. Furthermore, the average sulphide content of the rocks of the Friday Mine, excepting those in immediate proximity to the ore body, is 1.1 per cent, while the average for the basic rocks from other localities, leaving out of account those which carry no pyrrhotite whatever, is only 0.7 per cent. It is seen, then, that with the increase in basicity of the igneous rocks in the vicinity of the ore body there is also an increase in sulphide content.

The relations set forth above would lead one to expect gradational contacts between the massive ore and the norite. As has been noted before, the greater part of this contact is determined by slip planes; but at one point an unslipped contact is preserved. Here the transition from norite, carrying a few per cent of sulphides, to ore carrying over 50 per cent of sulphides takes place within a distance of less than one centimeter.

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[23] See pp. 240–241.

It is easy to understand how such a narrow transition zone could be erased by slight slipping, and the conclusion, based on lack of gouge, that the bounding slip planes of the ore body were the result of only minor movement, is confirmed.

Detailed description of gradational contact.—The following observations are based on the examination of a suite of thin sections of the different stages of the transition zone, and of a polished surface cut so as to show several centimeters on either side of the contact.

The norite from 1.5 to 2.0 cm. from the contact is an olivine norite with hypersthene, monoclinic pyroxene, and brown hornblende. The plagioclase is labradorite-bytownite. Some spinel and pyrrhotite, pentlandite, and chalcopyrite are present.

The rock at 0.5 to 1.5 cm. from contact is similar to the above except that the feldspar is anorthite. Sulphides occur in considerable amount, probably 5 per cent of the whole mass. The textural relations of the pyrrhotite to the silicates is no different from those seen in all norites. Rounded grains of pyrrhotite within fresh hypersthene crystals are particularly abundant. On approaching closer to the contact the spinel and sulphides increase in amount. The brown-hornblende also becomes more abundant while the hypersthene seems to remain constant in amount and the feldspar decreases. A few millimeters from the contact a large angular mass of pyrrhotite, containing chalcopyrite and polydymite (?), was noted within fresh silicates. The actual contact is an extremely irregular surface along which the ore and norite penetrate one another for distances up to 1 cm. from a median plane. The ore adjacent to the contact consists of pyrrhotite, polydymite (?), and chalcopyrite with bluish-green hornblende in somewhat rounded prisms and confused aggregates of actinolite. A small amount of calcite is found in minute veinlets and in pseudomorphs after primary minerals. Two minute rounded masses of a bright yellow substance, identified as serpentine, were found in one of the thin sections.

The ore adjacent to the norite is no different from that found in other portions of the ore body, with one exception. There is a yellowish material of high metallic luster that bears the same textural relations to both silicates and polydymite (?) and chalcopyrite as does the pyrrhotite. It shows a peculiar concentric banding which seems related to tiny veinlets of calcite which penetrate the ore. Microchemical tests did not establish the identity of this material, except to show the presence of irregular patches of pyrrhotite within its mass. The tests, however, are suggestive of marcasite and the material is probably then a partial replacement of pyrrhotite by that mineral.

Origin of the Massive Ore

The close genetic relationship of the massive ore body to the norite is shown by the following facts:

(1) The primary gangue minerals of the ore are ferromagnesian silicates commonly found in the norite.

(2) The ore minerals of the massive ore body are the same as those found as disseminated particles in the norite, save that polydymite (?) occurs in place of pentlandite.

(3) The ore was formed before the cessation of activity of the basic magma. This is shown by the fact that dikes of pyrrhotite-bearing, hornblende norite, cut not only the massive norite but also the ore body. The rock of these dikes is no different from the ordinary norite save that it is finer grained.

That the ore was not introduced from without after the solidification of the rocks which now inclose it is shown by (1) lack of either large or small scale veins of sulphides in the norite, (2) gradational contact between ore body and norite, (3) lack of replacement of the silicate by ore minerals.

The massive ore body is thought to have accumulated as an ultra basic differentiate of the norite magma, before or during the consolidation of the norite which now forms its walls, for the following reasons:

(1) The molten norite was a competent source, as the norite now carries disseminated sulphides which were normal constituents of the magma.

(2) The rock surrounding the ore body is more basic as regards its silicate constitution than is the whole mass of the Cuyamaca Basic Intrusion, and its content of sulphides is greater than is that of the whole mass. If differentiation from a gabbro-norite with labradorite-bytownite feldspar, and 0.7 per cent sulphides, to an olivine norite, with bytownite feldspar and 1.1 per cent sulphides, can take place, there is every reason to suppose that further action could produce a rock made up of pyrrhotite, nickel and copper sulphides, hornblende, and augite.

It was shown, in the case of the disseminated ore particles in norite, that the sulphides were probably still in liquid condition after the solidification of the silicate minerals. It is probable that this condition also obtained in the massive ore. While the polydymite (?) and chalcopyrite of the ore body show some tendency to occur in vein-like forms, such veins are not nearly so well marked as are those in nickeliferous pyrrhotite from other districts. The occurrence of these veins has been used by several investigators as proof that the nickel and copper minerals were introduced from without after the solidification of the pyrrhotite. That such is not the case in the Friday Mine deposit is shown by the following observations:

(1) The polydymite (?) and chalcopyrite are found only in pyrrhotite. When a "vein" of one of the former minerals reaches a silicate mineral it stops abruptly. This is well shown in plate 9, figure 3.

(2) Certain rocks immediately adjacent to the ore body carry no trace of nickel, although they do carry considerable pyrrhotite. A dike of hornblende norite that cuts the ore body carries nearly 1 per cent of pyrrhotite, but shows not a trace of nickel with the most delicate tests.

THEORIES OF ORIGIN OF NICKELIFEROUS PYRRHOTITE

Deposits of nickeliferous pyrrhotite occurring in intimate association with basic igneous rocks are of world-wide distribution. The marked similarity both mineralogical and geological between the different deposits suggests that all have been formed by essentially similar processes.

The geologic literature descriptive of these deposits is voluminous and the theories advanced as to their origin are varied. The writer will not attempt to summarize the literature on this subject, as excellent summaries have already appeared in the works of Tolman and Rogers[24] and of the Royal Ontario Nickel Commission.[25] A brief statement will be made, however, of the various theories advanced for the origin of these ores.

Since 1891 a controversy has been waged as to whether the nickeliferous pyrrhotite deposits are of a magmatic or non-magmatic origin. Up to a recent date the term *magmatic* has been applied to those deposits in which the ore minerals are conceived to have been essential constituents of the igneous magmas which consolidated to form the country rock of the deposits, the segregation of the ore minerals, into masses more or less free from silicate minerals, taking place before

[24] Tolman, C. F., Jr., and Rogers, A. F., A study of the magmatic sulfid ores, Leland Stanford Junior University Publications, 1916, pp. 23–55.

[25] Royal Ontario Nickel Commission, Toronto, Report, 1917, pp. 95–286.

or during the solidification of the magma. The proponents of the non-magmatic theories conceive of the introduction of the sulphide minerals into the igneous rock, after its consolidation, by either hydrothermal or contact metamorphic processes.

Tolman and Rogers in their recent paper conclude that the ore minerals were introduced by mineralizers during a "late magmatic stage," and replace the previously formed silicate minerals. They apply the term magmatic to this process. Following their complete theory we must admit that the mineralizers, which they believe effected the replacement of silicates by sulphides, would be magmatic in ultimate origin. Their application of the term magmatic seems unfortunate, however, as the rocks in which the deposits occur were, according to their conception, solid rocks and not magmas at the time the ores were introduced.

In order to avoid confusion the terms syngenetic and epigenetic will be used here. *Syngenetic* implies that the materials of the ore bodies were essential constituents of the magma before its consolidation and that the ore bodies were formed from material derived from the adjacent magma before or during its consolidation. *Epigenetic* implies that the ore minerals were introduced after the consolidation of the igneous rocks. The magmatic theories of most authors postulate a syngenetic origin of the ore bodies.

Theories of Syngenetic Origin

In 1890 Dr. Robert Bell announced, as a result of his study of the Sudbury deposits, that the ores were syngenetic with the inclosing igneous rocks. The following is quoted from his paper:

> The ore bodies . . . . do not appear to have accumulated like ordinary metalliferous veins from mineral matter in aqueous solution, but to have resulted from igneous fusion. The fact that they are always associated with diorite, which has been left in its present positions in a molten state, points in this direction. As the diorite and the sulphides fuse at about the same temperature, they would naturally accompany each other when in the fluid condition.[26] The bodies of molten diorite and the sulphides, being large, would remain fluid for a sufficient time to allow the diffused sulphuretted metals to gather themselves together at certain centers by their mutual attractions and by concretionary action. In the case of great irrupted masses of diorite, the bodies of ore which had formed near enough to the solid walls cooled and lodged with a mixture of the broken wall rocks where we now find them, while larger quantities, remaining fluid, probably sank slowly back through the liquid diorite to unknown depths. . . . .[27]

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[26] The diorite and part of the greenstone of the earlier investigators of the Sudbury district are norites. (F. S. H.)

[27] Bell, Robert, Bull. Geol. Soc. Am., vol. 2 (1891), p. 135.

In a later paper[28] Bell states that the ores have possibly been modified by aqueous solution.

Barlow at about the same time published an almost identical theory. He recognized three modes of occurrence for the sulphides. These are: (1) at contacts of diabase and gabbro against other rocks; (2) impregnations throughout the diabase and gabbro; (3) in veins subsequent to (1) and (2). The disseminated sulphides, while common in the basic igneous rocks, are absent from the clastic wall rocks at any great distance from the diabase and gabbro, and the sulphide-bearing veins are said to be rare.[29]

Von Foullon published an account of the Sudbury deposits in 1892. His theory of origin[30] is in no way different from that of Bell and Barlow.

In the following year Vogt published his work on the "Formation of ore deposits through differentiation processes in basic irruptive magmas."[31] He discusses not only the nickeliferous pyrrhotite deposits but also those of titaniferous magnetite, magnetite, ilmenite, chromite, etc. Vogt concluded that the nickeliferous pyrrhotite deposits are border facies of the accompanying igneous rocks and that their position at the borders of the irruptive masses is due to the fact that the sulphides as a liquid differentiate have been concentrated against the cooling surfaces, following Soret's principle.[32] The following is a summary of the observations which led to his conclusions:

(1) The numerous deposits of nickeliferous pyrrhotite, in basic irruptive rocks, are of world-wide distribution. They form both mineralogically and geologically a sharply bounded "world group" whose mineralogy is so simple and monotonous that we may discuss in common the collected occurrences of the whole world.[33]

(2) From the constant relation of the nickeliferous pyrrhotite deposits to basic irruptive rocks, it follows that they stand genetically in a regular relationship to the rock in question.[34]

(3) The nickeliferous pyrrhotite deposits are often united to the irruptive rocks by gradational, petrographic transitions, to such a degree that one may draw the conclusion that the sulphide masses are not later penetrations into the irruptive rock, but that they were already present during the solidification of the rocks.[35]

(4) The norite magmas with which the ores are associated generally show a wholly extraordinary inclination to often very considerable splitting or dif-

[28] Bell, Geol. Surv. Can., Ann. Report, 1890–91, pt. F, p. 50.

[29] Barlow, A. E., Geol. Surv. Can., Ann. Rept., 1890–91, pt. S, p. 122.

[30] Foullon, H. B. von, Jahrb. d. k. k. R. A., XLIII (1892), p. 223.

[31] Vogt, J. H. L., Zeit. f. prakt. Geol., vol. 1, 1893.

[32] *Ibid.*, p. 265, pp. 271–283.

[33] *Ibid.*, p. 126. [34] *Ibid.*, p. 262. [35] *Ibid.*, p. 262.

ferentiation processes. In most cases one finds even in rather small masses a whole series of different varieties, often of rather dissimilar chemical composition.[36]

(5) There is not a mathematic proportionality between the size of the gabbro fields and the amount of ore contained in them. However, it may be said that the ore masses in very small gabbro fields are always rather unimportant, and that the larger ore concentrations are all in the larger gabbro fields. . . . In gabbro fields of less than 1000 square meters area the ore bodies appear to be unimportant. With an area of 3000 square meters, however, the sulphide deposits are sufficient for work on a small scale. In gabbro fields of 50,000 to 200,000 square meters, that is, 0.05 to 0.2 square kilometers, we find many of the larger sulphide segregations of the Scandinavian peninsula. Finally the gabbro fields measurable in miles are only exceptionally wont to carry sulphide segregations.[37]

(6) The gabbros of southern Norway, leaving out of account the anorthosite and the saussurite gabbro, may be divided in two great petrographic groups: (1) olivine hyperite (olivine + diallage + plagioclase, with ophitic texture); (2) norite (rhombic pyroxene + plagioclase, with eugranitic-granular texture) with ''gabbro-diorite,'' which in general is thought to be uralitized norite. The olivine hyperite has here and there ''oxide'' segregations of ilmenite-enstatite. Further, there are apatite-rutile dikes, formed by ''irruptive after effects.'' The norite, however, is the mother rock of the most important sulphide segregations of nickeliferous pyrrhotite.[38]

(7) In most gabbro areas we observe normal pegmatitic granite dikes. Also dikes of pegmatitic, granite-like rock, carrying characteristic nickeliferous pyrrhotite. . . . . The latter type of dike, the so-called oligoclase-granite dike, contains at Romsaas, according to Meinich, nickeliferous pyrrhotite, chalcopyrite, hematite, tourmaline, garnet, biotite, oligoclase, and quartz. The nickel and copper content are high enough so that the dike has been mined. In a similar dike at Erteli the ores and ferromagnesian minerals are concentrated on the borders of the dike, while the later crystallized plagioclase and quartz are in the center. . . . . From the characteristic content of copper and nickel one may say with certainty that these dikes originated from splitting processes, in a similar way to the nickeliferous pyrrhotite concentrations.[39]

(8) There is a regular relationship between the absolute nickel content of the pyrrhotite on the one hand and the proportion of nickel to copper on the other. The higher the nickel in the pyrrhotite the lower the copper in proportion to the nickel.[40]

(9) In the segregations of magnetite and ilmenite not only the titanium iron oxides but also the ferromagnesian silicates are concentrated. Generally there is no corresponding phenomenon in the sulphide deposits, the ratio between ferromagnesian silicates and plagioclase being as a rule the same both in the pyrrhotite-norites and gabbros as in the normal, sulphide-free rocks.[41]

Other observations made by Vogt having more or less bearing on his conclusion are:

(1) In the pyrrhotite-norites and pyrrhotite-gabbros the pyrrhotite always reaches a solid condition at the end, after the individualization of the ferromagnesian silicates and the feldspars. It follows from this that the rhombic

[36] *Ibid.*, p. 134.
[37] *Ibid.*, p. 141.
[38] *Ibid.*, p. 132.
[39] *Ibid.*, p. 135.
[40] *Ibid.*, pp. 129 and 264.
[41] *Ibid.*, p. 138.

and monoclinic pyroxenes, the olivine, mica, etc., and also the plagioclase lie with idiomorphic contour within the pyrrhotite. They show, however, somewhat rounded edges and angles. . . . . That the pyrrhotite was in fluid condition after the solidification of the silicate minerals is shown by the occasional fine veins of pyrrhotite that bend and split them.[42] Garnet zones were observed at contacts of pyrrhotite and plagioclase.[43]

(2) Oftentimes fine ore veins or again thick ore dikes shoot off from the sulphide mass either into the gabbro or schist. Also we find corresponding veins, schlieren and dikes, in part of pyrrhotite-norite with varying sulphide content, in part of pure sulphide, within the gabbro massif, or more often in the peripheral part. These occur without relation to any observed regular ore concentration.[44]

(3) The copper always separates as chalcopyrite ($CuFeS_2$). It never forms bornite (Cu_3FeS_3) or chalcocite (Cu_2S), apparently due to the mass influence of the iron sulphide. Nickel concentrates in part in pyrrhotite (Fe_8S_9) and, with higher nickel content, in part also in millerite (NiS), pentlandite ([Ni, Fe]S) and polydymite (R_4S_5), that is, in minerals of low sulphur content.[45]

(4) *Crystallization series.* Crystals of pyrite, rich in cobalt, and of ilmenite are often found with good idiomorphic contour intergrown in the pyrrhotite and chalcopyrite. The pentlandite, millerite, and, to all appearances, also the polydymite are always of an earlier stage than the pyrrhotite. Chalcopyrite appears to be earlier than the pyrrhotite.[46]

Following Vogt's paper many authors have advocated a "magmatic origin" for these deposits. Some have simply contented themselves with affirming a magmatic origin, not concerning themselves with the details of the process. Others have followed Vogt in applying Soret's principle to explain the occurrence of ore bodies along the walls of the intrusive masses. For instance, Barlow, in a detailed account[47] of the Sudbury deposits, presents a theory for their origin much like that of Vogt.

Coleman believes that the dominant process in determining the position of the deposits along the margins of the irruptive mass is gravitative settling of sulphides.[48]

Hore also subscribes to the settling theory and believes that the accumulation of considerable masses of the pure sulphides may be explained by the limited miscibility of sulphide and silicate melts.[49]

Browne investigated nickel mattes and compared them with Sudbury ores. He concluded that

the nickel deposits of Sudbury existed primarily as eruptions of molten sulphides mixed with the constituents of the dioritic enclosures, and that by gradual cooling

[42] *Ibid.*, p. 138. [43] *Ibid.*, p. 140. [44] *Ibid.*, p. 137.

[45] *Ibid.*, p. 264. [46] *Ibid.*, p. 128.

[47] Barlow, A. E., Can. Geol. Surv., Ann. Rept., vol. 14 (1901), pt. H, p. 125.

[48] Coleman, A. P., Ont. Bur. Mines Report, vol. 12 (1903), p. 277; also in later papers by same author.

[49] Hore, R. E., Can. Min. Inst. Tran., vol. 16 (1913), p. 271.

the diorite was first separated, then the copper as copper pyrites, and the iron as pyrrhotite containing some nickel, and finally, in those portions remaining longest molten the nickel separated as a true nickel mineral.[50]

Vogt's latest ideas, published as a part of Beyschlag, Krusch and Vogt's textbook on ore deposits,[51] depart but little from those in his earlier publications. He appeals to the theory of limited miscibility to explain the separation of sulphides from a sulphide-rich silicate melt. This is derived from Harker's original statement of the "theory of limited miscibility in rock magmas."[52] Soret's principle is still believed to be the explanation of many of the peripheral ore bodies, while the idea of gravitative settling is employed to explain the Sudbury and certain Norwegian occurrences.

As a result of detailed petrographic work on rocks from the Sudbury "nickel-eruptive," Dresser[53] concludes that the larger masses of ore are syngenetic and that their segregation was due to their immiscibility in molten norite. In addition to this, he believes that the partially consolidated norite contained liquid sulphides and "acid mother liquor," which, as a result of dynamic action, may have been "filter pressed" to regions of less pressure. This theory is used to explain the presence of sulphides found high up in the norite and the quartz and pegmatite of the lower part of the norite.

This section of the report would be incomplete without reference to an important paper by Knopf, descriptive of "A magmatic sulphide ore body at Elkhorn, Montana."[54] The ore here consists of pyrrhotite, containing no nickel, augite, and a minor amount of chalcopyrite. Brown hornblende, biotite, plagioclase, and quartz occur sparingly.

The pyrrhotite and chalcopyrite are closely associated, the chalcopyrite, as seen both with the unaided eye and with the metallographic microscope, forming small, separate and distinct, solid particles surrounded by pyrrhotite. The available evidence appears to show that the two sulphides are essentially contemporaneous in origin. They occur either as interstitial masses between the augite grains, or as irregular intergrowths with them. It is noteworthy that the augite, although invariably anhedral where in contact with other grains of augite, shows a closer approxmation to its idiomorphic outlines where it is joined or surrounded by sulphides. Characteristic quadratic cross-sections with truncated corners are occasionally found. The grains of augite, where enveloped by

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50 Browne, D. H., Col. Univ. Sch. Mines, Quart., vol. 16 (1895), p. 311.

51 Beyschlag-Krusch-Vogt, Die Lagerstatten der nutzbaren Mineralien und Gesteine (Stuttgart, 1914), vol. 1, pp. 300–311.

52 Harker, A., The natural history of igneous rocks (New York, 1909), pp. 196–200 (Harker's statement is much clearer than Vogt's).

53 Dresser, M. A., Econ. Geol., vol. 12 (1917), pp. 563–580.

54 Knopf, Adolph, Econ. Geol., vol. 8 (1913), pp. 323–336.

sulphides, are, as a rule, somewhat rounded and smoothed as if by corrosion, and are frequently penetrated by the sulphides in distinct embayments, which resemble those so common in the magmatically resorbed quartz phenocrysts of rhyolitic rocks.[55]

The sulphide-augite mixture constituting the ore grades out to a quartz monzonite in a distance of from six to twelve feet. The quartz monzonite is of normal composition and appearance. Its plagioclase varies from Ab_{60} An_{40} to Ab_{55} An_{35}. The rocks of the transition zone are such as would be obtained by mixing the quartz monzonite and the ore in varying proportions. Their textures are hypidiomorphic granular and the lack of idiomorphism of their augite individuals is as pronounced as it is in the augite of the ore body. The plagioclase of the transition zone varies from Ab_{65} An_{35} to Ab_{67} An_{33}, a less calcic feldspar than that of the normal quartz monzonite. It would appear from his descriptions that pyrrhotite and chalcopyrite give way to magnetite, titanite and pyrite as accessory constituents at about four feet from the edge of the ore body proper.

Knopf concludes that the primary igneous origin of the sulphide ore body . . . . is believed to be established by the following facts, stated summarily:

(1) All the rocks, including that which composes the ore body and those which surround it, show an entire lack of pneumatolytic or hydrothermal alteration, such as the development of tourmaline, sericite, chlorite, carbonates, or other secondary minerals. They are fresh unaltered rocks in which the ferromagnesian minerals are notably lustrous and the feldspars clear and vitreous. Such minor alteration as was noted is plainly owing to slight post-mineral action.

(2) There is a textural relation of the sulphides to the augite as shown by the tendency of the pyroxene to show idiomorphic boundaries against the sulphides. This is a feature not easily explainable other than by the hypothesis of an igneous origin.

(3) The zonal arrangement of basic phases of the quartz monzonite around the ore body indicates that a marked differentiation has taken place in the magma concurrently with the segregation of the sulphides. This differentiation is expressed mineralogically by the decrease of plagioclase, orthoclase, and quartz, and the concurrent increase in ferromagnesian mineral as the ore body is approached. The increase of ferromagnesian content, instead of appearing as hornblende or biotite, however, appears almost exclusively as augite in the ore body. It is noteworthy in this connection that if the differentiation took place through the agency of the mineralizers or the volatile fluxes of the magma, as believed by Michel-Levy, there is a conspicuous absence of flourine-bearing and hydroxyl-bearing minerals in the final product. Contrary to what might be expected under this hypothesis, the minerals biotite and hornblende decrease in amount with increasing proximity to the ore body.[56]

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[55] *Ibid.*, p. 330.

[56] *Ibid.*, pp. 335 and 336.

Theories of Epigenetic Origin, Involving Replacement

Previous to the work of Bell, Barlow, and Vogt, the deposits of nickeliferous pyrrhotite were thought by all investigators to have been formed after the formation of the inclosing rocks by pneumatolytic or hydrothermal agencies.

Thus in 1888 Collins advanced the theory that the Sudbury deposits were concentrations of the copper that was originally disseminated through the clastic or fragmental beds, this concentration taking place after the intrusion of the diorite. He was impressed by evidence of veining action and faulting and failed to note deposits enclosed entirely within the igneous rock.[57]

Posepny, referring to the theories of Bell and von Foullon, stated that ''these surprising statements assume a chemical impossibility, namely, the presence of metallic sulphides in the magma of the molten eruptive rock . . . . on the strength of metallurgical analogies.''[58]

This objection has not been put forward since Posepny's time. There seems to be no theoretical basis for it, and, as a matter of fact, sulphides have been collected in samples of molten volcanic rock.

Dickson from the results of a careful petrographic study of Sudbury ores concluded that they were of epigenetic origin, formed by replacement processes along crushed and faulted zones.[59] His observations pointing to this conclusion are:

(1) Brecciation, faulting, and shearing are everywhere characteristic. (2) The main brecciation and shearing was anterior to formation of the ore bodies proper. (3) Abrupt contacts of ore and barren rock and angular nature of rock fragments in the ore seem irreconcilable with magmatic theory. (4) Uralitization and chloritization of the rocks is widespread and where fresh pyroxene remains it is brecciated. (5) This alteration is most marked near the ore bodies. (6) In general, the more complete the alteration of the rock the more complete has been its replacement by sulphides. (7) In all cases the sulphides show a tendency to occur along lines of weakness and in connection with fibrous minerals. (8) Secondary quartz and calcite are often present in the ore in appreciable amount while they are insignificant or lacking at a little distance. (9) Sulphides are practically lacking in the rock a short distance from the ore. The rock fragments included in the ore are also comparatively free from ore, except in veinlets.[60]

Weinschenk studied the nickel deposits of St. Blasien and observed phenomena much like those noted by Dickson in the Sudbury ores. The rocks here are thoroughly altered to a mixture of uralite and saussurite. The ore occurs invariably in the most altered rock

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[57] Collins, J. H., Quart. Jour. Geol. Soc. London, vol. 44 (1888), pp. 836–837.
[58] Posepny, F., Am. Inst. Min. Engin., Trans., vol. 23 (1893), p. 330.
[59] Dickson, C. W., A. I. M. E., Trans., vol. 34 (1903), p. 63.
[60] *Ibid.*, pp. 59, 60, 61.

and as it penetrates the hornblende is said to be later than the period of uralitization. The saussurite is cut by veins of clear quartz carrying pyrrhotite. The fresh rocks carry no ore.[61] He concludes that the "world group" of nickeliferous pyrrhotite deposits belong more with true *contact deposits,* and are in no way *magmatic segregations.*[62]

Dickson's conclusions as to the relation between the silicates and sulphides are supported by Campbell and Knight. They studied polished surfaces of the ores and believe that the order of formation of the various constituents, beginning with the earliest, is (1) magnetite, (2) silicates, (3) pyrrhotite, (4) pentlandite, (5) chalcopyrite.[63] They conclude that the basic rocks were more or less fractured and ore-bearing solutions came in and replaced the rock matter wholly or in part by pyrrhotite. Later another period of straining and breaking was followed by deposition of pentlandite and chalcopyrite. They finally state that the foregoing explanation has been rejected by men of considerable ability who have studied the deposits in the field and that such geologists may put an entirely different interpretation on their work.[64]

Reference has been made in the introduction to this chapter to the work of Tolman and Rogers. Their paper[65] presents the results of study of "magmatic sulphide" ores from most of the noteworthy deposits of the world. Their summary of geologic literature of these deposits is good and their photographs of thin sections and polished surfaces of the ores and associated rocks are the best that have been published.

Tolman and Rogers' conclusions are:

> The ore minerals are the final magmatic product, and are formed later than the magmatic hornblende, which we believe to be produced by magmatic alteration.
>
> The ores replace the silicates and, in general, the later-formed ore minerals replace the earlier ore-minerals.
>
> There is a regular order of formation of the magmatic minerals, which shows no variation in the deposits studied. For the nickel-copper group of sulfid ores it is as follows: (1) silicates, (2) magnetite and ilmenite, (3) pyrrhotite, (4) pentlandite, and (5) chalcopyrite. . . . . All alteration minerals except hornblende are later than the above mentioned magmatic ores.[66]
>
> They state that in the Sudbury ores uralitization (tremolitization) occurred after the introduction of the sulphides.[67]

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61 Weinschenk, E., Zeit. f. Prakt. Geol., vol. 15 (1907), Jahrg. Heft 3, pp. 82–84.

62 *Ibid.,* p. 86.

63 Campbell and Knight, Econ. Geol., vol. 2 (1907), pp. 353–365.

64 *Ibid.,* pp. 365–366.

65 Tolman and Rogers, A study of the magmatic sulfid ores (Stanford University, 1916).

66 *Ibid.,* p. 14. 67 *Ibid.,* p. 31.

We conclude that the ores are later than the silicates, for the reason that all the silicates indiscriminately occur as relicts in a groundmass of ore. The ore-minerals surround the silicates, enter along the contacts between them, cut them, and penetrate easily cleavable minerals such as biotite. In some cases they cut the silicates in well defined veinlets. These relations are explained, in part, by those favoring an early magmatic origin of the ores as follows: The sulfid ores remain in a molten condition during the formation of the primary silicates (we add: during the formation of the late magmatic hornblende), and then solidify.

From the latter part of the foregoing statement one would think that Tolman and Rogers believe that the sulphides existed at one time as molten substances, and one might conclude that their theory of origin differed from that of Vogt only with regard to the precise time when the sulphides solidified. That such is not the case is shown by the following quotation in which the authors clearly state that the ores *came from without,* and replaced solid silicate minerals:

The process, however, is not one of corrosion, but of replacement. If the ores were molten, corrosion should produce metallic silicates by reaction. No such metal-bearing slag is found. The phenomena are those of ordinary replacement, and the agency that brought in the sulfids removed the dissolved silicates, all of which indicates active mineralizers.[68]

Intrusive Sulphide Theory

From a petrographic study of rock from the Frood Mine, Howe was unable to conclude as to whether or not the ore and silicate minerals were contemporaneous.[69] On the other hand, he concluded from both field observations and laboratory study that the Creighton deposit resulted from an intrusion of pyrrhotite into already solidified norite, the differentiation of sulphides and silicates having been effected, not in the place where the ores are now found, but in the magma chamber from which the norite originally came.[70] He accepts the statement of Campbell and Knight that in the ore pyrrhotite is cut by pentlandite and these two in turn by chalcopyrite, but believes that the relations can be better explained by the ''nearly simultaneous cooling of the different sulphides that had previously separated as distinct mineral compounds, non-miscible, though still molten.''[71]

Bateman has presented an hypothesis which is a modified or amplified form of that advanced by Howe. In brief it is that the Sudbury deposits are to a minor extent due to magmatic segregation in place; in greater part to intrusions of pyrrhotite, as postulated by Howe, and in minor part to hydrothermal action.[72]

[68] *Ibid.,* p. 15.
[69] Howe, E., Econ. Geol., vol. 9 (1914), p. 514.
[70] *Ibid.,* p. 521,
[71] *Ibid.,* p. 522.
[72] Bateman, A. M., Econ. Geol., vol. 12 (1917), p. 426.

APPLICABILITY OF THE VARIOUS THEORIES TO THE FRIDAY MINE DEPOSIT

Syngenetic theories.—Three theories have been advanced to explain the differentiation process by which syngenetic deposits of sulphides are formed in igneous rocks. The failure of these theories to fully explain the origin of the Friday Mine deposit is shown by the following observations:

(*a*) Segregation according to Soret's principle. While in many districts the pyrrhotite bodies occur at the edge of the irruptive masses, in other localities, as for instance the Friday Mine, the ore bodies are found well within the igneous mass. It might be thought that the schist body of the Friday Mine acted as the cool surface toward which the sulphides migrated. Again, certain outcrops of gossan that are found along the norite contact north of the Friday Mine are thought to represent oxidized pyrrhotite. If such is the case, we have here examples of deposits along the contact, and as the contact is nearly vertical Soret's principle might be urged as against the idea of gravitative settling.

Many ore bodies, however, belonging without doubt to the magmatic class, occur within igneous rocks at some distance from boundaries and with no relation to included bodies of older rocks. For instance, of numerous chromite deposits studied by the writer in the Coast Ranges of California, south of San Francisco, not one is located at a contact. Of some 200 chrome deposits examined by Mr. N. L. Taliaferro in the Sierra Nevada only one was directly on a contact of the basic intrusive against older rock, and, taking into consideration the width of the various igneous bodies, the remainder of the deposits can be said to be well within the igneous rock. The writer has seen one chromite deposit, at the Daisy Prospect, west of Jolon, in Monterey County, where the ore bodies occur along the median plane of a narrow body of serpentinized peridotite, and is informed that similar deposits occur in Montana.[73]

From the above observations it seems very doubtful if Soret's principle is the law under which magmatic ore deposits accumulate.

(*b*) Gravitative settling. Evidently gravitative settling will not explain the Friday Mine deposit, and it appears also inadequate to account for the supposed ore bodies along the steep north contact of the norite.

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[73] Mr. Geo. White, oral communication.

(*c*) Limited miscibility of silicate and sulphide melts. After studying the textural relations between sulphides and silicates in the norites, gabbros, and other basic rocks that carry disseminated particles of ore, there can be little doubt that there was extremely limited miscibility between the silicate and sulphide portions of the magma, immediately prior to its consolidation. If this was the case with small particles of sulphide, it seems likely that it also held for the large masses.

The theory of limited miscibility by itself, however, does not explain why the sulphides aggregated into large, fairly pure masses.

Intrusion of sulphide magma.—Howe and Bateman, while stating that some of the Sudbury deposits are the result of magmatic differentiation *in situ,* believe that the most of them were formed by the intrusion into already solidified norite of a sulphide magma, which formed by differentiation in the magma reservoir from which the norite came.

At the Friday Mine there is strong evidence for differentiation, in place, of the sulphide mass from the norite magma. Not having seen the Sudbury occurrences and having examined only a few specimens from that locality, the writer is not qualified to pass judgment on the applicability of the intrusive sulphide theory to those deposits. It is thought, however, that one of Coleman's objections to this theory is worth noting. He says:

> As mentioned before, pyrrhotite-norite is invariably found above the ore bodies in the marginal mines, and the enormous volume of this rock, running into cubic miles, is quite unaccountable if the ore was segregated before the norite reached its present position. These completely enclosed blebs of sulphides are like shots of matte in slag where cooling has advanced too rapidly to allow of complete gravitational separation. The pyrrhotite-norite probably contains as much ore as all the mines of the region, and if half the sulphides of the original magma are still enclosed in the rock, is it probable that the other half lagged behind and came up after the norite had cooled and solidified?[74]

In other words, with a competent source, the disseminated sulphides of the norite, at hand, why deny the possibility of differentiation in the norite body now exposed to view, and seek the locality of this action in some deeper magma chamber?

Epigenetic theories involving replacement.—The theories for the origin of nickeliferous pyrrhotite bodies advanced by Campbell, Knight, and Tolman and Rogers are based to a large extent on the observed textural relations between the various ore minerals and between these minerals and the silicates.

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[74] Coleman, A. P., letter to editor, Econ. Geol., vol. 10 (1915), p. 392.

The writer has concluded that in the case of the Friday Mine deposit the preponderance of evidence points to a syngenetic origin. The almost complete lack of veining effects, either of silicate minerals by ore minerals or of one ore mineral by another, is noteworthy in this deposit.

Even had such veining effects as are described by the proponents of replacement theories been noted in the Friday Mine ore, still the writer would have held to the syngenetic theory on account of the evidence of the larger scale geologic relationships.

The reason for this statement is that he questions the validity of the criteria employed by Campbell, Knight, and Tolman and Rogers to establish the *order of arrival* of the various minerals at the *particular point studied.* In the first place, it should be noted that both Howe and Dresser, who made careful petrographic studies of Sudbury material, deny the definite order in the relations between the sulphide minerals that has been affirmed by the other workers.

Even if the various sulphides should cut one another in a definite order, and granting as a fact that the sulphides sometimes cut the silicates in veinlets, no evidence has been offered that this proves the relative time of arrival of the minerals from some source outside the rock in which they are now found. Many examples might be cited of veins that without any doubt grew in their present positions without accession of any material from without, e.g., quartz veinlets in radiolarian chert, calcite veinlets in limestone, etc.

Objection may be raised to such examples as being not pertinent to the present discussion. As offering almost perfect analogies to the nickel ores, we may turn to the evidence furnished by metallurgical products, e.g., mattes and alloys.

Plate 4, figure 6 is reproduced from Fulton's "Metallurgy."[75] It is a photograph of a polished surface of copper matte. The light portion is substance "D" ($Cu_2S, + Cu$) with dissolved $FeS - Fe$. The dark portion is metallic copper.

The textural relations between the metal and sulphide here are much like those between pentlandite and pyrrhotite in plate 13, figure 1. Now substance "D" melts at something less than 1150° C., while metallic copper melts at 1084° C. The temperature of matte smelting generally exceeds 1200° C. It is evident, then, that the matte was entirely molten when poured from the furnace and that all of the solidification took place within the matte pot. The textural relations between the metal and the sulphide are the result of one

[75] Fulton, C. H., Principles of metallurgy (New York, 1910), p. 305.

of two processes: either (1) two immiscible liquids, copper and sulphide, were present prior to solidification, and the copper persisted in the molten condition after the solidification of the sulphide, and was thus able to vein the sulphide, or (2) a solid solution of copper in substance ''D,'' stable at the temperature of consolidation, broke down as the matte cooled.

Fulton and Goodner have observed the sudden appearance of ''moss copper'' in mattes of comparatively low copper content when the matte was nearly cold but still too hot to bear the hand upon it. They suggest that the dimorphic point, 103° C., marks the throwing out of metallic copper from solution in the Cu_2S — FeS.[76] If this be so, then the second of the two processes suggested in the previous paragraph is probably the correct one.

The ''veining'' of one constituent of *cast* manganese steel by other constituents is well shown in photographs presented by Potter[77] and Young, Pease and Strand.[78] These are reproduced as plate 13, figures 3 and 4 of the present report, together with two photographs of Sudbury ores (plate 5, figures 2 and 5) whose textures are much like those of the alloys. It is obvious that the veins in the manganese steel do not prove that the ferrite or the troostite were introduced from without after the solidification of the ground mass.

To the writer all these things go to show that veinlike forms of one mineral within another do not prove that the ''vein mineral'' was introduced from without, replacing the ''previously formed'' minerals. Neither can we assume that in all cases the ''vein mineral'' was molten after the solidification of the ground mass.

It is thought, then, that the conclusions of Tolman and Rogers, and Campbell, and Knight, based on the minute textural relations of the minerals, rest on very insecure foundation.

Without doubt there has been introduction of material from without after the primary ore formation in many of the magmatic ore deposits.

It is thought that in many such deposits the secondary action has masked the primary relationships. In such cases conclusions as to origin must be based on large scale geologic relations, just as Vogt, Barlow, Bell, Coleman, and many others have urged.

In the case of the Friday Mine deposit the absence of veining is considered as corroborative evidence pointing to syngenetic magmatic origin.

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[76] Fulton, C. H., and Goodner, I. E., A. I. M. E., Trans., vol. 39 (1908), p. 618.

[77] Potter, W. S., A. I. M. E., Trans., vol. 50 (1914), p. 465.

[78] Young, Pease and Strand, *ibid.*, vol. 50 (1914), p. 427.

EXPLANATION OF PLATE 9

Fig. 1. Thin section of norite. $\times$ 25.

The relations between the hypersthene and the plagioclase are typical of the rocks of the Cuyamaca Intrusive.

Fig. 2. Thin section of norite. $\times$ 104.

Brown hornblende separating grains of plagioclase.

Fig. 3. Thin section of olivine norite. $\times$ 6.7.

Plagioclase, light gray, hypersthene and olivine, darker gray. The hypersthene may be distinguished from the olivine by its lower relief and distinct cleavage. The texture is typical of the Cuyamaca Basic Intrusive rocks.

Fig. 4. Thin section of gabbro. $\times$ 25.

Augite, darker gray, plagioclase, lighter gray. Note the extremely irregular outlines of the augite.

Fig. 5. Thin section of gabbro. $\times$ 32.

Several augite sections, all parts of a single ophitic individual, associated with plagioclase. The augite is altered to a slight extent to green hornblende.

Within the augite are several magnetite grains, associated in such a fashion with spinel, *sp.*, that the two minerals appear contemporaneous.

Fig. 6. Troctolite. Trains of olivine grains in plagioclase. $\times$ 6.95.

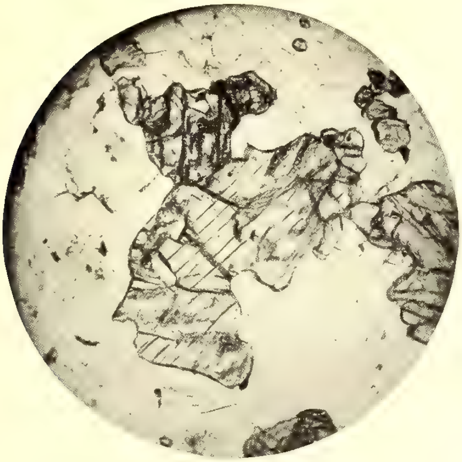
Fig. 1


Fig. 2

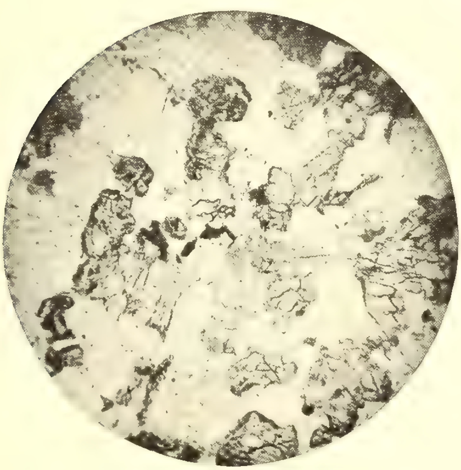
Fig. 3

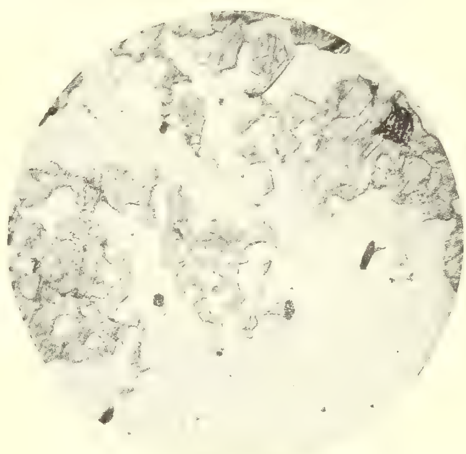
Fig. 4

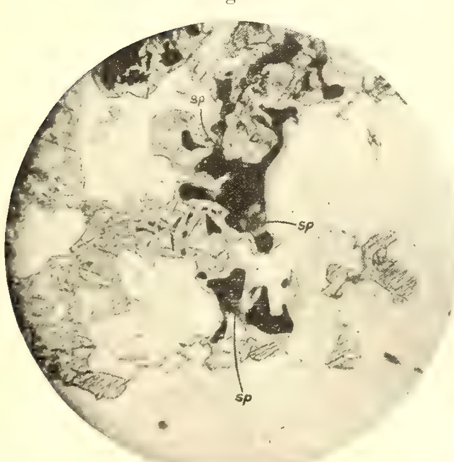

Fig. 5


Fig. 6

EXPLANATION OF PLATE 10

Fig. 1. Same field as figure 6, Plate 9, but with crossed Nicols.

Fig. 2. Thin section of hypersthene diorite. × 25. Crossed Nicols. The texture is typical of the rocks of the Cuyamaca intrusive.

Fig. 3. Photograph of thin section of ore from Friday Mine. × 25. Crystal of brown hornblende enclosed in sulphides. The dark substance in the center of the hornblende is chlorite, with which is associated actinolite in white ''needles.'' A rim of fibrous calcite surrounds the brown hornblende.

Fig. 4. Photograph of thin section of ore from Friday Mine. × 25. Brown hornblende in sulphides.

Fig. 5. Massive ore. × 12.5. Pyrrhotite shows parting cracks. Polydymite shows cubic cleavage. Chalcopyrite distinguished by high luster and freedom from cleavage. Dark gray patches are gangue minerals.

Fig. 6. Enlarged view of center of field shown in figure 5. × 25.

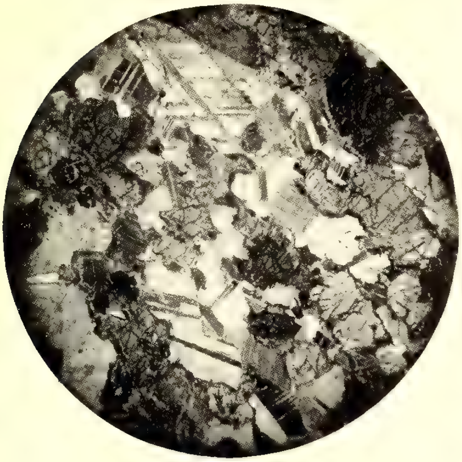

Fig. 1

Fig. 2

Fig. 3

Fig. 4

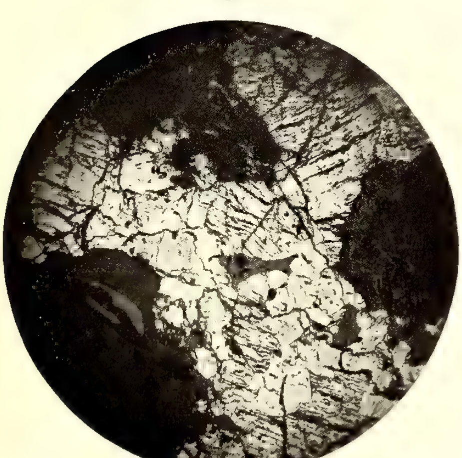

Fig. 5

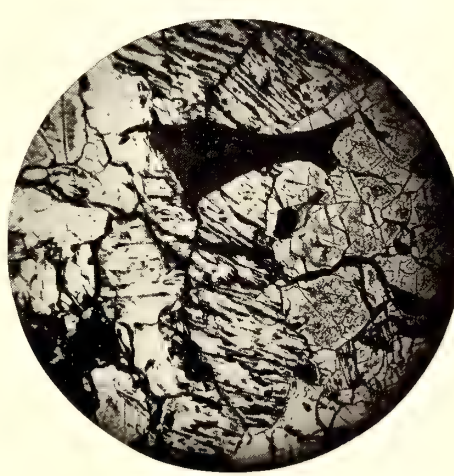

Fig. 6

EXPLANATION OF PLATE 11

Fig. 1. Massive ore, Friday Mine. × 25.

Note the vein-like mass of chalcopyrite in the pyrrhotite. This vein stops abruptly against the silicate, showing that the two sulphides act as a unit in their textural relations with the silicates.

Fig. 2. Polished surface of norite. × 233.

Two simple grains of pyrrhotite inclosed within a single, fresh, unfractured silicate. Note that each of the pyrrhotite grains contains a minute mass of pentlandite.

Fig. 3. Polished surface of peridotite. × 108.

A vein-like mass of pyrrhotite connecting two grains of that mineral. Note the tiny ''bar'' of pentlandite lying across the vein-like mass near its middle portion, the pentlandite terminating abruptly against the silicate walls.

Fig. 4. Polished surface of peridotite. × 233.

Vein and grain of pyrrhotite inclosed in silicates. The vein-like masses shown in figures 3 and 4 are wholly exceptional, the two figured here being the only ones found in the detailed examination of eight specimens.

Fig. 5. Polished surface of olivine gabbro. × 125.

Shows a compound grain of pyrrhotite, white, and magnetite, gray.

Fig. 6. Polished surface of olivine gabbro. × 108.

Pentlandite at edge of a pyrrhotite grain.

Fig. 1

Fig. 2

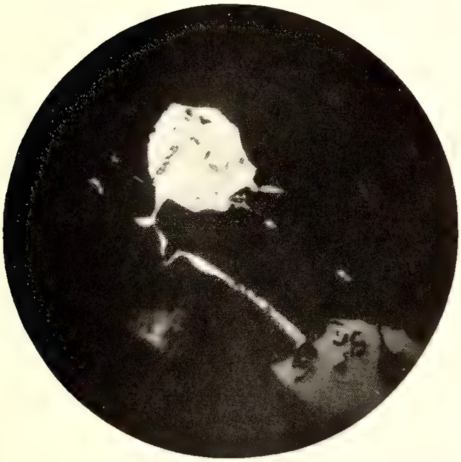

Fig. 3

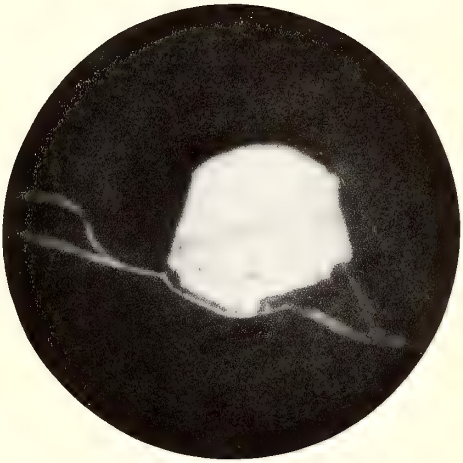

Fig. 4

Fig. 5

Fig. 6

EXPLANATION OF PLATE 12

Fig. 1. Polished surface of olivine gabbro. × 27.5.

A typical sulphide grain. Shows pentlandite, white, and chalcopyrite, inclosed in pyrrhotite.

Fig. 2. Enlarged view of portion of grain shown in figure 1. × 108.

Fig. 3. Polished surface of norite. × 108.

A typical sulphide grain, showing both pentlandite and chalcopyrite in the pyrrhotite.

Fig. 4. Another grain from same rock as that of figure 3, plate 12. × 108.

Fig. 5. Polished surface of olivine gabbro. × 108.

A grain of pentlandite and wedges of chalcopyrite, inclosed in a pyrrhotite grain. Note the minute tufts of pentlandite along a calcite veinlet which cuts the pyrrhotite. These tufts are believed to be secondary pentlandite derived from the substance of the primary grains and deposited by the same agency that formed the calcite veinlet.

Fig. 6. Copper matte.

The light portion of the field is substance ''D,'' the dark portion is metallic copper. (Figure 100, Fulton's Metallurgy.)

Fig. 1

Fig. 2

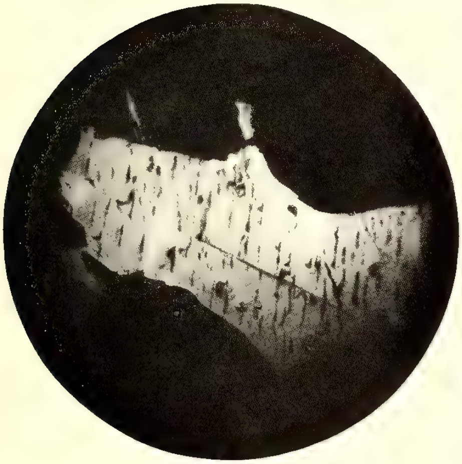

Fig. 3

Fig. 4

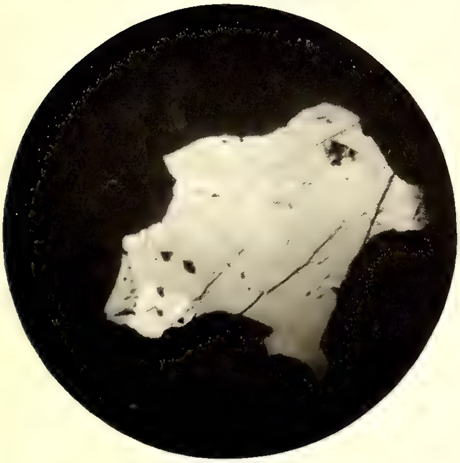

Fig. 5

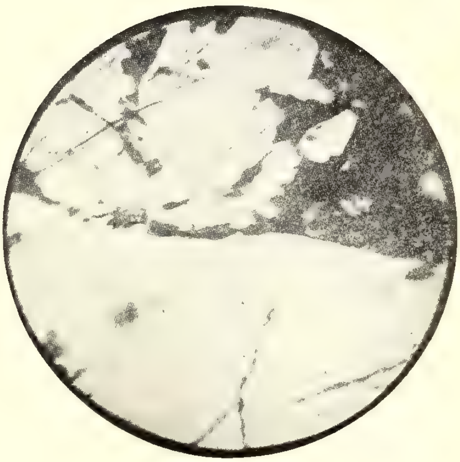

Fig. 6

EXPLANATION OF PLATE 13

Fig. 1. Nickel ore. Creighton Mine, Sudbury.

Pentlandite, *pn;* pyrrhotite, *p;* magnetite, *m;* silicates, *s.*

Fig. 2. Nickel ore. Creighton Mine, Sudbury. $\times$ 17.

''Veins'' of pentlandite in pyrrhotite. (Fig. 35, Tolman and Rogers.)

Fig. 3. Cast manganese steel. $\times$ 78.

''Veins'' of ferrite in groundmass of other iron substances. (Figure 4, Young, Pease and Strand, Trans. A. I. M. E., vol. L.)

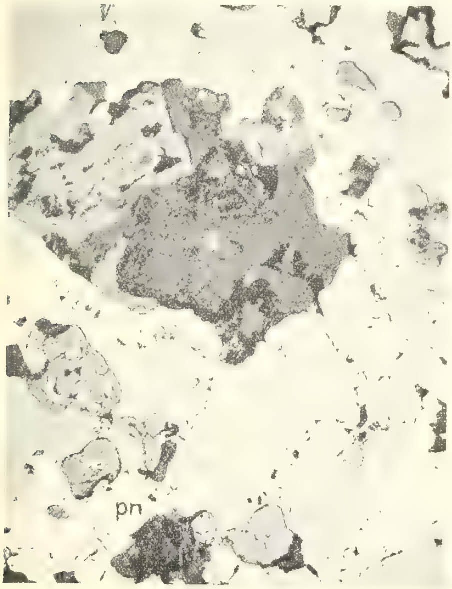

Fig. 1

Fig. 2

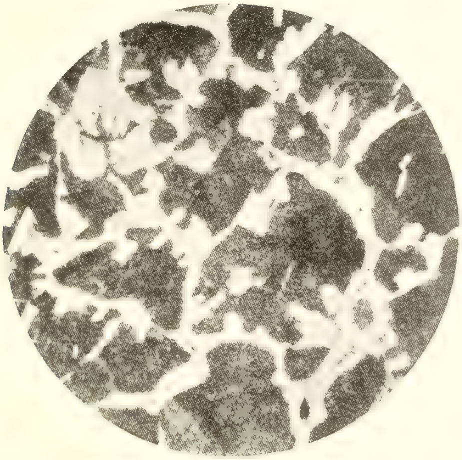

Fig. 3

EXPLANATION OF PLATE 14

Fig. 1. Cast manganese steel. × 392.

Eutectic and troostite in a groundmass of gamma iron. (W. S. Potter, Trans. A. I. M. E., vol. L, p. 465.)

Fig. 2. Nickel ore, Creighton Mine. × 608.

Chalcopyrite and pentlandite in a groundmass of pyrrhotite. (Tolman and Rogers, figure 36.)

Fig. 1

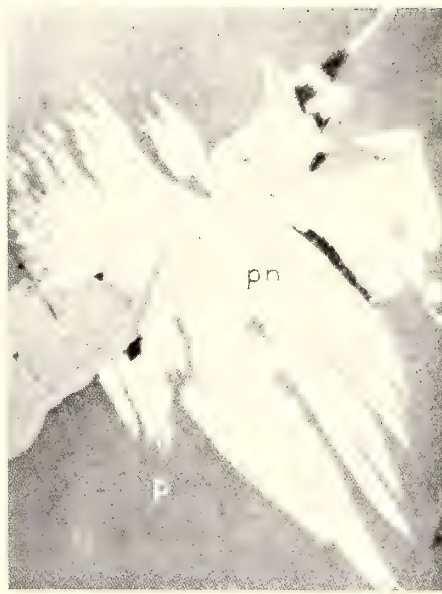

Fig. 2

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GENESIS OF THE ORES OF THE COBALT DISTRICT, ONTARIO, CANADA

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ALFRED R. WHITMAN

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VOLUME 9

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CONTENTS

INTRODUCTION

The mines of the Cobalt district of Ontario, Canada, have long been known as large producers of silver. The precious metal occurs associated with the arsenides of cobalt and nickel in veins of calcite, varying in width from a fraction of an inch to eighteen inches. Usually the silver is disseminated through the arsenide in the native condition or in such minerals as dyscrasite, argentite, and proustite. Frequently, however, it is found native in calcite, and locally it entirely displaces the gangue, filling the vein as a sheet of solid silver.

Silver was discovered in Cobalt district in 1903 during railroad construction; and in the same year Willet G. Miller, provincial geologist, made a preliminary study of the district. An official report was published by the Ontario government in 1904. Three later editions were issued, the fourth one appearing in 1913.[1]

Many geologists and engineers have visited the Cobalt District and much has been written about it. Various hypotheses concerning the origin of the ores have been suggested; but the deductions of Miller are probably the best known and most generally accepted. On account of the necessary limitations of this paper, I will not attempt to discuss the various views of others; but, as a background for my own conclusions, I will give a brief résumé of the current conceptions as I found them upon beginning work.

Grateful acknowledgment is due Professor A. C. Lawson and Dr. F. R. Bichowsky for helpful discussions and suggestions relating to the igneous and chemical problems dealt with, also to my assistants, Mr. W. L. Whitehead and Mr. Maurice Albertson.

REVIEW OF IDEAS CURRENT IN 1915

Formations.—The oldest formation recognized consists of altered Keewatin lavas, tuffs, and rocks resembling sediments, penetrated by pre-Laurentian finegrained intrusives, the lavas and intrusives ranging from the most acid to the most basic. All these formations were folded and were intruded by gray Laurentian granite, which in time became exposed by erosion and mantled by the Timiskaming Series of

[1] Ontario Bureau of Mines, Report, vol. 19, pt. 2.

conglomerates and finer sediments. These formations were, in turn, folded into nearly vertical attitudes, and were intruded by dikes of lamprophyre and batholithic masses of pink Lorrain granite.

The complex was then eroded until the Lorrain granite was exposed and the Cobalt Series of conglomerates and greywackes was deposited in horizontal or nearly horizontal beds upon a land surface which, according to Miller, was hilly and rough.

Miller refers to the Nipissing diabase as a sill between 600 and 1100 feet thick, probably of Keweenawan age, which was injected in an approximately horizontal position concordant with the bedding or with the contact between the Cobalt Series and the Keewatin formation, the amount of overburden not being estimated. The diabase is supposed to have come from a local vent, though the possibility is admitted that there might have been more than one feeding channel.

After intrusion this formation was in turn intruded by small dikes of granophyre and basalt, presumably representing segregation products from the plutonic source of the diabase.

At the beginning of the Silurian period the overburden and much of the diabase itself had been eroded away, and the region was submerged beneath the sea, where it remained until the Devonian, receiving a thick mantle of richly fossiliferous limestone. By the close of the Pleistocene the limestone had been largely removed, and the underlying formations exposed over the greater part of the region.

Structures.—Two systems of deep-seated structures were recognized as being in some way connected with the silver-cobalt deposits. They find topographic expression as long lines of depressions, occupied for the most part by streams and lakes. They trend respectively NW–SE and NE–SW; and their age was held by Miller to be post-diabase. In regard to them Miller wrote:

From the geological maps and the plan showing the distribution of the veins at Cobalt, which accompany this report, it will be seen that while belts of fragmentary rocks strike approximately northeast and southwest, as for example, the belt along the railway at Cobalt, and the Glenn and Kerr Lake belt, the majority of veins have a strike different from this. It would also appear that the strike of the veins in this area has little connection with the disturbance which caused the great majority of the great rivers and chains of lakes in the district to follow one or the other of the well defined directions.

The water courses and lake axes which lie in a northwest and southeast line are not so prominent on the maps as are the northwest-southeast ones just described. Still they form a not indistinct system, and as is indicated by Fig. 51, they seem to have an important, but as yet little understood relationship to the

Cobalt deposits of not only Cobalt proper, but of Rabbit Lake 30 miles to the south, Casey Township 15 miles to the northeast, South Lorrain to the southeast, and others.

Believing that the occurrence of ore is in some way connected with the northeast-southwest lines of weakness, the writer advised prospectors to search for deposits in the vicinity of Animanipissing. This resulted in the first finds of cobalt there.

It was also recognized that folding occurred along NE–SW axes, and that Cobalt Lake lies in a syncline ruptured along its axis on what is known as the Cobalt Lake fault.

Cobalt-silver veins.—The deposition of the ores was considered by Miller to have occurred along joints and joint-like fissures, which, he suggested, may represent cracks resulting from the contraction of the diabase shortly after its intrusion.

The genesis of the ores was variously assigned by different writers to ascending juvenile waters or to descending meteoric waters. According to Miller:

The relation of the veins to the intrusive flat-lying sill of Nipissing diabase is unique. The veins have not been filled by waters ascending vertically, as some writers on the Cobalt area have assumed; neither are the veins that are being worked the narrow parts of wide veins that penetrated the now eroded overlying rocks. It can not be proved that any of the veins in the Cobalt area reached the surface as it existed at the time of the intrusion of the Nipissing diabase. The occurrence of ''blind veins'' makes it doubtful whether or not all the veins associated with the sill did not have a comparatively short vertical extension.

The material in these veins has, in all likelihood, been deposited from highly heated impure waters which circulated through the cracks and fissures of the crust and were probably associated with . . . . followed . . . . the Nipissing diabase eruption. It is rather difficult to predict the original source of the metals—silver, cobalt, nickel, arsenic, and others—now found in these veins. They may have come up from a considerable depth with the waters, or they may have leached out of what are now the folded and disturbed greenstones and other rocks of the Keewatin. Analysis of various rocks of the area have not given a clew as to the origin of the ores. However, the widespread occurrence of cobalt veins in the diabase or in close association with it, shown by discoveries during the last seven or eight years, throughout a region over 3000 square miles in extent, appears to be pretty conclusive proof that the diabase and the ores come from one and the same magma.

The veins, as is generally known, occur chiefly in the Cobalt sedimentary series beneath the diabase sill; but good veins are also found in the sill itself, and in the adjacent Keewatin, both above and below it.

The essential minerals of the veins as given in Miller's report, in what he considers their order of deposition, are: smaltite, niccolite, (period of moving and fracturing), calcite, argentite, native silver, native bismuth, (period of decomposition), erythrite, annabergite.

Proustite, breithauptite, dyscrasite; a long list of unimportant silver and arsenic and other minerals is also recognized. The areal geology of the district has been mapped by Miller and Knight[2] and the reader is referred to their map.

DESCRIPTIVE GEOLOGY

The Pre-Cobalt Surface

The basement complex upon which the Cobalt Series was deposited is here referred to as the Keewatin, since that is the local usage. Its eroded surface has been found in the Cobalt area to be remarkably smooth and flat, such irregularities as may exist being much smaller than any of the hills of the present surface. One of the original irregularities is a low knob on the north end of Cobalt Hill about 2000 feet northeast of the low-grade mill of the Nipissing Mining Company, where the conglomerate of the Cobalt Series may be seen lapping unconformably against the lower slopes. Another irregularity occurs as a depression exposed by the workings of the Seneca Superior Mine. Other minor ones have been found here and there in the mines of the district, but they are never comparable in size with the major undulations caused by folding. Probably the Cobalt, Prospect, McKinley-Darragh, Lawson, and other hills of the district are not original irregularities on the Keewatin surface, but are anticlinal folds.

In the course of my studies I constructed a contour map of the contact between the Keewatin and the Cobalt Series (see fig. 1). When the dips of the overlying sediments were superposed, they were found to conform to the slopes of this surface. Although the slopes lie between 10 and 30 degrees, the depth of the sediments and the exactness of their parallelism with the lowest layers would seem to exclude the possibility of sedimentation on slopes, since this condition persists for several hundred feet above the contact.

Further evidence that the major undulations of this contact are due to folding lies in the fact that when the dips of a certain set of flatly inclined joints were plotted upon the formational contour map, they coincided with the contoured slopes, and with the dips of the beds overlying them. These flatly inclined joints are of a type produced by shearing stresses during the folding of rock masses, and are parallel to the warped or folded surface.

[2] Ontario Bureau of Mines, Report, (XVI), 1907.

The validity of this evidence is borne out by the fact of general shearing on the contact, accompanied usually by the development in the overlying sediments of large and small dip-slip reverse faults parallelling the contact in a rough way. Finally, further confirmation is found in the relations of certain other joints, particularly those which constitute the vein fissures.

The origin of the flat surface of the Keewatin upon which the Cobalt Series was deposited is still obscure. The hypothesis of glaciation was tentatively discarded in view of the weight of evidence that

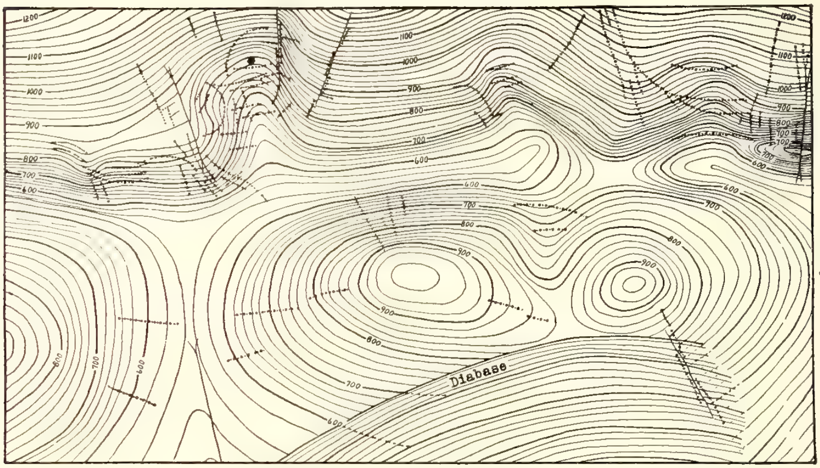

Fig. 1. Idealized plan showing relation of veins to folds. The contours represent the Keewatin-Cobalt contact and the Keewatin-diabase contact respectively, the dotted lines veins, and the solid lines strike-slip faults. Scale 1″ to 5000′.

accumulated in favor of normal secular delay and stream erosion. All the evidence on this point offered by Miller has been corroborated by myself. A particularly convincing example in support of the idea of secular decay is found on the third level of the Buffalo Mine, where the old Keewatin bedrock can be seen with jagged serrations protruding up into the ancient soil, in which angular fragments detached from the bedrock were mingled with rounded granite and other foreign pebbles, which had worked their way down through the soil. If the surface had been produced by the glacier assumed to have deposited the Cobalt Series, it must have been pared down sufficiently to remove the preëxisting topographic features or to have considerably modified them. But had that occurred, then none of the residual soil of the older surface could have remained. The fossil soil found by Miller and myself must be regarded as a proof that the surface was not

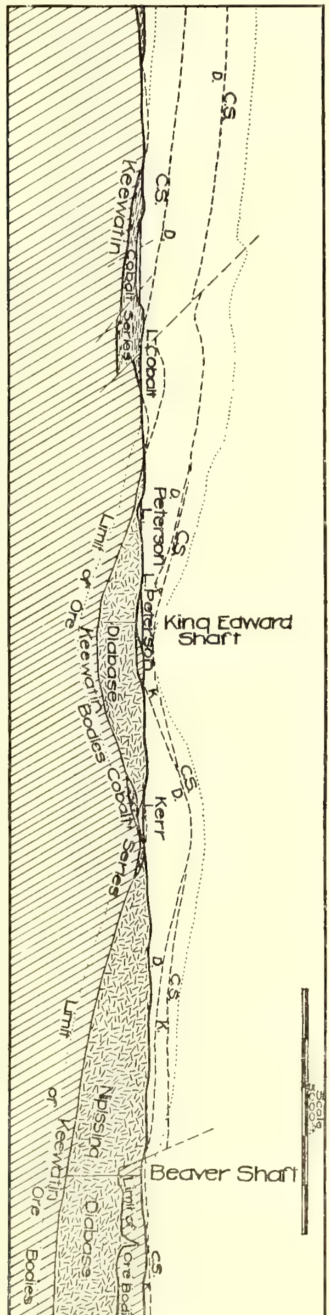

Fig. 2. Showing the relation of diabase sill to Keewatin and Cobalt series.

produced by glaciation. The character of the sediments points strongly to their deposition by streams, since the beds of greywacke interstratified with the conglomerate are not extensive sheets, but are discontinuous and lenticular, having been observed often to end abruptly against steep former embankments of pebbles. The extensive beds of clay and sand covering much of the present surface, which were left by the Pleistocene glacier, make a striking contrast with the limited beds of greywacke which characterize the Cobalt Series.

The Diabase Sill

On northwest sections constructed through the two Keewatin roof blocks of the diabase sill, on the King Edward and Nova Scotia properties, respectively, the sill is found to have an average thickness of 1000 feet. The same approximate thickness was found at the Timiskaming property, where the shaft was sunk through the sill. At Kerr Lake the base of the sill plunges down across the tilted Cobalt Series, making an angle of 40 degrees with the beds, which slope at 10 degrees in the same direction; also on the west side of Peterson Lake the sill cuts across the sediments at a low angle, and down into the Keewatin; while at the Shamrock Mine the upper contact of the sill and the Keewatin takes a vertical attitude. The Keewatin roof blocks lie between conglomerate areas on the under side of the sill, and hence must have been elevated vertically a distance of approximately 1000 feet. Evidently the sill was not injected in an even horizontal position, but only roughly approximated it, plunging at one point and arching at another, the contacts and the whole configuration of the mass being uneven. Attention must be called especially to the great plunge taken by the sill between Kerr Lake and the west shore of Peterson Lake, which area was probably originally covered by a continuous sheet of conglomerate. The Keewatin roof blocks lie approximately along the axis of the depression. This is explained by the injection of the sill downward beneath the Cobalt Series into the Keewatin basement, and the lifting of the roof. The erosion of this lifted mass resulted in the almost complete removal of the conglomerate sheet, and the leaving of only three small remnants of Keewatin resting upon the sill (see fig. 2).

It has been noted in the Rochester and neighboring properties that offshoots from the sill penetrate the Keewatin of the roof for short distances, and that blocks of Keewatin are found imbedded in the sill, representing fragments of the roof or floor torn loose by the moving magma during its injection; while in the Beaver Mine a block of

Lorrain granite was found imbedded in the upper portion of the sill many hundred feet away from any known parent mass.

In the South Lorrain district I found that the Nipissing diabase exposure is in no sense sill-like in form, but is a hollow arching shell plunging into the Keewatin in all directions around the enclosed area, having apparently once met overhead before erosion carried the higher portion away. In the Gowganda area also, it appears that the diabase is more commonly dike-like than sill-like in form. This points to the origin of these masses as many independent offshoots from a deep-seated mother magma, attempting to rise through devious channels through the Keewatin, and stopped or deflected beneath a great thickness of flat-lying sediments, perhaps themselves overlain by a lava flood-sheet of the same magma. However hypothetical the assumption of such an overburden may be, the evidence nevertheless points to the existence of a heavy flat barrier beneath which the diabase was forced to spread out, and assume irregular forms.

The diabase is characteristically fairly coarse-grained, that is to say, it exhibits phenocrysts of plagioclase averaging from two to three-sixteenths of an inch in length. Its margins are characteristically fine-grained, usually aphanitic, visible phenocrysts not being discernible within five to ten feet of the contacts. In the interior of the sheet, however, the evenness of the texture disappears, and patches of coarse hornblende porphyry and pegmatitic material become more or less abundant. There are a few anomalous occurrences of diabasic impregnation of the adjacent Keewatin rocks in the form of small reticulate and ill-defined veinlets of diabase penetrating into the walls of the sheet, these veinlets or dikelets varying in width from one-half to less than one-sixteenth of an inch. One of these cases occurs in the south workings of the Kerr Lake Mine on the under side of the sheet; and a careful study indicated that the space occupied by the dikelets was not produced by distension but by assimilation. Examples of this phenomenon, however, are rare.

Sufficiently close study was not devoted to the post-diabase intrusives to enable me either to add to or detract from what has already been written on the subject. However, as the matter bears upon a study of the diabase, and indirectly upon the problem of ore genesis, it received enough consideration to warrant the conclusion that these differentiation products, which form dikes cutting the sheet, did not come from the sill itself, since it has undergone only incipient segregation; but that they probably came from its mother-magma lying far below the surface.

Structures

It has been found possible to follow out roughly folds in rock devoid of stratification and to detect and follow important faults and joints by the evidence found in topography and certain sets of other joints. This is because the joint systems express the structure, and because the chief method of degradation employed by the Pleistocene glacier was the plucking of joint blocks. The walls of faults are strongly jointed, and in consequence of this, the glacial plucking was most active on these lines, sculpturing valleys, and here and there precipitous escarpments, which in many cases overhang. On the limbs of folds, where gently inclined joints were developed by folding, making with oblique vertical joints rhombohedral blocks, the glacial plucking similarly exposed the structures.

Folds.—All the folding was quite gentle, the usual minimum dip of the slopes being from 10 to 15 degrees, and the usual maximum being from 25 to 35 degrees for both major and minor folds. Prospect Hill on the west side of the town of Cobalt approximates a monocline, the area to the west being essentially flat save at one or two points where a slight westerly dip is visible. Cobalt Hill on the east side of Cobalt Lake is a slightly asymmetric anticline, the eastern slope into Peterson Lake being the gentler. The Lawson Hill immediately east of Kerr Lake, and the McKinley Darragh Hill southwest of Cobalt Hill, are also of a similar character. The Keewatin area between Cart Lake and Contact Bay on Giroux Lake is a nearly flat anticline.

Of the two sets of tectonic forces which produced these folds the greater acted along a NW–SE axis and tended to produce folds striking NE–SW, as if the especially strong NW–SE structural lines were the outcrops of strike-slip faults between which longitudinal compression occurred. The strength of the lesser set of forces is indicated by minor folds superimposed upon the northeasterly ones, and generally striking northwesterly. As a rule the northeasterly or major folds are the older of the two, but in one or two cases major folds were at least accentuated after the development of the minor folds on their flanks. Although there is thus a simple sequence in the salient events, still in the lesser deformations there were various and indeterminable alterations of strain from one major axis to the other.

Faults.—In studying the geo-mechanics of the district it is necessary to picture a restoration of the region, and regarding the entire rock mass as a composite medium, to consider the mechanical peculiarities of each component formation.

The Keewatin is relatively plastic in contrast with the other formations. This is due chiefly to its varied lithologic character and to its complex structure, which is reflected in the erratic nature of its joints. Certain strong vertical joints, however, occur in expected positions, notably the principal vein joints, and more particularly those near the diabase contact rather than near the sedimentary contact. The faults are particularly characteristic of the formation. All faults passing from other formations into the Keewatin promptly flatten their dips, and frequently change their strikes also. Usually, even though their actual displacements are small, they have considerable gouge, are accompanied by pronounced border zones of breccia and have slickensided walls. Their most significant and important feature is their discontinuity. A given slip diminishes in all directons from a center of maxmum displacement to a periphery of no displacement. Often where one slip ends another begins, lying parallel in an offset position. Also, the fault surfaces are so warped as in no way to approximate planes; and sometimes a fault clean-cut at one point will pass into a set of step faults or a distributive fault at another.

The Cobalt Series is intermediate in mechanical strength between the Keewatin and the Nipissing diabase. It has the peculiar property of being plastic in one direction and elastic in another. It is well cemented and firm, and is highly elastic to stresses normal to the bedding, certain types of joints having a considerable extension in that direction; but along the bedding it yields plastically to slight stresses, so that bedding joints and bedding faults are very abundant.

The diabase is the most homogeneous, elastic, and tough of the formations. Its joints frequently exhibit a conchoidal curvature, their junctions with one another being rounded with mutual branches in the four quadrants. Frequently also a curved or cuplike form is found in parallel joints closely set, like exfoliation fractures, or the layers of an onion. Even the faults often have very sinuous courses, the curves being from five to thirty feet in length.

All the significant tectonic effects within the district were produced shortly after the injection of the diabase, and presumably ended at a time not long subsequent to the dissipation of its initial heat. During this time the chief structures developed were folds, indicating that there were no tendencies toward distension, and there was therefore no opportunity for the formation of gravity or normal faults. As a matter of fact no such faults have been discovered; and all known faults have resulted from compressive stress.

When rocks are folded at a considerable depth below the surface, or under certain other conditions of uniform horizontal compression throughout a considerable vertical column, so that *parallel* folds are not possible, and only *similar folds*[3] can be produced, shearing must develop on their flanks to accommodate the shifting of material from the limbs to the axes of the folds. As pointed out in a previous paragraph the axes of folding are also neutral axes with reference to shearing, and the regions of maximum shear are midway between them. The direction of shearing is that of dip-slip reverse faulting parallel to the warped surface. The surfaces of shearing in a thick homogeneous formation are distributed throughout its thickness, and are probably of small individual area, the displacement on each one being small; but in a flat bedded formation they probably coincide with the beds. In either case, here and there all local strains will be concentrated upon a single surface, which will, in consequence, have a large displacement and a large area. In such a case the recognition of a fault is an arbitrary matter depending upon the quantity of displacement adopted as critical for the definition of a fault; and all surfaces of shearing of less magnitude must be classed as joints. In the absence of any better means of designation, I shall refer to these as *shear joints.*

During deformation strains must tend to be concentrated in regions of weakness, relief of one strain precipitating others until all local stresses are relieved, down to the limiting strength of the material. In this manner, the contacts between formations, being lines of initial weakness, must become the chief loci of relief of strain; and in their vicinity faults and joints must be most abundant; this is notably true at Cobalt. This rule, however, is variously limited, and particularly applicable to contacts which were flat or nearly so before folding began, the shearing stresses due to folding being concentrated largely upon them, the very steep contacts being virtually immune. As would be expected the shearing and fracturing on the limbs of folds is proportional to the amount of folding.

The Cobalt Lake fault is the only known local representative of either of the major systems, and is the chief reverse fault that is not related to the folding shear strains, having an oblique shift of 500 feet, at an angle of 25 degrees with the dip, toward the west. All other reverse faults are related to the folds, and dip with their dips at the same or steeper angles, usually striking approximately with their

[3] C. K. Leith, Structural geology, p. 107.

strikes. On these the known shifts vary from one foot to approximately 100 feet, making various angles with their dips on the surface of movement. Some of them are on bedding planes in the Cobalt Series, and can scarcely be detected at certain points except by the measured shift on them. Others are more obvious, carrying as much as four inches of selvage, and having crushed and jointed walls; but the amount of crushing seems to be quite unrelated to the amount of displacement, apparently being more closely connected with the kind of rock. Often, also, striae on the fault surface plainly indicate the direction of slip.

Attention was called in a previous paragraph to the remarkable evenness of the original undeformed Keewatin surface upon which the Cobalt Series was laid down. It must be understood that this is to be taken in a broad relative sense. It is not conceivable, for instance, that it could approximate the evenness of a surface of sedimentation, but must necessarily have had small and perhaps gently undulating relief, the details of which could not now be defined, except by the fractures they would cause in the overlying formation as it was shoved over them during folding. These erratic fractures would tend to confuse the evidence gathered for use in other connections, without being of any value in themselves. Also, local strains would be set up by this means, which would be expressed as joints, sometimes, doubtless, of such a nature as to constitute vein fissures. These erratic and misleading fractures have caused a certain amount of error in ore predictions; but their influence in comparison with the other factors is usually small.

A distinct set of easterly-westerly faults is to be found in all parts of the district. They usually dip at angles varying from 45 to 90 degrees, the steeper ones predominating. They usually carry from one-half inch to six inches of gouge, and frequently have strongly striated walls, the striae often being perfectly horizontal. Now and then one set of striae is found crossing an older set. In one case a vein of silver and smaltite had been deposited on a strongly striated fault, and two subsequent movements had striated the ore, so that a hand specimen exhibited two sets of striae making an angle of ten degrees with one another. They are not strike-slips nor oblique slips in the strictest sense, but range from one to the other. The shifts usually vary from a few inches to perhaps 50 feet; and they cut through all formations and folds.

Joints.—The vein fissures are major joints of a type heretofore unrecognized, not being cooling cracks but being due to mechanical stress. They characteristically span the minor folds which pitch down the limbs of the major folds, more generally the minor synclines, or they lie along the axes of the minor anticlines. They also frequently lie along the dips of the major folds. They vary in length from perhaps 100 to 1000 feet, and in height from 50 to 500 feet. In their characteristic position, spanning minor synclines normal to their axes, they occur generally in groups of from two to a dozen spaced at intervals of not less than 30 nor more than 100 feet. Groups of this kind generally occupy the part of a minor syncline which has suffered the most acute compression. Their occurrence in these peculiar situations, parallel to the folding stress which produced them, has led me to name them *split joints.*

Major joints of this type have probably escaped the notice of other geologists, because by the time they usually become exposed to view on the surface by its degradation, the rock strains have been relieved by many lesser joints which are much more closely spaced, and thus obscure the manifestation of this older, less numerous, and more significant type. The recognition of them at Cobalt was unavoidable from the fact that they are virtually the only joints mineralized, since they were the only ones open at the time and place of mineralization. The fact of their containing veins often of pure silver was the extraordinary circumstance that led to their being scrupulously followed by mine workings for hundreds of feet along their strikes and dips, and thus brought to light.

Other types of mineralized joints are of less importance, but require mention; they are: (1) fairly strong joints of either no displacement or very slight displacement parallel to and in the walls of inclined faults, (2) strong vertical joints branching from inclined faults, but parallel in strike, (3) lesser joints, vertical, branching from inclined faults, and parallel to their dip, (4) strong joints branching from strike-slip faults, nearly parallel in dip, but diverging in strike.

All other joints are uncemented and have obviously originated after the period of mineralization. They are of two general classes, namely, those which are related to the cemented joints, and those unrelated. Each typical cemented joint is paralleled in its walls by one or more of the first class of uncemented joints; and each fault wall contains many and various joints of the same first class. Of the second class there is one type which bounds rhombohedral blocks situated and oriented not with reference to local structures, but rather to the major stresses. Jointing of this type is more abundant and more perfectly developed near the surface, and is to be regarded as a strictly surface phenomenon. Further notice of the uncemented joints is unnecessary beyond the observation that in general they grow less abundant and less perfectly developed with depth.

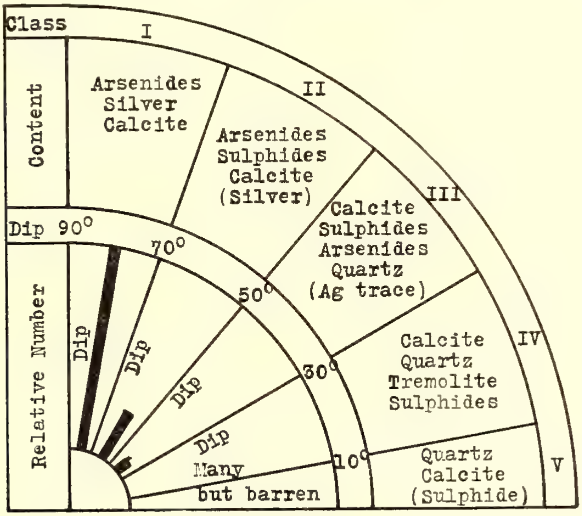

Fig. 3. Showing relation of vein content to dip of veins.

Cobalt-Silver Veins

The veins logically fall into the following types, which are arranged in the order of their productiveness: (1) The first or normal type includes only veins formed in split joints. (2) The second includes veins formed in major joints branching from or parallel to steep faults. (3) The third includes veins formed in faults. (4) The fourth includes veins formed in shear joints and faults of low dip.

Vein contents.—Calcite and dolomite are the characteristic gangue minerals, the latter being usually more intimately associated with the ores. The other constituents are grouped in the veins more or less together, and occur in accordance with definite rules, very interesting and significant relations being discoverable in them. The rules are for the most part well represented by the accompanying diagram[4] (fig. 3), in which the richness of veins is shown to be proportional to their angle of dip.

[4] After W. L. Whitehead, Econ. Geol., vol. 15, no. 2, p. 117.

As values are apparently related to gravitative stress (all veins having been formed during the same uninterrupted period), so are they related to horizontal stress, vertical veins parallel to a line of compression being typically productive, and vertical veins normal to it being typically unproductive. Furthermore, in a given vertical vein, parallel to a line of compression and rising from a strong shear joint or fault of low dip, but diminishing and finally vanishing in all directions in its plane outward from the flat shear, the values are greatest at that central point, and are arranged fanlike on the plane of the vein, diminishing to zero at the edges. Thus at the center of the fan is native silver in large proportion, associated with dyscrasite, and perhaps breithauptite, also with niccolite or smaltite; in the semi-circular zone immediately next to it are chiefly niccolite or smaltite or both with more or less gangue; while in the third zone is only gangue. These, of course, are typical relations, being departed from in different ways and degrees under various conditions.

Vein structures.—Although branching, reticulate, and offset veins are perhaps the rule, and twin or companion veins are more or less common, nevertheless the typical joint vein is a simple tabular body. Its walls, however, are not often sharp and free, but usually are "frozen" to the vein, and frequently blend imperceptibly into it. Inclusions in the veins, and parallel veinlets in the walls, are the rule. Frequently there is such a gradual transition from inclusions of wall rock in the vein, to thinner and thinner veinlets in the walls, that it is impossible to say where one begins and the other ends. The aspect is altogether that of reticulate and branching fractures whose walls have been replaced by a volume-for-volume reaction. Veins frequently are banded, but not continuously nor symmetrically, the banding not being due to crustification, but apparently to stages in the growth of the vein by replacement. Crustification has been recognized in a few cases; but it is quite rare. Inclusions of wall rock are of all sizes and shapes, in most cases retaining the same orientation as the unaffected walls.

A few instances have been noted where a vertical or steep vein has curved in its lower portion into a flat position, its mineralization changing as it did so according to the rule expressed by the diagram (fig. 3). In more cases, where a vertical vein rests upon or intersects a flatly inclined joint, the mineralization of one blends with the different mineralization of the other, as if they had been formed simultaneously.

A few stopes of high-grade ore were developed on the Cobalt Lake fault, where at first glance it would seem that, according to the rule, ore of that quality could not occur; but on close study it was recognized that these kidney-shaped ore bodies occurred where the fault surface had been warped by a subsequent minor synclinal fold, as a result of which the stress conditions in the fault walls must have been locally disturbed, the transverse compression being relieved on the limbs of the fold, thus making a favorable situation for the deposition of ore according to the stress rule.

The mineralization of faults even with calcite is usually discontinuous, and ore is very sparsely distributed. Another very significant relationship lies in the fact that the richness of veins is related with fairly pronounced consistency to the number and strength of shear joints or flat faults which intersect them, as if these had served as feeders for the supplying of ore materials to the veins.

Space relations.—In a region deformed as this was, it may properly be assumed that the folds, major and minor, with their various associated joints and faults, would not be limited to a particular horizon, but would be general throughout all known horizons; and this has been proved at Cobalt. The structurally favorable sites for ore deposition have, therefore, no immediate relationship to the diabase sheet. In view of this fact it is significant that only those favorable structures are mineralized which occur within 350 feet of the margins of the diabase, both in the diabase itself and in the adjacent Keewatin, or within 550 feet of the diabase in the Cobalt Series. This applies at both upper and lower margins of the sheet, indifferently, to 187 stoped veins and many nonproductive ones, including all the veins of the district without exception, as well as all known veins of the South Lorrain, Casey, and Gowganda areas, not to mention other known occurrences of either silver or cobalt ores in northern Ontario. In connection with this, it is an interesting fact that the ore bodies show no distribution with reference to steep faults or other deep-seated structures or contacts, while either commercial or non-commercial veins of silver ore, cobalt ore, or calcite with traces of cobalt or nickel are coëxtensive, over large areas, with the Nipissing diabase.

On a smaller scale, a very peculiar and interesting phenomenon is the relation of joint veins in the Cobalt Series to the bedding joints and faults, presenting the aspect of post-vein dislocations. Probably geological observers at first sight would almost unanimously pronounce most of these cases as prima facie evidence that the veins had been dislocated. Long and careful study of many such occurrences, however, has brought out evidence which seems to prove the contrary, namely, that the veins were formed in dislocated fractures. The fact that the surfaces of dislocation are not themselves mineralized with ore is the outstanding first-glance evidence against this interpretation; but it is only superficial evidence, and is illusory. By turning again to the diagram (figure 1) illustrating the stress rule of deposition, the true explanation of this condition will be readily seen. A more complete discussion of this matter will be taken up in subsequent paragraphs. In the meantime a study of the accompanying vein photographs will be of service (pls. 15, 16).

Paragenesis.—In typical cases where calcite or dolomite is the gangue for smaltite, niccolite, breithauptite, and silver, it is found that in different spots in a given vein or in different veins the spacial relations of these minerals vary. It is a common thing to find sheets of silver lying in fractures and cleavages of the calcite or dolomite; but it is an equally common thing to find masses of smaltite in the midst of carbonate as if of simultaneous origin, with wire silver imbedded in the unfractured smaltite. Smaltite fringes occur on carbonate veins, and carbonate fringes occur on smaltite veins. Breithauptite is commonly associated with silver more intimately than is niccolite, and niccolite more intimately than is smaltite, and both occur in associations with smaltite and silver. It is therefore impossible to recognize any consistent sequence in origin. Silver in many cases occurs in fractures in smaltite and niccolite, and yet a very common phenomenon is the occurrence of pellets of smaltite in dolomite, the pellets being from one to five millimeters in diameter, and containing a central pellet of niccolite or breithauptite, which in turn contains a core of silver, the metal being perfectly spherical in form. The carbonates vary from pure calcite to dolomite, containing notable percentages of iron or manganese, the latter imparting a strong salmon red color to many of the veins, and being regarded by the miners of the district as a "good sign." The distribution of these various carbonates makes it difficult to formulate rules that will consistently bear out any idea of regular sequence in origin. A rule embracing 75 per cent of the carbonate occurrences will not be sufficient to establish an age relation, for the 25 per cent of exceptions must be explained. The only rule which I have been able to develop is that the gray dolomite is the most usual associate of the rich ores, pink manganiferous carbonate is next most closely associated with them, and white calcite is more generally the filling of barren veins; but to this rule there are many and notable exceptions.

Native bismuth, dyscrasite, native silver, argentite, and proustite frequently occur in fractures in the ore bodies or in fractures in their walls, commonly penetrating the walls in this manner for distances up to 20 feet. This apparently sequential relation to the vein matter will be explained on a different basis in a later section.

THE GENESIS OF THE ORES

Believing it to be a more scientific method of treatment, I have endeavored to separate, as well as possible, description and inference. Inference necessarily enters into description in the guise of interpretation, and description to some extent must accompany inference in cases where its value and bearing would not otherwise be fully appreciated. However, it is the purpose of this section of the paper to present as exclusively as possible the results of research without which the statistics would be valueless; for no one can be in such a good position to correlate the facts of the case and indicate their significance as the one who gathered them; although he may not be able to present them in their entirety.

Diastrophism

Major structural axes.—A quotation in a previous paragraph shows that Miller suspected a genetic relationship between the cobalt-silver veins and certain major structures which are dominant throughout the mineral-bearing region, and which are indicated on the maps by long NE–SW and NW–SE chains of depressions, occupied for the most part by rivers and lakes. My observations have seemed to confirm those suspicions in the sense that these lines appear to be expressions of the general determining structural factor connected with the genesis of the vein fissures.

These and similar physiographic axes extend over a good portion of the pre-Cambrian area in Canada, but seem to be particularly pronounced on the map in the provinces of Ontario and Quebec. Their rule of arrangement apparently is that in any given area where system is observable, not more than two systems dominate, one being the complement of the other, save where one system represents the resultant between the other and its complement. In many localities described in the geological literature of Canada, these lines are known to be, or to be parallel to, lines of faulting or folding, or of foliation and metamorphism. In some areas these lines are known to be of great age, and are believed to have persisted by continual renewal from the earliest geological times. My belief is that most of them are earth-joint systems or deep-seated complementary fractures resulting from the deformation of the earth, dividing the crust into blocks, and constituting surfaces of variable adjustment, sometimes serving thrusts in one direction, and sometimes in another, the chief component of displacement being horizontal.

In the district about Cobalt these systems are represented, respectively, by the west shore of Lake Timiskaming, the Montreal River, the line of valleys including Cross, Kirk, Crown, and Goodwin lakes, and other parallel features, and by the axes of Kerr, Peterson, and Cobalt lakes, and the northwest arm of Lake Timiskaming. The exact nature of some of these local lines is not definitely known, but it seems highly probable that the west shore of Lake Timiskaming is determined by a fault which existed in pre-Cambrian time, and was renewed after the Silurian limestone was laid down, as indicated by the displacement and local tilting of the limestone. The evidence of pre-limestone faulting consists in the fact that the system of structures to which this fault belongs originated before the cobalt-silver veins, whose age is approximately Keewenawan.

So far as exploration has gone, there has been no proof developed of the character of the Cross-Lake structure, but jointing seems to indicate an axial fault. Such a fault has been found on Cobalt Lake, and this fault is believed by Miller and myself to extend southwesterly many miles, and northeasterly across Lake Timiskaming into the Province of Quebec.

In the Meyer workings of the Nipissing Mine along "490 Vein" an abrupt slope occurs on the old Keewatin surface. It proved to be 30 feet or more in height, and several hundred feet in length, dying out to the southwestward, and reappearing in the northeast end of the Townsite Mine. A higher but shorter rise of similar kind was discovered in the Chambers-Ferland Mine adjacent and parallel to that on the "490 Vein." Still another similar and parallel feature was found on Nipissing Hill north of the low-grade mill. The unconformable lapping of the overlying beds of the Cobalt Series against these small ridges would seem to indicate that they represent pre-Cobalt relief; and their parallelism with each other and the axis of the Cobalt Lake syncline, which is postdiabase in age, would seem to indicate that at least a parallel drainage existed on the pre-Cobalt surface. If this can be taken as evidence that the major line now represented by the ruptured Cobalt Lake syncline existed during the carving of the pre-Cobalt surface, then on this line we have evidence corresponding to that along the supposed Lake Timiskaming fault to show that such structural lines have persisted in activity through long periods of time, the Cobalt Lake fault probably having been active from pre-Cobalt to post-Keewenawan time.

Injection of the diabase.—Perhaps it is permissible to discuss in this place the injection of the sheet of Nipissing diabase, since I regard it as an important diastrophic agency; and although interest attaches to other aspects of its advent, its participation in the production of significant structures is sufficient reason for its special mention.

Attention was called in the first reference to the diabase to the fact that the margins are finegrained, indicating that at first the losses of heat to the adjacent rocks were more rapid than the accessions of heat from fresh arrivals of magma, and that the interior of the sill for 100 feet is of fairly even grain, and unsegregated. The mass must have slowly wedged its way into place, bodily lifting the roof an average distance of 1000 feet.

In the roof rocks of the sheet are certain faults and dykes of diabase, which seem to have had their origin in the uneven lifting of the superjacent mass as the sheet slowly entered its berth. Also in the configuration of the mass itself, there are abrupt slopes which indicate that it was injected along a warped surface. It must be admitted that the roof rock was lifted irregularly, and suffered jostling first from one direction and then from another. The structural effects of this process are nowhere determinable with exactness, because the overlying sediments have been eroded away, and the heterogeneous character of the basement complex has been responsible for such a differential propagation of stresses that the deformations defy analysis.

At the time of injection the Cobalt Series lay perfectly flat and undisturbed. The entering magma probably wedged open its own channel, since the form of it is quite arbitrary and undulating, in some cases following, and in others ignoring contacts and bedding planes. When the invasion was completed the sheet had a roughly uniform thickness over the entire area, but topographic relief was most likely reflected through isostatic adjustments as an influence tending to produce unevenness in the sheet's thickness, which varies from 600 to 1100 feet, and more.

The heat given off from the mass must have so expanded the adjacent rocks as to set up severe strains in them; but if the accessions of magma were as I have indicated in a previous paragraph, these heat effects could scarcely be discriminated from those which accompanied its contraction. In considering the mechanical effects of this magmatic heat it would be the logical thing to divide them on a time basis separated by the instant when expansion had reached its maximum. It is generally admitted that the heat conductivity of rock is very low, and that at the time of its injection an igneous mass does not impart its heat to a great thickness of wall-rock surrounding it. Assuming a depth of 24,000 feet, and a magma 1800° F. above the temperature of its walls, Daly[5] calculates that in average rock at a distance from the magma of 400 feet no heat would be felt in the course of 16 years, and that in 100 years the temperature would have been raised only 283° F. In view of this it would be difficult to imagine that the vertical expansion of the foot wall of the diabase sheet at Cobalt could have amounted to many feet during the entire period of injection and solidification of the magma. However, the expansion tendency of this rock would not have been only upward; it would have been also lateral; and the summation of that tendency over the lateral dimensions of the sheet must have totalled to a force of considerable magnitude. The escape of this increased volume of rock, inhibited laterally, must have been upward; but its upward movement would have been caused by reaction against the force of its lateral expansion, taking the form either of reverse faulting or of folding.

Since the margins of the sheet are chilled, and no assimilation of its walls occurred, it must have made room for itself by mechanical displacement, probably entering as a thin wedge, and splitting its own path before it. This procedure is evidenced by the indifferent transgression of the surface of injection across beds and contacts. It is very significant that the original undulations of this surface conform to the major structural axes of the region, as if following a zone of weakness and shearing due to incipient folding on those axes. If it be assumed that the magma ascended from the depths along one of these axes, advancing laterally with a fairly even front from that starting point, then perhaps the lateral pressure resulting from the expansion of the underlying rocks would have advanced before its wedge-like front parallel with its initial alignment causing incipient folding parallel with the structural axes, which thus produced the zone of weakness invaded by the magma. This method of origin of the

[5] Igneous rocks and their origin, p. 198.

undulations, however, is dubious, being possible only if the magma advanced slowly. In any case, a secondary warping of the surface of injection in the first period of heat deformation would probably have been parallel with the chief structural axes and coincident with the original undulations of the diabase sheet, since those undulations represented directions of maximum length of the sheet, and axes of minimum resistance to folding.

In the first heat period, deformation must have been caused chiefly by reaction against the lateral expansive force generated by the distension of the wall-rocks. It would have behaved in every way as an external compressive force exerted parallel with the major structural axes; and the folds induced by it in the diabase and wall-rocks must have possessed the usual characteristics of folds due to compression. But this folding would have deformed the plastic diabase, and would therefore have left no record in it. When the temperature of the immediate walls had become approximately the same as the interior of the sheet, expansion may, perhaps, be said to have attained its maximum. At that juncture the walls would have reached their maximum content of heat, while the diabase would, some time since, have been undergoing contraction. This condition must have produced true cooling cracks in the diabase; and some of these might have formed avenues of escape for small quantities of aplitic and pegmatic material. This in fact appears to have occurred since the few vein-dikes of this material which have been found are in fissures which seem to have, as a rule, erratic orientations.

From this point onward the sole influence in diabase and wall-rocks would be contraction. Not only would an arch or sag in the heated zone tend to draw in upon itself, matching its tensile strength against its own shearing strength, but the shrinkage of the entire length and breadth of heated rock would have borne in upon the regions of yielding, consisting of the initial undulations, tending to accentuate them by folding. This period of deformation would have left its traces in the diabase because this would have been solid and resistant.

The foregoing suppositions are offered as an explanation of the observed fact that the folding of the district, affecting both the adjacent sediments and the diabase itself, developed innumerable large and small surfaces of shearing in both formations parallel with the surfaces of folding, which in their turn paralleled the original undulations of the diabase sheet. This phenomenon has been observed also to some extent in the South Lorrain and Casey areas.

On several of the lesser faults of the district evidence in the way of superimposed grooves on slickensided surfaces indicates movement in different directions at different times on a single fault. In view of such other evidence as reversed sequential relations in minor faults and joints, it seems clear that stresses on the complementary structural axes must have been active alternately in one direction and then in the other. From the orientation of the structures as described, it appears that the principal structural stresses must have been in a general sense simultaneously active throughout the period of deformation which immediately followed the injection of the diabase. This being true, there must have been times when there was simultaneous stress from two oblique directions producing torsion effects; and this is borne out by numerous examples throughout the district, of groups of small gapping fractures arranged in echelon. Whether these stresses sprang from the same source as those which produced the major complementary structural lines, or resulted from movement upon them, or whether they were directly due to the shrinkage of the diabase and its environs due to the loss of heat, is difficult to decide; but whatever the source, it may be presumed to have been not spasmodic and variable, but continuous, the apparent alternations being due to the fact that the media under strain were of various strengths. The network of stresses over the region would thus be finding relief in a given direction at various points at the same time, and at intermediate points simultaneously in the complementary direction; here and there torsion would arise from the relief of strain in both directions at the same time and place. Strain resultants might also be expected; and fractures thus oriented are not uncommon.

Minor structures.—The most significant of the minor structures are the split joints, which occur most characteristically in groups spanning the minor synclines, or extending along the axes of minor anticlines, or which occur singly and less frequently striking with the dips of the limbs of major folds. In detail, a split joint is typically a single strong major joint; but frequently it consists of a pair or triplet of fractures, or a chain of branching and reticulate fractures having a zonal width of between five and fifteen feet.

The split joints in a major syncline have difficulty in completely spanning the structure, and are generally related to the limbs rather than to the structure as a whole; but a minor syncline is usually completely spanned by them, and on its limbs they will intersect not only the shear joints developed on the sides of the major syncline down which the minor one pitches, but also those developed on the limbs of the minor syncline due to its own lesser folding.

If minor synclines and anticlines pitch down the sides of a major syncline, and folding is renewed on the latter, then the minor anticlines will act as resistant ribs tending to oppose the folding. They will therefore receive a heavy endwise thrust, and split joints will develop along their axes, the earlier transverse split joints at the same time being closed. However, if this renewed major folding were only slight, it might explain irregular conditions of stress in the walls of the two intersecting sets of joints. This is the anomalous condition under which mineralization took place in the veins of the Crown Reserve and Kerr Lake mines.

It would seem that these joints must have been produced under conditions of large differential stresses capable of splitting the rock in such extensive fissures against a general three-dimensional stress due to the effect of gravity upon this resilient medium. There was a fracturing force, and a resisting pressure which tended to limit fracturing to such places and intervals as would give the maximum relief to the differential stresses, with the minimum of openings. It must be inferred from the facts thus far presented that when the vein fissures originated the rock containing them was at a sufficient depth below the surface to be incapable of developing small joints. The measure of that depth can only be roughly approximated. From the nature of fractures generally encountered in mining operations, I would postulate a depth of several thousands of feet; and this may well be assumed, for the time which elapsed between the invasion of Nipissing diabase and the carving of the surface upon which the local Silurian limestones were laid down, probably includes the Cambrian and Ordovician periods; and in that span of time there may have been considerable material eroded from this region. The explanation of the existence, position, and character of the gaping fractures must then lie in the reduction of gravitative stress effected by the degradation of the surface. These fractures have opened in the walls of cemented split joints and elsewhere in further relief of the elastic deformation produced during the folding.

The steep easterly-westerly faults, although in some instances striking due east and west, and frequently departing from that direction by only small angles, vary in important instances from a strike of N 70 W to S 70 W. The major structural axes of the region strike respectively N 35 W and S 42 W, the major folding having occurred parallel to the latter axis. If before deformation, a circle had been drawn about the area at the horizon of the present surface, after deformation it would have had the form of an ellipse whose longer axis would have been only slightly greater than the short one, and would have had a strike of perhaps N–S. The two diameters connecting the four points of intersection of the circle and the ellipse might then have had strikes approximating N 70 W and S 70 W respectively, these being axes of maximum shear.[6] This may explain the mysterious easterly-westerly faults. The difficulty with this explanation, however, is that it implies contraction in one horizontal direction and elongation in another, whereas the escape of material due to the twofold compression must have been upward. It would seem more satisfactory to regard these faults as expressions of the resultant of the two horizontal compressive stresses as they acted upon non-homogeneous media, the variations in strike representing the intensity fluctuations of the forces. At any rate these faults seem to be closely tied up with the deformative forces which accompanied the cooling of the diabase, since they traverse it, and in two instances, where they meet the Cobalt Lake fault, are dislocated by it. One of these is on the La Rose property northeast of Cobalt Lake, and the other, on one of the Hudson Bay claims southwest of the Lake. The fact that such faults sever the diabase sheet, as in the O'Brien and Beaver mines (although scarcely dislocating it), need cause no confusion in this regard, since the compressive stresses caused by the radiation of magmatic heat were generated not only in the diabase mass itself, but also in the heated rocks adjacent.

Summary.—The significant relationships of time and structure in the ores of the Cobalt District probably center about the advent of the diabase. The Cobalt Lake fault in its earliest activities dates back to the early part of the erosional epoch preceding the laying down of the Cobalt Series, the supposed Timiskaming fault dates back at least to pre-Silurian times, and each of these faults represents one of two oblique complementary systems of lines of deep-seated diastrophic adjustment. These axes of strain presumably determined the warped surface along which the diabase sheet opened its way during injection, as it assumed its present position, lifting the roof rock a distance of 1000 feet. Its advent was accompanied by deformations due to the heat-expansion of the neighboring rocks which were slowly raised to the same temperature for a considerable distance back from the magma.

[6] C. K. Leith, Structural geology, p. 16.

As the diabase sheet cooled and contracted, it tended to accentuate its own undulations parallel to each of the major tectonic lines; and when this process was completed the force exerted by the cooling magma was greatly exceeded by the contraction of the inclosing rocks. This shrinkage, conformable with the two controlling tectonic axes of the region, gave rise to folds parallel to them, and at the same time gave rise to associated faults and joints. The Cobalt Lake fault reopened as a rupture along the axis of the Cobalt Lake syncline, displacing the Cobalt Series a distance of 500 feet diagonally upward, dislocating certain of the easterly-westerly faults, and being followed by folding parallel to the other axis. As these deformations began, the first effects were the inception of NE–SW folds accompanied by the development of shear joints and reverse faults, then by split joints and the E–W faults, then by dislocation on the Cobalt Lake fault; then came minor folding superimposed on the other, parallel to the NW–SE axes, and the warping of the surface of the Cobalt Lake fault where two of these minor synclines cross it. There followed further intensification of all the folds, and the considerable dislocation of many split joints on shear joints and flat dip-slip reverse faults. Then came the ore.

Current Theories of Vein Genesis at Cobalt

Descending solutions.—In view of the fact that these veins contain large percentages of native silver, dyscrasite, argentite, and proustite, easy first thought supposes that they may have originated through processes of downward secondary enrichment. Some writers have suggested that the veins at Cobalt may be the roots of vertically more extensive veins of cobalt and nickel poor in silver, which have been enriched through the solution of the silver of the upper portions of the veins in the products of their oxidation, and its redeposition in their lower portions through the precipitating agency of smaltite and niccolite. Research may have demonstrated the feasibility of this precipitation process; but it is more relevant to the problem in hand to consider whether such solutions could ever have been delivered to the cobalt veins.

The consideration of any one of a number of conspicuous conditions would suffice for the rejection of any idea of downward secondary enrichment. First of all, the products of oxidation of the veins would be preponderantly arsenious and scarcely at all sulphurous; and at no place in the district are the lower portions of the deepest veins different in composition from the upper portions of the outcropping veins, there being no evidence that either silver or the other metals ever existed in that region in any other condition than that in which they are found just below the outcrops. Furthermore, no veins at any time in the camp's history have shown consistent oxidation to a depth of more than a few inches or feet, except in two or three anomalous cases due to peculiar local conditions; and no consistent nor even certain enrichment has been found below these insignificant zones of oxidation. Generally where arsenides outcrop they are fresh and unoxidized, or only crusted with a thin layer of erythrite or anabergite. Many veins which have proven rich in their lower portions grade upward into barren arsenides and then into unmixed calcite. In addition to these facts it is important to recognize that the water table throughout the northern portion of the Province is virtually at the surface; and it is highly improbable that it has ever been lower.

Ascending solutions.—After many years of mining it has become strikingly apparent that the ore bodies are distributed marginally with reference to the sheet of Nipissing diabase. Probably the depositions of ore were equally distributed with reference to both margins; so far as available evidence goes, that is true; but on account of erosion the chief production of the district has come from beneath the diabase. If the source of the ore were the visible diabase mass, it would be difficult to understand how this condition could have been brought about by ascending waters. If another igneous source is assumed it must have reached the level of the present surface, or have betrayed itself in some other manner; or else it must lie far below the present surface; but no such intrusive synchronous with or subsequent to the diabase has been found. If such a deep source is postulated, then the means by which its emanations reached the present horizon must receive scrutiny.

When attention is given to possible ore conduits and channels of distribution, it is recognized that the strike-slip faults, as a rule, having horizontal lengths of less than 4000 feet, and being due to horizontal stress, probably have less vertical lengths, while the common dip-slip reverse faults lie only on the limbs of the folds. The only faults, therefore, which could be presumed to penetrate to the required depths would be those on major tectonic lines, of which the only known representative in or near the mining district is the Cobalt Lake fault. There is known to be no such fault along the Peterson Lake syncline, nor the Kerr Lake anticline, nor in the neighborhood of either Glenn Lake or the Timiskaming and Beaver mines; and yet those have been very productive localities. Also the Cobalt Lake fault has not been productive to any notable extent, only small quantities of ore occurring within 400 feet of the surface for very limited distances along its strike, much exploratory work having been done on it only to prove it generally barren. Those who look to ascending solutions for the origin of these ores should certainly expect to find such a fault lined with ore bodies, or to find the ore bodies of the district grouped with reference to it. If they say that the ore-bearing solutions ascended along it, and upon reaching the diabase contacts, spread out along these to do their work, the answer is that, if that is true, those solutions then began at once to deposit ore in neighboring fractures—selecting only one particular kind—and that they must then have moved along these undulating contacts, ascending and descending, as far as the Timiskaming mine, where ore bodies as good as any in the district were deposited, no trace of these solutions being left along the contacts themselves. In view of the obvious difficulties in the way of this supposition, and the conspicuous scarcity of ore on the Cobalt Lake fault, the theory seems entirely untenable.

It is further to be noted that although commercial ore bodies have been mined in the South Lorrain, Casey, and Gowganda areas, no faults of any description have been found to carry notable quantities of ore there, and the ore bodies mined seem to be wholly unrelated to any sort of faults or steep contacts. Even in the Cobalt district where rich ore bodies have been mined on steep-dipping minor faults, such occurrences are the exception rather than the rule.

In times past there was waged a notable controversy on the matter of the circulation and burden of underground waters, one side maintaining that the source of ore-bearing waters lay in congealing intrusive masses, while the other side held their origin to be atmospheric. The waters were presumed to be either juvenile or meteoric, and to have circulated in such quantitity along the sites of ore-deposition as to have brought thither, in spite of their acknowledged diluteness, all the ore-forming substances. It is interesting to note that each side showed the suppositions of the other to be untenable, and its kind of water to be incapable either of acquiring an adequate mineral burden or of flowing in sufficient quantity to accomplish the work ascribed to it. In my study of the problem of vein genesis at Cobalt I have been forced to the conclusion that each side in that controversy was correct in its exclusion of the claims of the other.

In the year 1893 Franz Posepny expressed his idea that the bulk of mineral-bearing waters are essentially meteoric. He said:[7] "There is a descent of groundwater through the capillaries of the rock, even in the profound region. Having arrived at a certain depth it is probable that a lateral movement takes place toward the open channels. Having reached these it returns, ascending to the surface." In this opinion C. R. Van Hise concurred. He defined capillary sheets as having widths varying from 0.204 mm. to 0.0001 mm., and indicated his belief that heat, pressure, and time must tend to increase the mobility and flow of water in the deep regions, as against the counter effects of friction and discontinuity. He says:

We conclude from the foregoing, that while underground circulation of water upward, downward, and lateral, is a possibility within the zone of rock flowage, it is very slow, and that it can not be appealed to to explain metalliferous deposits.[8] However, the ores are directly derived from rocks in the zone of fracture by circulating underground waters. The rocks which furnish the metallic compounds may be intruded igneous rocks; they may be extruded igneous rocks; they may be original rocks of the earth's crust; they may be sedimentary rocks; they may be the altered equivalents of any of these.[9] . . . . Hence so far as the main work of ore deposition is concerned, the water is that of the zone of rock fracture, and this water is water of meteoric origin, which makes its way from the surface into the ground, and there performs its work and issues to the surface again.

T. A. Rickard also concurred;[10] and A. C. Lawson treating the subject at greater length said:[11]

The circulation of the ground-water would in every case be profoundly disturbed by the injection of hot igneous magmas into sedimentary terranes. The disturbance would, however, be far from chaotic. The presence of the hot body would be the controlling influence in determining the circulation. The circulation would always be upward on the periphery of the hot mass. This would be true not only while it was still molten, but also long after it had solidified. Such a circulation of the heated ground-water would be quite competent to do all that is ascribed to magmatic water, including the formation of lime-silicate zones. It would not only bring to a zone of active chemical reaction the materials leached from the surrounding region, but it would attack the still hot, though solid, igneous mass itself and abstract from it part of its metallic constituents. . . . . I will first, however, disclaim the belief, which I fear will be imputed to me if I do not anticipate the imputation, that the sedimentary rocks of the earth's crust everywhere contain similarly large quantities of water. . . . . The inequality of

[7] The genesis of ore deposits, p. 38; also A. I. M. E. Trans., vol. 23, p. 197, 1893.

[8] Some principles controlling the deposition of ores, A. I. M. E. Trans., vol. 30, p. 45.

[9] *Op. cit.*, p. 46.

[10] Eng. and Min. Jour., Feb., 1894.

[11] Ore deposition in and near intrusive rocks by meteoric waters, Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, p. 221, 1914.

distribution is, however, due to the variation in size or in prevalence, or both, of the voids in the rocks. . . . . Nevertheless all sedimentary rocks below the water-level are saturated to an unknown but great depth. But saturation does not imply an abundant flow to a conduit or fissure. . . . . But making all allowance for this diminution of storage capacity there is a vast quantity of water contained in the sedimentary rocks in their unaltered state at all depths; and at high temperatures, which are an essential condition of our problem, the rate of flow and therefore the rate of escape to fissures, etc., is undoubtedly accelerated. Moreover, brittle rocks such as quartzite, sandstone, and limestone, which have been folded and otherwise disturbed, are usually traversed by fractures, faults, and joints, and these, together with the partings of stratification, afford comparatively free access of surface waters to the limit of the zone of fracture of such rocks.

He also points out that both walls and periphery of an igneous mass will probably be fractured as a result of cooling phenomena, and that the ground water will move laterally through fractures and through them ascend both beside and through the igneous mass. Farther on he says:

The failure of ''evidence of fracture or paths which could have been followed by the water'' applies equally well to magmatic as to meteoric waters, and is of little moment when we reflect that the water in either event was probably in the form of superheated steam.

In the concluding paragraph of this same paper Lawson says:

Now if the view which Spurr expresses is correct, and it is substantiated by a great many observations, the hypothesis of magmatic waters becomes far-fetched and difficult of acceptance. It throws us back for the source of the solutions upon a residual differentiate far in the depths, as Spurr holds. It fails to account for the restraint of the magmatic waters till this residual stage is arrived at. It assumes great depths for small intrusions which were probably injected from narrow vents. And it fails to explain the peripheral disposition of the ores deposited from the waters thus rising from a presumably central reservoir.

Waldemar Lindgren in his ''Mineral Deposits''[12] indicates his belief that the flow of water through rock pores is exceedingly meager and practically nil at really moderate depths.

Kemp and Fuller have both brought out the fact that the deep sedimentary beds are often remarkably dry. The well 4262 feet deep at Wheeling, West Virginia, was in absolutely dry rocks for the lower 1500 feet. Wells sunk at Northampton, Massachusetts, and at New Haven, Connecticut, to depths of 4000 feet have failed to obtain water. A number of other instances are mentioned, and in many cases the dry part consists of sandstones or other porous rocks.

Again he says:

Van Hise suggests that the decreasing density and viscosity of water at higher temperatures may lessen the head necessary for ascending springs, but it may be doubted whether these factors would ever offset the great friction encountered during the downward passage.

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[12] Edition 1919, p. 29.

Also:

> In conclusion it is believed that water in quantities sufficient to supply an ascending circulation can only exceptionally attain a depth of 10,000 feet and that, except in regions of great dynamic movements, the active circulation is confined to the uppermost few thousand feet. More commonly the depth of active circulation is measured by the level of surface discharge and the water below that level is practically stagnant; the lower limit of the body of stagnant water then forms an irregular surface descending to greater depths along the fractures and rising higher in the intervening blocks of solid ground.

In regard to the magmatic origin of mineral bearing waters Lindgren says in a later chapter:[13]

> The water existed in the solution constituting an igneous magma. Crystallization of the magma or its irruption into higher levels of the earth's crust liberated the water as one of the most volatile constituents, thus permittinig its ascent to cooler regions. Such water may be called magmatic or juvenile.

Then:

> Volcanic phenomena are almost always accompanied by the emissions of large quantities of steam and other volatile substances, and geologists generally have agreed that part of this water is a contribution to the atmosphere and hydrosphere from the magmas. . . . . Regarding plutonic rocks the direct evidence is lacking but indirect testimony is supplied by the inclusions of aqueous solutions found in granular rocks and by the presence of minerals like mica and amphibole which contain the hydroxyl molecule. . . . . The best general evidence of the existence of juvenile waters is furnished, not by observation of the present springs, but by the study of old intrusive regions. Here the granites merge into pegmatite dikes, the latter change into pegmatite quartz, and this into veins carrying quartz and metallic ores, such as cassiterite and wolframite. Here we have evidence difficult to controvert that dikes consolidated from magmas gradually turn into deposits the structure and minerals of which testify to purely aqueous deposition; this admitted, it is difficult to see what would prevent such waters from reaching the surface in the form of mineral springs. . . . The constant admixture with vadose waters forms another difficulty, but accounts well for the many derivatives of varying characteristics which accompany every spring of deep-seated origin. . . . . Much more work must be done before we shall be able to establish the magmatic origin of any given spring.

J. F. Kemp[14] in general agreement with Lindgren, argues that at varying depths below 10,000 feet the friction resistance offered to the flow of ground water in fissures must seriously limit its mobility and the quantity which can descend or flow laterally; while at higher levels the significant circulation of descending waters, in so far as they move in notable volume, must be confined chiefly to fissures. On the basis of experiments performed by himself he points out that the volume

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[13] Chap. VI, p. 87.

[14] The problem of the metalliferous veins, Econ. Geol., vol. 1, no. 3, p. 225, Dec.-Jan., 1906.

of water under atmospheric pressure which will be absorbed by granites, diabases, and gabbros is equal to from one ninetieth to one one-hundred-and-tenth of the volume of the rock, and that this ratio would be sufficient to bring the water in contact with only from 1 to 15 per cent of the leachable ore material contained. It would therefore be very difficult for the descending water to leach any significant metallic content from any formation along its deeper course, no matter how hot and chemically potent it might be.

It has been impossible in these few paragraphs to do full justice to both of these views of eminent disputants; but I trust no injustice has been done in thus partially quoting them. They seem in the main to agree that the circulation of ground water must be chiefly and almost exclusively through fissure conduits; for its circulation is excluded from the rock pores, in which it is generally admitted to be present in a state of virtual stagnation, by the influence of adhesion and the loss of head energy through friction in the capillary and subcapillary spaces of most firm rocks, increased mobility due to heat notwithstanding.

Partisans on both sides have indicated their belief that the mobility of fluids in small pore spaces may be greatly increased by heat; but none of them makes a strong point of it nor mentions the fact that in the passage of any fluid, no matter how highly heated, through capillary and subcapillary openings, its progress would be so slow that it could not be presumed to carry heat above that of the rocks through which it is passing. In fact, its initial pressure would probably be converted by friction into heat and thus lost to the surrounding rock.

In spite of this fact both schools conceive water circulation to be the principal agency by which the ore materials are transported and deposited, apparently overlooking the fact that crustification deposits are in the minority, most ore bodies being due to replacement and impregnation of wall rocks. On the hypothesis of deposition from circulating solutions they are obliged to interpret metasomatic deposits as due to the passage of immense volumes of dilute mineral waters through the pore spaces of the wall rocks, from which the disputants have excluded themselves by their own arguments. If a fissure too narrow to exhibit the phenomena of crustification becomes sealed in the first stages of vein formation, as must be the case since the major circulation and easiest deposition would be along the open channel rather than in its walls, why should the mineral-bearing solutions thereafter prefer to circulate along its frozen and irregular walls rather than elsewhere through the rock, where the pore spaces are just as large and the impediments no greater?

One school has argued that meteoric water would have great difficulty in attaining any but a very weak concentration in metalliferous minerals before reaching the vicinity of a freshly intruded igneous mass, and that it would also have difficulty in approaching the latter through the rock pores to absorb further quantities of mineral, on account of the heat present. On the other hand the opposed school has indicated that meteoric waters could pass through rock pores as well as magmatic waters, that they could issue hot from fissures in the walls and through the interior of an igneous mass on an equal footing with juvenile waters; and as pointed out by Lawson with particular strength in the paper above referred to, the idea that juvenile mineral-bearing waters may issue in quantity from a marginally crystallized magma is weak in that it assumes the restraint of the magmatic waters from escaping until the last stage of segregation when the pore spaces of the crystalline margins would offer a serious barrier to its escape.

R. A. Daly in his book, "Igneous Rocks and Their Origin," makes the strong point that the long preservation of the heat and life of volcanoes is most easily interpreted as being due to the continual migration to the vent, of masses of gas-rich magma from all parts of the fluid reservoir beneath. These partial segregations of volatile constituents of the mother-magma occur here and there through its mass, or along its periphery, and by virtue of the lightness imparted to the portions of magma in which they are occluded, these rise to the margins of the reservoir, drift along its roof to the extrance of the vent, and thence rise to its crater where they escape by explosion or quiet bubbling according to the concentrations of gas in them. On this basis it can be easily understood that the great quantities of water given off as steam at volcanic vents is misleading as to the proportion of volatile material contained even in hydrous magmas. The flow of lava from a vent might thus represent merely the escape of the masses of convected magma which served as the vehicles for segregations of magmatic gases. From other considerations advanced in Daly's book it is also easy to understand that a magma which comes to rest beneath the surface might be relatively deficient in volatile materials, since if these were present magmatic "blow-piping" would have taken place in a "cupola" above the mass, fluxing and stoping a passage for the ascent of the magma to the surface. These considerations must materially detract from the weight of the argument that volcanic phenomena indicate the presence of large quantities of water in magmas, and that batholithic or laccolithic masses may be presumed to exhale considerable quantities of it either before or after crystallizing.

The phenomena of aureoles about igneous masses and of pegmatitic offshoots are usually interpreted as indicating the escape of juvenile waters from the magma. Some mineral springs may be placed in the same class of evidence. In mineral springs we have to account for mineral, heat, and water. Lindgren indicates in the above quotations his suspicion that vadose water may greatly augment the volume of such springs; and Lawson points out convincingly that such springs may not only be augmented by additions of vadose water, but that almost the entire volume may be meteoric, having passed through fissures in the igneous mass itself, arriving there through fissure conduits from distant sources. All parties agree that the heat and mineral content may be of igneous origin; but that argues nothing relative to the passage of large quantities of juvenile, or of meteoric water either, for that matter, through rock pores. Even pegmatitic and pneumatolitic phenomena argue nothing as to volumes of water. They merely indicate transfers of material. Their transitions in mineral content and various other evidences point strongly to a fluid medium of transfer, but neither to its volume nor to the duration of the process of dike and vein formation. The dikes appear in many cases to occupy fissures, but in others there is a vague transition from pegmatite to mother rock. The material may have been expelled from the igneous source in a single short interval, along a fissure; and the excretion may have been a very rich liquor of comparatively small volume. In any case there is no sound evidence of long continuance of the process, nor of the issuance of large quantities of water such as would be implied in the idea that these phenomena were connected with hot springs. The same holds for aureole phenomena. The assumption of large emanations of water is unwarranted. There may be a way of understanding the migration of material without recourse to the postulation either of the escape of considerable quantities of water from an igneous mass or of its passage through rock pores.

Crustified veins may be regarded as good evidence of the passage of large volumes of hot mineral-bearing waters through open channels, issuing at the surface as mineral springs; but here as in the case of mineral springs in general the waters are probably dilute and of meteoric origin. At any rate it does not follow that the same sort of solutions circulated through the rock pores to produce metasomatic deposits. These latter phenomena belong in an entirely different category.

When a fissure becomes sealed by a mineral vein, and the vein continues to grow by marginal accretion, whatever conditions may have existed there to direct the flow of mineral-bearing solutions, they have been obliterated by the freezing of the vein to its walls, and its penetration into them. After that stage is reached the hypothetical waters are as free to move through the pores of the country rock in all upward directions as along the sides of the sealed fissure. There is no directive force in hydrostatic pressure. But if instead of moving waters, we assume the means of mineral transportation to be the force of diffusion, driving migrant ions along the capillary and subcapillary passages of the rock, then precipitation will be a directive force capable of compelling the limitation of the diffusing of the metalliferous ions to the shortest available paths leading to the seats of deposition. The feasibility of that process and its application to vein genesis at Cobalt, I will attempt to make clear in the succeeding paragraphs.

General Role of Diffusion in Vein Genesis

In approaching the subject of geological diffusion the first question to be met is: How is diffiusion through large masses of rock to be reconciled with our conception of the processes of geochemistry? High heat and pressure are of course involved, but we are very apt, on account of our petty habits, to overlook the most important factor, namely, that of time. In considering whether concentrations of mineral have been effected chiefly by the mechanical circulation of solutions or by the diffusion of solutes through relatively stagnant solutions, one finds it easier to see efficacy in flowing ground water than in the tedious slowness and seeming weakness of diffusion. Forty thousand years is the time estimated by some authorities since the continental glacier disappeared from Ontario, yet the glaciated surface in many spots still retains its polish. Vastly larger figures are used to represent the duration of the Pleistocene period; but that period, in its entirety, is short as compared with other periods. If diffusion is a slow and weak process, it might nevertheless, in the long span of time at the disposal of the genetic processes operative at Cobalt, have accomplished surprising results.

The reconciliation of our notions to the idea that diffusion can produce large ore bodies must necessarily center about an analysis of the mechanism of diffusion, and also about a scrutiny of rock media as sites for its operation. Whatever may be the intimate nature of the phenomena their general characters are familiar to everyone. Osmosis may be looked upon as a tendency of water or any solvent to mingle to the maximum with a solute, while diffusion may be looked upon as the reciprocal tendency of a solute to become equally distributed throughout a solvent. R. E. Liesegang[15] has pointed out that a large molecule behaves in a manner intermediate between a colloidal particle and an ion, diffusing with great slowness against gravity, while an ion diffuses with comparative rapidity. It appears that diffusion is roughly inversely proportional to the size of molecules and ions, and that dissociation is proportional to heat and pressure. Soret has also shown that diffusion is proportional to temperature; while Fick has shown that the rate of diffusion is proportional to concentration. G. F. Becker,[16] applying Fick's law mathematically, has derived some useful figures showing the distance covered by a diffusing salt in a given time. He says:

> In "linear" motion as defined by Fourier the subject of motion, or the "quantity" as Lord Kelvin calls it, varies only in one direction; in other words, it remains uniform at all points in any one plane at right angles to this direction. . . . . For quantities obeying the law of diffusion the differential equation is $\frac{dv}{dt}=k\frac{d^2v}{dx^2}$. Here v is the quantity, t the time, x the distance from the plane of contact between the subject of diffusion and the medium into which it diffuses, and k is the "diffusivity" assumed to be constant. The equation may be expressed by the statement that the time rate of change of quality is proportional to the space rate of the space rate of change of quality. . . . . The quality at any distance measured perpendicularly to the initial plane is then proportional to the area of the "probability curve" taken between certain limits. . . . . If the accessible tables have the usual form, it is only necessary to write the equation as follows:
>
> $$\frac{v}{c}=1-\frac{2}{\sqrt{\pi}}\int_o^q \epsilon^{-q^2}\,dq$$
>
> In this equation c represents initial concentration, and $q=\frac{x}{2\sqrt{kt}}$. . . . . the least laborious method is to assume q at some tabulated even value, find x or t from the first of the above equations and v from the second.

[15] Geologische Diffusionen, p. 5. See also Wolfgang Ostwald, Handbook of colloidal chemistry.

[16] Note on computing diffusion, Am. Jour. Sci., ser. 4, vol. 3, art. 25.

Pointing out the laboriousness of computation from this equation as it stands he then undertakes its simplification. He says:

> The abscissa of the probability curve is not the natural independent variable for calculating diffusions. Greatly preferable is the quantity $\frac{v}{c}$. . . . . What is needed to facilitate computations of diffusion in a neat form, such as will not require diagrams to render the relations clear, is a table in which q, or better $2q$, is expressed in the terms of v/c. Such a table is given below, but only in skeleton for intervals of v/c of .05. . . . . Knowing $2q$ for a stated value of v/c the value of x in centimeters follows easily from the equation, $x = 2q\sqrt{kt}$. . . . . The values of $2q$ are given in part because they are the distances in centimeters after the lapse of one particular time, that, namely, which is the reciprocal of the diffusivity. Thus in the case of salt with a diffusivity of .00001, after a lapse of 100,000 seconds, or some 28 hours, $kt = 1$ and $2q$ represents the distance answering to v/c.

In computing the table referred to, his value for the diffusivity of salt, $k = .00001$, refers to a concentration of 0.14785 gms. per cubic cm. at a temperature of 7.7°, then for the dilution of $v/c = 0.5$ per cent he finds that in 100,000 years salt would diffuse a distance of 731 feet.

In rock media water must be considered as dispersed in films through the pore spaces, and a diffusing substance would therefore have to travel a relatively great distance to obtain only slight dilution. The tendency would probably be for it to move more rapidly through space, but this would be to some extent offset by the tortuousness of its path. In the face of these considerations the evaluation of the rate of diffusion can not be greatly assisted by mathematical calculation, but must depend upon experimentation. This, however, is a difficult matter, since the duplication of geological conditions in the laboratory would be very dubious, especially in view of the necessary magnitude of the time factor. It is therefore necessary for the present to depend chiefly upon the results obtained in nature's laboratory, knowing that diffusion must occur wherever solute and solvent are in contact, and bearing in mind the quantitative results obtained by G. F. Becker for diffusion in a homogeneous and concentrated solvent.

In the dispersion of a solute through the ground water filling the pore spaces of rock, diffusion can not be supposed to operate alone. Osmosis would undoubtedly play an important part in many instances. For example, suppose that a solute has obtained a fair degree of concentration in a rock chamber, either by diffusion or by convection, and the surrounding rock is saturated with comparatively pure ground water. If the pore spaces of the chamber walls are too small to permit the passage of the ions of solute, and yet are large enough to permit water to pass, then, due to the tendency of water to diffuse into the solution, an endosmotic pressure will be built up, which may reach a magnitude of several atmospheres. Now, if passages exist in the chamber walls, which, while not large enough to permit the free passage of the solute ions actuated by diffusion, are, nevertheless, large enough to permit them to be dragged through by a current of water, then, when the endosmotic pressure reaches a certain point, some of the solution will leak out into the wall rock. In this manner, local convection under a high osmotic head may be presumed to assist in the dispersion of the solute. Probably in actuality the process would not occur in stages, but osmotic pressure would be constantly coöperating with diffusion, local obstructions to diffusion being frequently overcome by the operation of osmosis.

Fick's law that the rate of diffusion is proportional to the concentration of the solute leads to the recognition of a diffusion gradient relating concentration to the distance migrated in any given interval. With such a gradient in mind it is easy to realize that after a considerable time a diffusing salt will have established a concentration gradient such that its further migration will be at a very slow rate. However, the moment the solution becomes impoverished in the solute at any given point within the gradient, the gradient is at once steepened. In this manner a point of precipitation within a diffusion gradient not only causes the migration of solute particles to be directed toward that point from all parts of the solution, but also accelerates diffusion in that direction, and accelerates dissolution at the source of the solute if that is a dissolving substance. Thus, if there are within a solution a point of dissolution and a point of precipitation, there will be a directed flow of matter from the former to the latter, both dissolution and diffusion being accelerated by the presence of the precipitant.

In the application of the principles of diffusion to earth phenomena, it becomes necessary to consider the effects of heat and pressure upon solubility, dissociation, diffusion, and precipitation. It is somewhat hazardous to assume that the phenomena and the laws apparently governing them within the narrow field of human observation continue unaltered into the inaccessible regions where certain conditions are known to be different to an unknown extent. The recognition and projection of tendencies, however, is legitimate within certain limitations; and in that sense it is probably safe to say that heat and pressure tend to produce fortuity, while cold tends to produce differentiation, discreteness, and order. Solubility and dissociation are in general increased by pressure and heat, and valency is reduced; diffusion and gas expansion are also increased; and as depth increases there is probably an increasing tendency for one substance to mingle with another, water permeating everything, and every substance dissolving in water to extents unknown within the horizon of observation. There is an increasing tendency for dissolved substances to ionize, and for ions to still further dissociate, every substance thus tending toward reduction to the atomic state, maximum dispersion and commingling. On the other hand as the surface is neared there must be the reverse of these tendencies, valency increasing, ions becoming more complex, solubility and diffusion diminishing. In the depths the tendency must be for reactions to occur in such a manner as will result in the greatest economy of space and absorption of heat; therefore, where crystallization is occurring the molecules will be the most complex ones possible, the paucity and largeness of individuals being most economical of space; but as the surface is approached there must be the reverse tendency, namely, for simpler molecules to form, or for the more complex ones to become unstable and to break down. Examples of this are seen in the complexity of the feldspars and pyroxenes, which are unstable at the surface and weather easily, saussuritization and uralitization often taking place some distance below the surface.

The intimation above, that water may permeate everything in the depths, requires explanation. I venture this as a probability partly on the basis of theory, and partly on the evidence of the microscope, where surface alterations affect such minerals as feldspar, for instance, at some distance back from cleavages, a diminishing cloudiness being visible in the unfractured and uncleaved mineral within its intermolecular space at a distance from any visible opening. Ions evidently enter and leave those intermolecular regions; and water molecules being among the smallest, probably smaller than the ions in question, they could as easily diffuse into that region as the other substances could diffuse out. If the intermolecular space of rock minerals is accessible to water it must be assumed present. Perhaps the migration of the mineral ions might even be taken as an evidence of the presence of water, since it constitutes a good medium for diffusion; and the ions of mineral matter could not be supposed to have moved away by any other process. The fact that such hypothetical water does not show itself by reactions with the minerals is no evidence against its presence; since whether the minerals are of igneous or aqueous origin they were probably formed or aggregated in its presence and are stable there under the conditions of the depths.

As soon as shallower depths are reached by erosion, such that hydration becomes stable, then chlorite, amphibole, serpentine, etc., are formed as a consequence of the presence of the intermolecular water. Or if the rock finds itself in an oxidizing environment before such change can occur, oxygen may diffuse into the crystal substances through the water which has always been in them, perhaps accompanied by carbon dioxide, and thus produce alterations more intense along the mineral cleavages and diminishing away from them. With this idea, the fact of fluid inclusions in igneous minerals is in no way incompatible, since such a phenomenon would be interpreted merely as a case where the fluid was in excess of the capacity of the intermolecular space of the minerals to accommodate it, thus compelling its segregation.

Water, should it exist in those situations, could not leave them. It would be imprisoned there. Such water as might exist in cleavages and fractures of minerals, as well as water in the rock fractures, must be supposed to be a residuum of segregated magmatic water, or, more probably, meteoric water which has found its way thither by the influence of gravity or capillarity, which forces, according to Van Hise, Posepny, Lawson, Lindgren, Kemp, and others, are adequate to accomplish that result within the zone of fracture, and perhaps even deeper.

If diffusion is a considerable factor in geo-chemical processes, it must have many phenomena standing to its credit; but the existence of a phenomenon is one thing, and the recognition of it another. The mere mention of certain of those phenomena, however, will probably suffice for their acceptance without the necessity of argument. In this category I propose such phenomena as the (1) occurrence of amygdules in vesicular lavas, (2) pseudomorphism, in which case the moleclues of one substance find their way into the interior of another, after replacing its outer portions, and the molecules of the original mineral find their way out, the passage of both being through the pore spaces, or rather, through the intermolecular space of a solid mineral substance, (3) the uniform salinity of the ocean,[17] (4) the remarkably uniform composition of magmas, and particularly the uniform distribution in them, of silica, iron, alumina, lime, magnesia, and the alkalis. In this last case, in spite of the infinite variations of composition of even such fundamental magmas as basalt, their general uniformity is probably more remarkable than their minor variations.

[17] This matter is ably discussed by R. E. Liesegang in his excellent book referred to above. He also discusses a number of other phenomena, important among which is the banding of agates.

Hoping to throw some experimental light upon the problem, I sought the help of the laboratory with the following results:

A hole one inch in diameter and three inches deep was bored in a block of coarsely crystalline marble eight inches long and about three inches in average cross-section. The block was then suspended in a steam chest and for two weeks subjected to a steam pressure of 60 lbs. for about nine hours per day, the steam being shut off at night. At the end of that time it was assumed that the alternations of pressure had induced the saturation of the rock with water. The hole was then about half filled with commercial sodium sulphide saturated and covered with water; a cork was inserted; and the cork and rock surface for an inch or two about the hole were covered over with several successive layers of a hot cement consisting of resin and beeswax. The rock was then placed, cork up, in a battery jar on a layer of pure beach sand about an inch and one-half thick. A strong solution of lead acetate in tap water was poured into the jar about the rock until it reached nearly to the cement on the top of the block. In order to exclude the air and other impurities from the jar, a layer of paraffin nearly one-quarter of an inch thick was poured over the surface of the acetate solution so that it made a firm union with the jar on the one hand and the rock on the other. This accomplished, the cemented top of the marble block projected above the paraffin seal, and was exposed to the air in such a manner that any capillary leakage of the sodium solution under the cement would be evaporated before it could reach the lead acetate solution beneath the paraffin seal.

When the lead acetate solution was made up with tap water a white precipitate at once formed, due perhaps to the presence of carbonic acid or chlorine in the water; but this soon settled making a white layer over the sand and leaving a clear solution of lead acetate above. Three weeks elapsed without any change being noted within the jar, but in the middle of the fourth week it was noted that the sand was becoming dark colored. Not believing it possible that the sodium sulphide in the cell could diffuse out in such a short time, even though the cell wall where thinnest was an inch thick, I did not visit the experiment for several days thereafter. When next I observed the jar I found the sand quite dark gray, and even black in places, and a pronounced black precipitate upon its surface, the white layer, which was originally there, being apparently much reduced. Fearing a leak had developed somewhere, I broke the paraffin seal and withdrew the marble block. A careful inspection showed that no leak existed. A strong odor of H_2S came from the jar when I withdrew the block; and I had in its presence an obvious proof that sulphur had found its way from the interior of the cell through the pores of the rock into the acetate solution. I washed and tested the black precipitate and found it to contain sulphur. As the former acetate solution in the jar now contained no lead, I was forced to the conclusion that all the lead originally introduced had been precipitated as sulphide. Still fearing a leakage somewhere, I broke the cement seal and removed the cork from the cell, but while the cork was wet the cement was not only dry where it had been in contact with the rock, but fragments of rock came away with it, testifying to the firmness with which it had gripped the surface. Upon breaking the marble block to bits in search of discolored fractures, I found it to be moist, but to contain no visible fractures nor discolorations such as must have been found had there been any passages larger than the calcite cleavages through which the acetate could have entered the rock to meet the sulphide.

The conclusion is inescapable that at least the sulphur of the sodium sulphide had passed through one inch of rock in thirty days.

Mode of Genesis of Veins at Cobalt by Diffusion

Inception of diffusion.—Inasmuch as segregation of the diabase did not extend beyond the most rudimentary stage, and the margins of the mass were chilled and impervious long before the magma had ceased to flow, it must be supposed that, if ore materials were contained in it, they were entrapped there. Having had no time nor opportunity to segregate they must have remained in a dispersed condition, probably being imprisoned, perhaps along crystal boundaries or as mineral inclusions; or, more probably, as components of complex molecules, either replacing or accompaning the essential atoms of rock-forming minerals. The minerals which thus were forced to accommodate the ore materials in a state which must necessarily rapidly become unstable, may have been the feldspars and pyroxenes. At any rate, such is my supposition; and the substances of this sort with which we are concerned were sulphur, arsenic, antimony, cobalt, nickel, silver, iron, bismuth, lead, and copper. Mercury and other substances may also have been present, but for the present purpose they may be ignored, since they were very minor constituents of the ores.

The magma, at some time after the crystallization, but while still hot, was deformed and fractured, and penetrated by the ground water.

While this process was in progress, magmatic juices, probably in small quantity, carried a little aplitic and pegmatitic material into the first fractures formed, and with it, small quantities of ore material. This, however, may be passed by for more significant processes, since these indications of segregation are not inconsistent with what has already been said nor with what is to follow; it is mentioned in this place to give ground for the supposition that in the saturation of the diabase with a fluid medium for the operation of diffusion, the magmatic juices, by largely uniting with the ground water, may be regarded as having made a material contribution.

When the ground water arrived it may have been saturated with such dissolved substances as lime and magnesium carbonates, silica, alkaline carbonates, and a certain amount of sulphates and sulphides. It must also be supposed that the magmatic juices contributed a certain amount of solvent substances. If it is admitted that sulphurous acid and sulphur may have been present to make thiosulphates with the alkalis, or that the S_2O_3 ion may have been produced by such a reaction as:

$$S_5 + H_2O = S_2O_3 + 3H_2S,$$

then what Roscoe and Schorlemer have to say about thiosulphates[18] will be of interest:

Thiosulphates exhibit a great tendency to form double salts; those of the thiosulphates insoluble in water are found to dissolve in an aqueous solution of sodium thiosulphate, which also has the power of dissolving other insoluble salts such as silver chloride, silver bromide, silver iodide, lead iodide, lead sulphate, calcium sulphate, etc., thus:

$$\left.\begin{matrix}Na\\Na\end{matrix}\right\} S_2O_3 + AgCl = \left.\begin{matrix}Na\\Ag\end{matrix}\right\} S_2O_3 + NaCl$$

$$Na_2S_2O_3 + NiCl_2 + H_2O = H_2SO_4 + NiS + 2NaCl$$

$$Na_2S_2O_3 + CoCl_2 + H_2O = H_2SO_4 + CoS + 2NaCl.$$

The same authors make reference in another place[19] to the complex nickel silicates, rewdanskite $(Ni, Fe, Mg)3Si_2O_7 + 2H_2O$ and garnierite, $2(Ni, Mg)_5Si_4O_{13} + 3H_2O$. It may be useful to bear these in mind in connection with the idea of the impurities assumed for the essential minerals of the diabase.

The rôle of arsenic and antimony in these reactions can probably be safely assumed to be in many cases that of partial substitutes for sulphur. At any rate it is to be assumed that the solvent for the ore metals is a solution of sodium thiosulphate, and that the ore elements, being unstable in their false positions in the pyroxenes, etc.,

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[18] Vol. 1, p. 414. [19] Vol. 2, p. 1040.

of the diabase, leave them and diffuse to the nearest cleavage, crystal boundary, or fracture, where they enter into the composition of the highly dissociated equivalent of such complex molecules as:[20]

$$Co_2S_2O_3 . Na_2S_2O_3 . H_2O \text{ and}$$
$$Ag_2S_2O_3 . Na_2S_2O_3 . H_2O.$$

Migration.—At this point the mechanism of diffusion may be supposed to begin in its general geological manner. It must be recalled here that whatever may have been the span of geological time in which these operations were going on, they began with a temperature in the diabase and its immediate neighborhood but little below the temperature of solidification; and the heat emanated was not only the superheat of the magma, but also the specific heat of the minerals which crystallized from it; while there was a molar pressure due to several thousand feet of overburden and the cooling contraction of the igneous mass and its wall rocks. There must also have been a slow-acting but none the less effective hydrostatic pressure upon all free water in fractures and pore spaces, due to a head of several thousand feet and to a high vapor pressure due to the temperature. The solvent was probably highly superheated either as liquid or gas, and had extreme power of penetration. It was not only saturated with all substances with which it came in contact, but was probably heavily charged with them, and carried also the ore materials in fairly strong concentration. All its solutes were highly dissociated and reduced in valency to their lowest terms, and at the same time highly charged with free energy. This was the result not only of high temperature and pressure, but also results of the catalytic influence of such solvent agencies as thiosulphates and alkaline carbonates, or sulphides.

Since the solvent in which the ore ions tend to diffuse is not *en masse* but is disposed in films, the ions would have to travel far in order to attain an appreciable attenuation. This form of the medium of diffusion would therefore greatly increase the distance traveled by an ion in a given time, the diffusion gradient being in no way affected, since the gradient refers to the amount of solution traversed for a given change in concentration.

As pointed out by Daly[21] the heat conductivity of rocks is very low. The rate of radiation from an intrusive mass must fall off rapidly after the first extreme differences have been dissipated by

[20] Abegg, Handbuch der anorganischen Chemie, Ableitung 1, p. 714.

[21] Igneous rocks and their origin, p. 198.

the emanation of the superheat of the magma, and the heat gradient has become relatively flat. It may reasonably be expected, therefore, that although the diabase and its neighborhood did not long remain at their initial temperature, the diabase itself must have remained hot for a considerable length of time.

In the course of that time the ore materials must be conceived to have found their way from mineral cleavage to crystal boundary, thence to shear joint and flat fault, and to the flatly inclined diabase and Keewatin contacts where shearing was chiefly concentrated, and thence to split joint and steep fault, where deposition occurred. At certain points here and there the journey of the ore ions may have been hastened by water circulation, but probably in general that was a negligible factor in their dispersion. Finally, a given ion may be supposed to have arrived at a point in the adjacent conglomerate where it was removed from the solution by precipitation. At once the neighboring ions, being relieved of its active presence, moved to take its place in the solution and were themselves precipitated in the same manner. As precipitation progressed at that point, thus impoverishing the neighboring solution, the diffusion gradient was steepened there, and a general migration to the point occurred throughout a larger and larger region about, until it finally extended to the source of the ions in the diabase, reduced their concentration there, and thus hastened the solution of others. In this manner solution and diffusion were accelerated throughout a considerable space about the point of precipitation, and the movement of ions from their source became increasingly direct to the point of precipitation. As one point of precipitation after another was established, the entire locality and mass of diabase became impoverished in ore ions, and these ions were exclusively concentrated in the veins.

Miller and Knight[22] made many careful analyses of the Nipissing diabase and found it to contain no silver. If the mother-magma of the diabase had been the source of the ores, surely some silver should be found in the diabase. One might say, if the visible diabase itself were the source of the ores, why does it show no silver? The answer is, that if the silver came from the diabase it could not still be in the place from which it came. One might object to this that a residiuum of silver should remain at its source; but that would imply that the extraction was only partial. What right have we to assume that? If some agency was able to extract and remove the silver, why should it

[22] Ont. Bur. Mines, Report, vol. 19, pt. 2.

not have removed all there was, and have deposited it entirely in the veins? My assistant, W. L. Whitehead, proposed a comparison of the production of the mines with the calculated volume of diabase which is presumed to have contributed to them. My figures for these computations follow. In making the computations I assume that the average distance from the point of origin to the point of deposition of a particle of ore was 500 feet, and that as much ore was deposited along one margin of the sheet as along the other. This assumption necessitated the estimation of the volume and weight of a sheet of diabase 500 feet thick over or under each group of veins, and surrounding it for a radius of not more than 500 feet, upon the assumption of a thickness of 1000 feet for the total diabase mass. Many errors are undoubtedly represented by the resulting figures; but I have tried to throw all non-estimable errors onto the side of excessive richness in silver on the part of the diabase.

The computations assume the weight of the diabase to be 187 pounds per cubic foot. The production of silver is taken as being 314,391,494 ounces from the years 1904 to 1919 inclusive, as indicated by the government reports; and the volume of diabase involved is estimated at 37,739,500,000 cubic feet, which would weigh 3,528,643,250 tons. This estimate would give a silver content of 0.089 ounces per ton of diabase, or 0.0000037 parts, or 0.00037 per cent by weight, or 0.26 gms., of silver per cubic foot of diabase.

Such a silver content is not unusual in igneous rocks. In "The Data of Geo-Chemistry,"[23] Clark quotes Hillebrand's analyses of Leadville porphyries as indicating an original silver content of 0.000009 parts. The same ratio was obtained from a volcanic ash from Tunguragua, while an ash from Cotopaxi contained 0.0000119 parts of silver. J. B. Harrison is also reported to have found in igneous rocks from British Guiana a silver content of 0.0000016. Perhaps the reason why the original silver content was found in these rocks is that they did not contain also solvents for the silver, and whatever ground water may have reached them was deficient in like manner.

Deposition.—Split joints have already been discussed, and it has been pointed out that those in which ore was deposited were the ones the walls of which were the most free from lateral compression, being under longitudinal compressive stress. Attention was also drawn to a remarkable relationship existing between the mineralogical contents of veins and their dips. The arrangement of the mineral constituents

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[23] U. S. G. S., Bull. 148.

was stated to be fan-shaped, the richest ore being at the center of the fan where the midpoint of the vein rested upon a strong shear joint or flat fault. Briefly, all these and similar phenomena appear to find their explanation in the stresses existing in the vein walls during vein deposition, the richness of the ore deposited being inversely proportional to the later compressive stress in the walls. In the description of the veins I attempted to show evidence indicating that they were due to the metasomatic replacement of the wall rocks. I regard it as obvious that the replacement was grain-for-grain in the sense of volume-for-volume and not molecule-for-molecule, since the veins in mineral character, structure, and all other respects are the same in diabase, Keewatin, and Cobalt Series, and the pebbles in the Cobalt conglomerates consist of virtually every sort of igneous and sedimentary rock, and yet are replaced indiscriminately and in the same manner by smaltite and its associates.

The even tabular dimensions of many veins, and the rare and anomalous occurrence of crustification as against the general massive character of the vein matter must be regarded as *a priori* evidence that the veins do not represent chamber fillings, since such chambers could not have existed under the conditions of origin of these fissures. In other cases the gradual transition between solid vein, vein with band-like inclusions of wall rock, unchanged in orientation, walls with parallel veinlets, and slightly altered walls, would seem to constitute equivocal evidence of replacement.

It seems clear, largely upon the basis of the vein characteristics already described, that a vein grew outward from the original narrow fissure as a starting point. It makes no difference, however, if one prefers to consider that the fissure, tight as it must always have been, remained open until the last, and then was sealed in such a manner as to show a total absence of comb structure. In either case the vein minerals were deposited in the midst of firm rock, and must have traversed either firm ore or firm rock in order to be deposited on the vein margins.

At this point, lest it might be thought that the last step in the delivery of the ore to its destination was accomplished by passage through colloidal vein matter, I must object that although the presence of colloids is often demonstrable or very plausible at or near the earth's surface, or in the vadose region, I believe the opinion of chemists will support me in denying such possibilities in the depths, where there is considerable heat for long periods of time, and particularly in cases of metasomatism, where precipitation is not hasty but is very deliberate, since under such conditions colloidal particles, even though formed, would have ample opportunity to undergo re-solution and re-deposition as crystalloids, according to the principles of crystal growth set forth by Wm. Ostwald.[24]

Coming now to a consideration of the conditions existing in the vein walls at a point where deposition of ore is about to occur, we must recall that the fissure in question is under longitudinal compressive stress and consequent lateral tension. A given wall particle is under differential stress, and is therefore several times more soluble than it would be otherwise, its solubility being proportional to the stress difference. At a point, then, midway between the ends of a split joint, and where it bottoms on a strong shear joint or flat fault, the stress difference is the greatest. That is the point, as has already been indicated, where the richest ore has been deposited. There the wall rock tends most strongly to pass into solution.

The fissure and the pore spaces of the rock are saturated with ore-bearing solution; and it may be assumed that all solutes are at the saturation point. It is assumed also that one of these solutes is silver sulphide, the solvent being a solution of sodium thiosulphate. The exact mechanism of replacement which takes place under these conditions can not yet be stated. However, were the replacement to be by chemical substitution, volume changes must occur and contraction or expansion would be evidenced by vugs in the vein or strain in the walls; but both these are absent. The replacement clearly is a matter of relative solubilities and of volume-for-volume substitution. It would seem that in the reaction the wall rock on passing into solution, as a result of the differential stress affecting it, must absorb energy, which assists the precipitation of metalliferous substances in which the solution is saturated. At the same time the solution of the wall-rock silicates probably consumes a certain amount of the solvent of the ore material, thus adding another cause for its precipitation; but the amount leaving the solution is just enough to fill the space vacated by the silicate, as otherwise a back-pressure might be established, so great as to inhibit further reaction.

The selective precipitation of ore and gangue minerals may have been governed by the fact that precipitating crystalloids exert a pressure due to the force of crystallization, and the substance with

[24] Wm. Ostwald, The scientific foundations of analytical chemistry, ed. 1900, p. 22.

the greatest force of crystallization, or with the largest volume change in crystallizing from solution, would be precipitated where the wall pressure is least, and vice versa. This would account for the preference of precipitating dolomite, which has a small atomic volume, for the marginal region of the fissure where the wall pressure is greatest. In the above reaction AgS is shown as the substance precipitated as a silver salt. The reaction, however, like the whole picture here presented, is intended merely as a similitude—a means of indicating the general sort of thing which may be presumed to have occurred. In view of the conditions of high temperature and pressure, it seems more likely that a large complex molecule was deposited as the ore molecule, containing silver, cobalt, nickel, arsenic and sulphur—a molecule stable only under those peculiar conditions, and unstable under conditions of less pressure.

Subsequent molecular rearrangement.—The most complex molecules to be found in the present ores are occasional sulpho-salts of silver, such as proustite, etc. The metals usually occur native or in binary compounds. In the mineral mixtures which constitute the present ores evidence was sought by Miller and Knight for paragenic sequences, but the evidence of the veins of many mines seems to show contradictory sequences. My conclusion is that no uniform set of sequences exists. Miller indicates his belief in a period of calcite and silver deposition subsequent to that of the arsenides; but I find silver in wire form lying within massive unfractured smaltite and niccolite, as if not having come after the arsenides but with them. Another and perhaps more common phenomenon is the occurrence of spherical pellets of silver, perhaps two millimeters in diameter, in the center of pellets of niccolite, which are themselves the cores of pellets of smaltite. The arsenides are never found replacing silver, nor is dolomite or calcite found replacing either silver or arsenide. The relationships are always the reverse; but this may be accounted for much better on the basis of relative forces of crystallization than of absolute time sequence.

The disorderly mineral relations obtaining in these ores seem to find a more consistent explanation in the rearrangement of vein constituents due to the breaking down of the original complex carbonate and sulpho molecules as the pressure was reduced by the approach of the surface due to erosion. A good line of evidence bearing upon this point is found in the fact that in wall fractures uncemented by typical vein matter, severing the veins, and obviously of later origin, are found crusts, often beautifully crystallized, consisting of proustite or argentite, or dyscrasite, or perhaps native bismuth, these crystalline masses coalescing with and blending imperceptibly into typical ore in the adjacent veins.

CONCLUSION

In this account and discussion of the geology at Cobalt the two principal points which I have intended to make are that the fissures in which the ores were deposited were not cooling cracks in the strict sense, but were joints developed as a result of folding subsequent to the solidification of the diabase, and that the ores were derived from the diabase sheet itself, transported, and deposited chiefly through the agency of diffusion through relatively stagnant water in the pore spaces of the rocks.

The folds, which affect diabase and sediments alike, are parallel with the major structural axes of the region and also with the original undulations of the diabase sheet which transgress the sedimentary beds, these folds being indicated in the diabase by innumerable large and small surfaces of shearing parallel with the surface of folding. The vein joints are spatially related to the folds and to the faults which originated during the folding. From these relationships it is inferred that such joints are genetically related to the other deformations and to external compressive stresses rather than to direct cooling shrinkage. It is immaterial, and impossible to conjecture, whether this compressive stress arose chiefly from the lateral expansive force due to the heating of the locality of the sheet, or whether it arose chiefly from the general contraction due to the cooling of the locality of the sheet, the latter having an undulating configuration, and the undulations being weak to lateral compression resulting from the contraction of their general environment. Since all the deformations, however, are clearly of the same immediate period as those in the diabase, the conclusion seems inevitable that the diastrophic activity followed the solidification of the igneous mass, and was of a compressive character.

In connection with the genesis of the ores it was pointed out that the commercial veins of the whole region as well as those in other parts of northern Ontario lie exclusively within marginal zones of the Nipissing diabase extending not more than 350 feet inward and outward in the diabase and Keewatin formations, nor more than 550 feet from the diabase margins in the Cobalt Series of sediments. Even the noncommercial deposits and traces of cobalt in the northern part of the province are clearly related to the diabase, and no occurrences are known in this whole region that are clearly related to deep fissures in controversion of this rule. These facts are taken as strong evidence that the visible diabase itself was the source of the ores.

Negation was resorted to in order to exclude any supposition that the ores might have originated either through the downward circulation of vadose waters or through the upward circulation of juvenile or of hot meteoric waters. These matters need not, perhaps, be reviewed here further than to recall that the principal points made in regard to ascending solutions were: (1) that the heated mineral waters of the earth, whatever their origin, are known to be very dilute, so that large volumes would be required to pass through the rock in order to produce a moderate amount of metasomatic ore; (2) that in the absence of crustification and comb structure, metasomatic veins can be supposed to have grown only by marginal accretion; (3) that the chief circulation of underground water must be through fissures, and that its passage in volume through pore spaces must be practically inhibited by the large coëfficient of friction due to the narrowness of the capillary and subcapillary openings and the tortuousness of its course; and (4) that, at least in the case of the silver ores under discussion, the veins and vein walls offer no more porous courses for the passage of water than the country rock offers, and therefore there would be no directive agency to cause mineral-bearing solutions to circulate there rather than at random through the country rock.

At Cobalt the chief ore production has come from beneath the diabase sheet, the veins being metasomatic replacements of the walls of *cul de sac* fractures. It seems far-fetched to suppose, since the diabase invaded chloritic schists which must have been saturated with ground water, that mineral-bearing solutions could have circulated downward from the diabase into the already saturated country rock in sufficient quantity and strength to have produced such metasomatic deposits in those blind fractures. Local convection currents could be supposed to have only gone round and round in a fracture of that sort without any chance of replenishing their original supply of mineral.

Water circulation being practically inhibited, recourse must be had to the principle of diffusion to explain the transference and deposition of mineral; but slow as would be the migration of metalliferous ions through the pore spaces of the rock, it would nevertheless be that of mineral at 100 per cent concentration; and, furthermore, it would be directed from the point of its origin to the point of deposition by the steepening of the diffusion gradient at the point where precipitation is going on.

Time seems to be the chief obstacle in the way of accepting diffusion as a dominant agency in the genesis of metasomatic ore deposits. The ratio of its effectiveness to that of water circulation is the point in doubt. There are two forces which may be considered as tending to actuate the circulation of water through the pore spaces of rock, capillarity and hydrostatic head, or difference in head. Capillarity operates only in the first wetting of the rock; after that hydrostatic head is the sole actuator. In the depths this can arise only from heat or the compression of rocks containing water in sufficient quantity to be squeezed out. In either case the head would have to be considerable to drive water through capillary openings for a great distance; and the propagation of that force would be so slow that the passage of large volumes of water past a certain point within a firm rock might easily take as much time as the migration, by diffusion, of an equivalent amount of mineral ions. This ratio of effectiveness is at present indeterminable, and must await the results of experimentation. In the meantime, however, we have some very definite chemical facts in which to find assurance that diffusion is a factor to be reckoned with. Fick, Soret, and others have made it clear that when a solute is in contact with a solvent it tends to diffuse into the solvent until equally distributed through it. The diffusion gradient consequent upon Fick's law supplies a directive agency and a means of acceleration the moment precipitation begins within the field of diffusion. Its operation is slow but relentless. The force actuating the diffusion of salts has not been measured directly, but its supposed equivalent in osmotic pressure has been equated[25] and measured, and found in certain instances to attain a magnitude of many atmospheres. Thus we already know that where there is water and a solute, the latter will tend to migrate through the former without cessation until equally

[25] Alexander Finlay in "Osmotic pressure," p. 31, states the thermodynamic equation for osmotic pressure as follows:

$$P = p - p_0 = \frac{RT}{V_0}\left[-\log_e(1-x) - \tfrac{1}{2}aP^2\right].$$

Here P = osmotic pressure, p = pressure of solution, p_0 = pressure of solvent, R = a constant depending upon the salt used, T = absolute temperature, V = molecular volume of solvent under standard pressure, x = molar fraction of the solute, and a = coefficient of compressibility of the solvent. This is for concentrated solutions.

dispersed through it; and when obstructed it will be assisted by the force of osmosis. Given the time, then, which is required for the flow of large volumes of water through a great thickness of firm rock, diffusion is a factor to be considered. The particular utility of that concept in assisting the understanding of the phenomena of vein genesis lies in the subtlety, mobility, efficiency, and vector quality of diffusion.

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EXPLANATION OF PLATE 15

A. Showing results of deposition in vein fissures. The white vein matter is barren calcite; the gray is silver-bearing smaltite and niccolite.

B. Enlargement of right-hand vein in A showing relations of minerals more intimately.

A

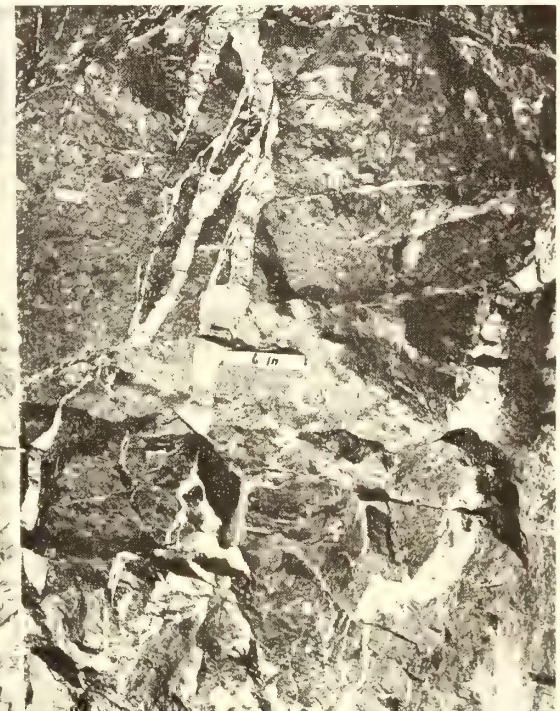
B

EXPLANATION OF PLATE 16

A. Branching vein.

B. Typical vein in conglomerate showing reticulate structure.

A



B

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CONTENTS

INTRODUCTION

During the summer of 1920 a field party from the Department of Palaeontology, University of California, visited the region of Logan Butte, south of the Crooked River in eastern Oregon, and collected in the John Day Oligocene deposits. Among the specimens obtained is a small, fragmentary skull apparently belonging to the genus *Peratherium*. An important member is thus added to the large and varied mammalian assemblage known from the John Day beds. The presence of *Peratherium* at Logan Butte records for the first time a marsupial in Tertiary deposits of the Great Basin Province and presumably represents the latest occurrence of the genus in North America.

The writers desire to express their appreciation to Mr. Gerrit S. Miller for helpful suggestions in the study of the John Day species and for the arrangement of a loan of mammal skulls from the U. S. National Museum. Drawings of the John Day material were submitted to Dr. W. K. Gregory of the American Museum of Natural History and to Mr. J. W. Gidley of the U. S. National Museum. Dr. Gregory and Mr. Walter Granger made comparisons with specimens in the American Museum and directed attention to the resemblance between

the Oregon form and the genus *Peratherium.* Mr. Gidley in a letter dated June 11, 1921, also indicated the didelphid affinities of the Logan Butte specimen. Through the kind efforts of Dr. Gregory and Mr. Granger the writers were permitted to borrow materials of *Peratherium* for comparison.

OCCURRENCE

The John Day Oligocene deposits occurring south of the type locality in the John Day Valley are well exposed in the drainage basin of the Crooked River southeast of Prineville. Along Camp Creek, a tributary of the Crooked River, the beds consist of volcanic ash, reddish brown and bluish green in color, and resemble the lower and middle John Day beds in the John Day basin.[1] At Logan Butte, a landmark near the head of Camp Creek and approximately fifty miles southeast of Prineville, Crook County, Oregon, the green colored tuffs of the John Day, in which occur the marsupial remains here described and many specimens of oreodons, are distinctly folded. The beds are overlain unconformably by a later Tertiary formation closely resembling in its lithological characters the Rattlesnake Pliocene deposits of the John Day Valley. The Oligocene fauna, as represented by the collections made during the summer of 1920, has not been completely reviewed. Dr. John C. Merriam[2] determined the presence of three carnivores, *Mesocyon brachyops* Merriam, *Temnocyon altigenis* Cope, and *Archaelurus debilis major* Merriam, from remains obtained in 1899–1900.

PERATHERIUM MERRIAMI, n. sp.

Type Specimen.—A fragmentary skull and lower jaw, no. 24240, Museum of Palaeontology, University of California, from the John Day Oligocene beds at Logan Butte, eastern Oregon. This species is named in honor of Dr. John C. Merriam.

Specific Characters.—Skull larger than in *Peratherium fugax* (Cope) from the White River Lower Oligocene of Colorado and smaller than in Lower Miocene species of *Peratherium* from Europe. The two posterior premolars of the superior dentition are relatively not so narrow as in *P. fugax.* M^4 is more robust than the corresponding tooth of *P. fugax.*

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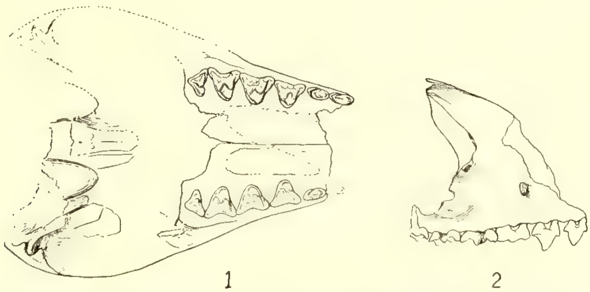
[1] Russell, I. C., Preliminary report of the geology and water resources of central Oregon, U. S. Geol. Surv. Bull. 252, 1905.

[2] Merriam, J. C., Carnivora from the Tertiary formations of the John Day region, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, pp. 1–64, pls. 1–6, 1906.

Description.—Specimen 24240 is smaller than skulls of Recent species of the South American polyprotodont genus *Marmosa*. The palate (fig. 1) in the John Day specimen has large fenestrae between the molar series, but the largeness of the fenestrae is in part due to a breaking away of the palatal margins. The tympanic process, which is bullate in *Marmosa* and formed by the alisphenoid, is as much developed in *Peratherium merriami* as in the former genus. In side view of skull (fig. 2), the exit of the infra-orbital canal is seen to be situated farther in front of the anterior border of the orbit than in *Marmosa*. In *P. merriami* the distance measures 3.3 mm., while in four skulls belonging to three species of *Marmosa* the measurement varies from 1.8 mm. to 2.8 mm. The exit is located above the anterior end of the first molar in *P. merriami;* in *Marmosa* it is often seen above the middle of the last premolar. In *Peratherium fugax* the facial exit of the infra-orbital canal is also situated at a greater distance from the orbit than in *Marmosa*.



Figs. 1 and 2. *Peratherium merriami*, n. sp. Skull, no. 24240, Mus. Palae. Coll., × 2. Fig. 1, ventral view; fig. 2, lateral view. John Day beds, Logan Butte, Oregon.

In *Peratherium merriami* and in *P. fugax* the anterior border of the orbit lies above the posterior end of M^2; in *Marmosa* the border may be situated above the middle or the front end of M^1. The orbit, therefore, does not extend so far forward in the Oligocene species as in the Recent *Marmosa*. The anterior border of the orbit in the Recent *Didelphys* reaches forward to a point situated above the posterior end of M^1 while the facial exit of the infra-orbital canal is located above the posterior end of P^2. The zygomatic process of the squamosal in no. 24240 is relatively shorter than in skulls of Recent *Marmosa*.

In the lower jaw the inferior border below the masseteric fossa is not deflected decidedly from that beneath the tooth-row. The angle is deflected inward as in modern didelphids. A mental foramen is situated beneath the anterior root of $M_{\overline{1}}$ in the preserved portion of the lower jaw.

Fig. 3. *Peratherium merriami,* n. sp. Left ramus, no. 24240, Mus. Palae. Coll., lateral view, × 2. John Day beds, Logan Butte, Oregon.

The dentition present in specimen 24240 includes the two posterior premolars and the four molars of the upper jaw and comparable teeth of the lower jaw. The two posterior premolars of the upper jaw are laterally compressed, but relatively not so much as the posterior premolars of *Peratherium fugax.* Each premolar possesses a single prominent cusp. In both of the teeth a small ledge is situated anterior to the principal cusp and a more extensive ledge is present behind. A furrow or concavity is plainly visible along the inner posterior side of the principal cusp in the last premolar. This furrow is not so distinct in the preceding tooth.

In superior molars 1 to 3 inclusive, $M^{\underline{1}}$ possesses the shortest transverse diameter. $M^{\underline{1}}$ and $M^{\underline{2}}$ have broad crowns while the crown of $M^{\underline{3}}$ is relatively narrow anteroposteriorly.

Fig. 4. *Peratherium merriami,* n. sp. Superior cheek-tooth series, no. 24240, Mus. Palae. Coll., lateral and occlusal views, × 4. John Day beds, Logan Butte, Oregon.

In $M^{\underline{1}}$ the metacone is larger than the paracone. At least four distinct elevations or stylar cusps are situated on the outer cingulum of the tooth. The most anterior cuspule of the four is located at the antero-external angle of the tooth. A ledge extends from the cuspule along the anterior base of the paracone. The second stylar cusp is more prominent than the first and is situated near the middle of the outer base of the paracone. These two elevations or cuspules are comparable to the *a* and *b* stylar cusps noted by Bensley[3] for the genus

[3] Bensley, B. A., The homologies of the stylar cusps in the upper molars of the Didelphyidae, Univ. Toronto Studies, Biol. Ser., no. 5, pp. 149–159, 1906.

Peratherium. Opposite the notch between paracone and metacone and on the external cingulum is situated a small elevation which is flanked behind by a larger cuspule, the latter being comparable perhaps to stylar cusp *c* of Bensley.[4]

In M^2 the metacone is also larger than the paracone, the difference is similar to that seen in the corresponding tooth of *Marmosa* and is not so great as that occurring in M^2 of *Didelphys.* This tooth, in contrast to the other molar teeth, possesses the greatest number of distinct elevations on the external cingulum. Two of the elevations are situated at the antero-external angle of the tooth and are perhaps comparable to the pair situated in this region in M^1. Opposite the notch between paracone and metacone may be seen two minor elevations with a somewhat more pronounced stylar cusp situated immediately behind. The latter is probably comparable to stylar cusp *c* of Bensley. The ledge which extends along the anterior base of the paracone from the most anterior stylar cusp is stronger than in M^1.

M^3 is less robust than M^2. In M^3 the paracone closely approaches the metacone in size. In the Logan Butte specimen a single stylar cusp appears to be present on the external cingulum at the anterior end of the tooth from which a well defined ledge extends along the anterior base of the paracone. A rather prominent stylar cusp is situated on the external cingulum opposite the notch between paracone and metacone.

A fairly prominent cuspule is developed on the cingulum at the antero-external angle of M^4 and from this a ledge extends along the anterior base of the principal V-shaped cusp of the crown. Opposite the middle of the principal cusp occurs a small elevation on the cingulum. Examination of M^4 in three skulls of *Marmosa* failed to reveal the presence of an elevation in this region of the cingulum. In several skulls of *Didelphys,* however, two distinct cuspules are present on the external cingulum. The posterior ridge or arm of the principal V-shaped cusp in M^4 of *Peratherium merriami,* as in that of *P. fugax,* joins the cuspule or style located at the postero-external angle of the tooth. The postero-external style or cuspule is not prominent in M^4 of the North American Oligocene *Peratherium.* In M^4 of the Recent *Marmosa* the postero-external style is well defined. The V-shaped cusp is not so prominent in M^4 of *Marmosa* as in that of *P. merriami,* but the inner cusp is much better developed than in M^4 of the latter form or of *P. fugax.*

[4] *Ibid.,* p. 152, fig. 1.

The two posterior premolars in the lower dentition are apparently less closely spaced than in *Didelphys.* Each of the premolars possesses a very prominent cusp behind which is situated a distinct ledge.

Fig. 5. *Peratherium merriami,* n. sp. Inferior cheek-tooth series, no. 24240, Mus. Palae. Coll., lateral and occlusal views, × 4. John Day beds, Logan Butte, Oregon.

The lower molar series is similar to that in *Marmosa.* In each molar the trigonid and talonid are distinct. The protoconid is a prominent cusp. A small cingulum is present along the antero-external border of the trigonid, comparable to that seen in molars of some species of *Marmosa,* and is not so well developed as in *Didelphys.* The cingulum is apparently but faintly indicated on molar teeth of specimen 5259, Amer. Mus. Nat. Hist. Coll., referred to *Peratherium fugax.* In $M_{\overline{1}}$ of *P. merriami* the antero-external cingulum barely reaches the protoconid. In the two following molar teeth, however, the ledge extends farther to the outer side, but does not quite reach the middle of the external surface of the protoconid. Unfortunately the trigonid in $M_{\overline{4}}$ has been destroyed. The talonid in this tooth is compressed transversely and consists of three distinct cusps. The hypoconulid is less prominent than either the hypoconid or the entoconid.

Measurements of Dentition

Length of upper tooth row, $P^{\underline{2}}$ to $M^{\underline{4}}$ inclusive	*a*10.4 mm.
Length of lower tooth row, $P_{\overline{2}}$ to $M_{\overline{4}}$ inclusive	12

SUMMARY

A fragmentary skull of the marsupial genus *Peratherium* described from the John Day Oligocene of Logan Butte, eastern Oregon, is regarded as the type of the new species, *Peratherium merriami.* The John Day form does not greatly exceed in size the species, *P. fugax,* from the Lower Oligocene White River beds of Colorado. In size, *P. merriami* apparently occupies a position between the Lower Oligocene *P. fugax* of North America and Lower Miocene species of *Peratherium* of Europe.

The material from the John Day beds furnishes additional information regarding the structure of the skull in *Peratherium.* The dentition exhibits clearly the close relationship that exists between *Peratherium* and the Recent *Marmosa. Peratherium merriami* is distinctly less advanced in certain dental characters than Recent polyprotodont marsupials of America.

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GEOLOGY OF SAN BERNARDINO MOUNTAINS NORTH OF SAN GORGONIO PASS

BY
FRANCIS EDWARD VAUGHAN

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CONTENTS

INTRODUCTION

Stretching eastward from the San Fernando Valley is the highest and most rugged mountain range in Southern California. About sixty miles from its western extremity there is a break known as the Cajon Pass. The portion west of this is called the San Gabriel Range. Eastward from the pass the San Bernardino Mountains extend for eighty miles to an intersection with a small chain of hills, known as the Cottonwood Mountains, which have a northeast trend. To the north of the range is the Mojave Desert. On the south the mountains are limited by the western part of the Colorado Desert, the San Gorgonio Pass, and the San Bernardino Valley.

The area described in this paper embraces that portion of the San Bernardino Mountains north of the San Gorgonio Pass and a small part of the Mojave Desert. It includes the entire San Gorgonio Quadrangle and a strip across the northern end of the San Jacinto Quadrangle. The total length is about 41 miles and the width 29 miles, which makes the area a little less than 1200 square miles.

During the summers of 1915, 1916, and 1917 the writer made excursions into this part of the San Bernardino Mountains and the Mojave Desert immediately to the north for the purpose of studying the geology of the region. The field is mostly a wild country and the writer is much indebted to Mr. R. H. Charlton, the forest supervisor, for information concerning trails, water, etc., and to the Swartout & Blair Cattle Company, the Banning Water Company, Mr. William McCormick, and Mr. C. L. Metzgar for their hospitality. In presenting the results the author has been greatly aided by criticisms and suggestions from Professor A. C. Lawson.

TOPOGRAPHY

General Statement

Near the eastern margin of the San Gorgonio Quadrangle there is a break in the San Bernardino Range, the most noteworthy features of which are Morongo Valley and a valley in the region east and north of The Pipes. To the east the mountains are much lower than to the west, where they rise gradually to their maximum height at San Gorgonio Mountain. About eight miles north of this is another important summit, Sugarloaf Mountain. From these two peaks the range is unbroken westward to Cajon Pass.

San Gorgonio Mountain is near the eastern end of a high ridge between two of the largest streams in the area, Santa Ana River on the north and Mill Creek on the south, both of which flow westward in deep cañons. South of Mill Creek there is another ridge parallel to that on the north.

The country north and northwest of Sugarloaf presents an old geomorphic surface. Here are found broad valleys with meadows at a general elevation of 7000 feet above sea level; and the hills have rounded profiles. The most important valley is Bear Valley, the eastern extremity of which is four miles northeast of Sugarloaf. It extends westward for twelve miles and is drained to the west by Bear Creek through a precipitous gorge. A dam has been constructed at the lower end of the valley, which retains a lake six miles in length and a mile wide. At the eastern end, separated by a low ridge, are two lakes, Baldwin Lake to the north and Erwin Lake to the south.

North of Bear Valley, parallel to it and separated from it by a low ridge, is Holcomb Valley, which is of the same general character. There are no lakes here, but at the lower or western end there is a large meadow. On the north side of this valley there is a low ridge and beyond this a precipitous declivity to the desert in evident geomorphic discordance with the broad valleys and smooth ridges of the uplands to the south.

East and southeast of the Bear Valley region the mountains are rugged, being traversed by many steep, crooked cañons. However, the tops of some of the ridges are smooth, and these are of great significance geomorphically, for they serve as links between old surfaces to the east and west.

On the south flank of the mountains the extremely rugged topography, as seen just south of San Gorgonio Mountain, gives way to low foothills, dissected by numerous streams draining southward into San Gorgonio Pass.

The country north of the mountains is typical of a large part of the desert region of Southern California. For the most part it is characterized by great, barren, sandy wastes above which rise steep hills. In some cases the smaller hills are almost completely buried in their own detritus. There are also numerous playas or dry lakes.

The San Bernardino Mountains contribute to three drainage basins. Bear Creek and all streams south as far as Smith Creek, a small stream three miles northeast of Beaumont, drain into the Santa Ana and thence to the Pacific. The streams between Smith Creek and the divide in Morongo Valley flow into the Salton Sink to the southeast, or are lost in the desert before getting that far. Those north of the Morongo divide and Bear Creek drain into the Mojave Desert, where they are lost by sinking into the sand and by evaporation.

The San Bernardino Mountains afford splendid views from the summits. Looking over the mountain mass as a whole, the upper portion seems to have a general level from which it drops off rather suddenly on all sides. This is in marked contrast to the San Gabriel Range, which can be seen in the distance and which seems to have a maximum central height at the intersection of opposing slopes. The significance of this seems to be that the San Gabriel has been uplifted longer than the San Bernardino, and hence has become more reduced on its outer portions. Mendenhall[1] says:

> The San Gabriel and the San Bernardino ranges are adjacent mountain masses, separated only by Cajon Pass, and holding identical relations to the valley of southern California, and to the Mojave Desert, lying to the north and east of it. They also are similarly related to the principal fault lines of this part of California, each of them being bounded along its southern margin by a major fracture, and one of them, the San Gabriel, certainly being limited in a similar way along its northern base, while less definite evidence indicates that the San Bernardino range is related in the same way to the desert lowland. . . . . The San Gabriel range has been completely dissected, resulting in thoroughly graded streams, sharp peaks, and knife-like ridges of discordant heights. No level areas at or near the summits, nor in the valley bottoms, exist within the mountain mass. The San Bernardino range contrasts sharply with its neighbor in these respects. Throughout its western end there is a strikingly level sky-line at an elevation of 5000 feet or more. It contains many broad meadows, with lakes and playas, separated by smooth ridges. The topography of the central part is, in brief, topography of an old, well reduced type. About its

[1] Mendenhall, W. C., Two mountain ranges of Southern California, Geological Society of America, Bull. 18, 1907, pp. 660–661.

periphery, however, topographic forms are strikingly new. Several of the streams are not reduced to grade; they meander through broad uplands in the central part of the range, then plunge over falls into steep canyons, which they follow to the valleys that border the ranges.

For these striking topographic differences there seems to be no adequate explanation in the rock types, in the relative masses of the ranges, in their relation to major drainage lines, nor in their relation to precipitation. It is concluded, therefore, that since each is a faulted, uplifted block, the San Bernardino mass, in which old topographic forms are well preserved, is much later in origin than its neighbor, the San Gabriel range, in which none of these old forms are now to be found.

While it is thus evident that there are considerable areas of an old erosion surface preserved in the higher portions of the San Bernardino Mountains, the case is not so simple as stated by Mendenhall. Two erosion cycles have been recognized by Mendenhall, but evidence will be adduced to show that four distinct cycles of erosion are represented besides several subcycles.

The First Cycle

The long, even summit ridge extending from San Bernardino Mountain to San Gorgonio Mountain is so striking that it at once suggests the remnant of an old peneplain; nor are we disappointed on closer observation (pl. 17A). True, San Bernardino Mountain itself culminates in a serrate ridge, but half a mile to the east this gives way to a narrow flat summit; and a mile and a half farther this broadens out to a considerable area which is strikingly distinct from the rounded topography of the second cycle sloping away from it on the north. Still farther eastward this area narrows to a broken ridge with occasionally a flat area. About a mile west of San Gorgonio Mountain glacial cirques have been effective in giving the ridge a rugged aspect, but at the summit of the mountain we again find a portion of the old surface. The fact that these flat areas extend across gneisses and schists, as well as granite, precludes the possibility of their being due to some dominant structural feature. They are therefore regarded as the remnants of an old peneplain.

East of The Pipes are several flat-topped summits capped with basalt (pl. 17B) which are perhaps correlative with the peneplain represented on the summit ridge. The granite surface below the basalt and the surface of the basalt itself are both flat. The latter, however, is traversed by a few broad, shallow gullies which cut through some of the basalt flows, thus showing that we have here a surface actually carved from the basalt and not merely the top of the basalt flow.

There is very little true soil on these hills in spite of their flatness; although basalt is a rock usually yielding readily to decay. Since the climate of the region is arid, the bareness is probably due to deflation. Another peculiarity is the presence of several inclosed basins; these may also be the work of deflation, although, being on a lava surface, there is the possibility of collapse.

The rather flat but hummocky surface on the granite west of The Pipes is probably a slightly modified portion of the pre-basalt surface which has been stripped of its covering. Remnants of the basalt are still present on some of the ridges to the southwest and present an appearance somewhat similar to the basalt-capped hills to the west (pl. 18, A and B). That all are part of a once continuous surface is evident. Remnants of a basalt flow are found on the ridges on each side of Antelope Creek, which indicate the pre-basalt surface. These remnants of basalt sloping up to the west suggest that either the surface on which the basalt rests or that carved in the basalt is correlative with the old summit ridge between San Gorgonio and San Bernardino peaks.

Looking eastward from Kitching Peak the whole country has the appearance of sloping in that direction and in some cases the crests of the ridges are smooth and even. Although it is not known whether these crests represent the first or second cycle, the general slope strengthens the argument that the flat ridge between San Gorgonio and San Bernardino peaks was once continuous with the old surface in the vicinity of The Pipes.

Baker[2] has described a post-Miocene surface in the locality north of Barstow, in the Calico Hills, and at Black Mountain. He says: "This old surface can be traced on the crests of the Sierra Nevada and Tehachapi mountains in the vicinity of Tehachapi Pass and on the summits of the latter range northeast of Tejon Pass. . . . . There is a disposition to correlate the surface developed during the first cycle of post-Miocene erosion with the surface of the summit ridge of the San Bernardino Mountains." This conclusion is based entirely upon the flat surface developed in each case.

The question arises as to whether this old surface was developed under humid or arid conditions. San Gorgonio itself is flat except for the knobs of granite. The boulders have peculiar forms; some are rounded but others have fantastic shapes and are pitted as if by wind-driven sand. There are also a few pinnacles consisting of granite

[2] Baker, C. L., Cenozoic history of the Mojave Desert, Univ. Calif. Publ. Bull., Dept. Geol., vol. 6, pp. 361, 365.

boulders and resembling crude monuments made by placing one stone above the other. Such erosional forms are usually found in desert regions which have become so reduced that the amount of wind-blown sand is considerable. The results of present erosion here are quite different; many of the boulders are angular, and some of these are in place where it is evident that they were derived by some sort of jointage. While some have been rounded, this is not due to true exfoliation, i.e., to spherically developed breaks, but to an irregular system of cracks which can be seen near the surface of the rock (fig. 1).

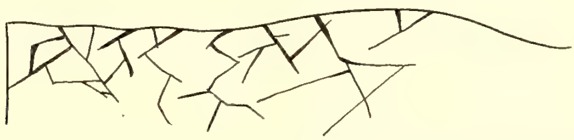

Fig. 1. Weathering of granite at San Gorgonio Mountain. Scale about ⅛ nat. size.

Below the basalt and between some of the basalt flows in the hills east of The Pipes are beds of arkose. This material contains mica and feldspar, as well as quartz, and appears identical with the material now being derived from the granite in the arid hills to the south. It is therefore probable that the surface on which the basalt rests was developed under arid conditions, and that these conditions persisted until some of the basalt had flowed over the region.

The Second and Third Cycles

The physiographic forms representing the second and third cycles of erosion in the San Bernardino Mountains so resemble each other and so grade into each other that their separation is often impossible, and it seems, therefore, most convenient to discuss them together rather than to treat each one separately.

The second cycle is exemplified by the country around Bear and Holcomb valleys. With its low hills and rounded outcrops of granite, this area is in marked contrast with the more rugged country to be seen on all sides. Many of the hills are covered with débris on the lower slopes, while on the upper slopes are often rugged outcrops; as at Gold Mountain, where the country rock is quartzite. On the south side of Bear Valley the detrital slopes are similar.

The streams of low gradient flowing through the meadows are the headwaters of streams which plunge down steep cañons in their lower courses. The whole aspect of the country is that of a mature surface still having a pronounced relief with rounded forms (pl. 19). The broad valleys had reached base-level before being uplifted. Crossing over the ridge to the south into Santa Ana Cañon a somewhat similar situation obtains. Big Meadows at the head of the cañon have the same general appearance as the meadows in Bear and Holcomb valleys. In Bear Valley there are remnants of an old surface above the present floor; as for example the plateau between Rathbone Creek and Erwin Lake. Holcomb Valley is nearly surrounded by similar benches. Likewise around Big Meadows, particularly to the north and east and just a little above them in general elevation, there are broad flats and flat-topped ridges. In both cases the flats merge more or less into the hills, but are rather sharply set above the meadows. However, some very significant differences are to be noted. The surface of Big Meadows is continuous with a great bench which extends several miles down the cañon, and on this bench there are several meadows. This was previously the floor of Santa Ana Cañon, but it is now deeply incised by the river, the new channel exposing about 500 feet of fanglomerate (pl. 20A), which shows that after the cañon was first carved the climate became less humid and the streams were unable to carry away their burdens. This same change in humidity is recorded in Bear and Holcomb valleys, for the benches above the lakes and meadows are mostly fanglomerate. Holcomb Valley is drained by Holcomb Creek, and this cuts bedrock at the very edge of the valley, thus showing that the filling of the valley cannot be very deep. Therefore the topography must have been of the broad rolling type before the deposition of the fanglomerate. But Santa Ana Cañon was cut 1000 feet below Bear Valley and had steep sides. The difference is further reflected in the nature of the fanglomerate. In Santa Ana Cañon boulders three to six feet in diameter are common, while in Bear and Holcomb valleys they are seldom greater than one foot. These valleys have broad level floors; into Bear Valley flows Rathbone Creek, a gentle graded stream, and a similar creek from the region of Erwin Lake south of Baldwin Lake. The old floor of Santa Ana Cañon differs in that it is not flat but has a decided grade, being about 1500 feet lower at Seven Oaks than around Big Meadows. In other words, the Bear Valley region possesses some of the features of old age while Santa Ana Cañon represents late maturity. The following explanation of all of these differences between the two regions seems plausible.

In discussing the structure it will be shown that the mountain mass has been uplifted between faults on the north and south sides.

The surface of the first cycle must have been developed before the inauguration of the upward movement. The rolling topography around Bear Valley represents a halt in this movement for a sufficient time to reach late maturity. It is altogether probable that this condition also existed in the Santa Ana. Renewal of the upward movement would cause rejuvenation of the streams and deepening of the cañons. Bear Valley has a smaller catchment area than Santa Ana Cañon and is drained by a stream having a longer course and hence requiring greater time to cut back to the valley. Hence the latter might be greatly deepened and widened by erosion while Bear Valley would change but little. A lowering of the rainfall in the region would result in extensive deposition of fanglomerate both in the Santa Ana and Bear Valley regions.

It is well to point out here that in an arid or semi-arid region the rainfall is somewhat dependent upon the relief. Examples are found the world over where there is an abundance of rain in mountains surrounded by desert. So here rains are frequent during July and August in the mountains, while all around them there is no rain from April to December. It is therefore difficult to say to what extent the present rainfall is due to change in climate and to what extent it is due to uplift since the deposition of the fanglomerate; but certain it is that we now find humid conditions modifying a topography developed under arid or semiarid conditions.

It is thus seen that the topography of the Bear Valley and Santa Ana areas is not the result of a simple erosional cycle, and that the former was evolved at an earlier date than the latter. The third cycle represented by Santa Ana Cañon is found in many other places and in some instances is even more readily distinguished from the Bear Valley or second cycle. In this connection the topography of the south flank of the range will be described at length.

Along the west side of San Gorgonio River a bench extends from one-half to one and one-half miles wide, known as "Banning Heights." To the north and west rise hills of mature aspect. The slopes are smooth and continuous with the heights. The graded condition of the hills is indicated by the fact that, when the slope equilibrium is disturbed by erosion at the bottom, small landslides are developed and the whole hillside is quickly rejuvenated. The rocks from which these hills are carved are granites and schists similar to those farther north, but so badly decomposed that a pick can be readily driven into them in many places. The present cycle is sufficiently developed around the edges of this area to show that the formation of the bench and surrounding hills is the work of an earlier cycle. Between Wallace Creek and Cherry Cañon and extending up Hog Cañon and Little San Gorgonio are flat areas which are at the same general elevation as Banning Heights and belong to the same old surface. Similar benches are seen on the east side of San Gorgonio River.

At the head of Hathaway Cañon and extending over to Potrero Cañon there is an open valley with a smooth granite floor. It could not have been developed in its present position by normal erosion, for that would have left a high ridge between the two cañons. The simplest explanation is that it must be part of an old surface faulted down and thus protected. (See structure.) Just when this surface was developed is a question. It may be part of the second cycle or even of the first.

On both sides of Millard Cañon the contrast between the upper and lower slopes of the foothills is remarkable. On the flanks of these hills the slopes are steep and free from soil; the small gullies are V-shaped and have high gradients. In the upper portions the slopes are well rounded and the soil is thick and supports a dense growth of brush. These facts indicate a mature topography before the cycle was interrupted. A horizontal stratum of gravel resting on schist near the top of the hill on the east side of Millard Cañon at its mouth serves to make the distinction between the old cycle and the present clearer.

Farther east the old surface is even more prominent. It includes the upper portions of the ridges between Millard and Cottonwood cañons since on these there are so many flat areas at an elevation of about 3500 feet that there appears to be a plain at that level above which rise low rolling hills. Some parts of this area are worthy of special mention. At the upper end of Deep Cañon on the west side there is a long bench just below the crest of the ridge. Over the ridge to the north is a small depression which, until recently, was undrained, but it is now reached by a small side-cañon from Millard Cañon. West of the first branch of Stubby Cañon there is a similar basin which still has no outlet. Such basins may be developed almost anywhere along a fault and are, indeed, important rift features; but here they form a part of an old surface which, it has already been suggested, was developed during arid conditions. They are often found in the desert and may be structural or formed by deflation. Certainly they must be considered as indicative of aridity, for in a humid climate they would soon be filled with sediments brought in by streams.

This old surface may be traced over the upper parts of the hills between Cottonwood and Whitewater cañons. It continues up the latter on both sides for several miles and is particularly prominent near Red Dome, where it takes the form of a bench on the west side of the cañon and a flat-topped ridge on the east. From this point it continues northward to Mission Creek. A line along the face of the hills east of Mission Creek continued westward is the locus of a series of longitudinal gulches. It seems that here there was once a valley with gently sloping sides and floored with a considerable depth of fanglomerate. The present streams are influenced by this old valley; they tend to follow it and are removing the old floor.

Near the head of Mission Creek and in the upper courses of Big and Little Morongo creeks extensive benches merge into the sides of the cañons. They are very similar to Raywood Flat, and, like it, are composed of fanglomerate and have been cut by recent erosion.

Morongo Valley consists of two parts, Upper Morongo, which is included in the San Gorgonio Quadrangle, and Lower Morongo, which lies to the east. They are separated by a divide shown on the edge of the map. Along the southeast side of Upper Morongo there is a strip of fanglomerate and on it there are remnants of a topography of low relief. North of the divide this surface may be seen developed on the granite.

There are some interesting points to be considered in connection with the topography along the south slope of the range. In a later section it will be shown that a fault traverses Potato Cañon to Pine Bench, thence to the mouth of Stubby Cañon, and thence nearly straight east beyond Whitewater River. While there are frequent depressions marking the position of this fault, there is no actual offsetting of the topography, although the fault crosses several flat places in the old surface that would surely record such a movement. On the west side of Whitewater River fanglomerate on the south side is faulted down against the schist on the north; but the flat surface passes over the contact with no sign of a break. The fault crosses the flat remnant of the old surface on the west side of Deep Cañon, but again there is no offset. So it is quite clear that the old surface is later than the most recent vertical movement on the fault at this locality. One mile and a half northwest of Hog Ranch another remnant is found on a ridge parallel to the Mission Creek fault; but at the southeastern end of this area it is hook-shaped and crosses the fault. Here again the flat surface must be later than the faulting. Now

Bear Valley was developed near base level and uplifted by movement on these faults. It is therefore evident that this mature surface along the south front of the range must represent a far younger surface than that of the Bear Valley region and is probably correlative with the Santa Ana or third cycle.

Around the headwaters of Whitewater River are extensive flats which once formed the floors of mature valleys, but are now deeply dissected. Raywood Flat (pl. 21A) is a remnant of one of these old floors, but others are numerous and, as seen from one of the hills, they all seem to form a continuous surface. As is the case in Santa Ana Cañon, they consist of fanglomerate and therefore represent extensive filling after the earlier excavation of the cañons. In discussing the structure it will be seen that the Mission Creek fault probably crosses this area. But there is no offset. This is, of course, in keeping with the statement that the surface belongs to the third cycle.

The topography of the Bear Valley area is more complex even than as described in preceding pages, for in many places there may be found evidence of subcycles; but the relationships between them in different areas are hard to determine. The ridge on the south side of Bear Valley broadens out toward the west and in the vicinity of Bluff Lake there is a considerable area of flat country which lies 700 feet above Bear Lake. This locality is a region of broad meadows separated by low but extremely rugged ridges (pl. 20B). The rounded forms taken by the granite are not due to exfoliation, but to a sort of crumbling of the disintegrating granite. This surface lies at about the same elevation as the bench between Rathbone Creek and Erwin Lake and the tops of the ridges farther east. Broom Flat and Cienaga Seca may also belong to this subcycle, although they lie at different elevations.

The streams down from the ridge west of Sugarloaf have very low gradients in their upper courses, i.e., near the crest of the ridge, while farther down they drop off precipitously. This condition is most pronounced near Sugarloaf itself. Northeast of the long ridge a mile east of Sugarloaf there is a small but well defined valley having a southwest course. Other valleys are found near by at about the same elevation. A similar topography is seen just below the crest of the ridge between San Bernardino and San Gorgonio peaks.

In lower Mill Creek Cañon and at the mouth of Potato Cañon the conditions were similar to those in Santa Ana Cañon, but only small remnants of fanglomerate remain. In Mill Creek Cañon these grade into the hills in much the same way as the old valley floor of the Santa Ana. A consideration of the atmospheric agencies explains the greater removal of the old floor from Mill Creek Cañon. The precipitation here is fully as great as in Santa Ana Cañon, since the moisture comes from the south and is intercepted by the summit ridge. In the spring the quick melting of the snow on the south or Mill Creek side of this ridge affords a great carrying power for the removal of detritus, while on the north or Santa Ana side the snow melts more slowly, some remaining throughout the year, which does not make for rapid erosion. Near the mouth of Potato Cañon are low ridges of fanglomerate which appear to have been deposited at the same time as the fanglomerate in Mill Creek Cañon, as they are of similar composition and lie at about the same elevation.

The crest of the ridge between Mill Creek and Potato cañons is certainly a portion of an old surface much reduced and covered with soil. It is so well preserved that one gets the impression of being in a broad rolling country rather than on a high ridge. It has crooked gullies with low divides and also small inclosed basins, a good example of which is found just above the head of the west fork of Birch Creek. All are abnormal in their present position; they must have been developed much nearer base level. Away from the crest the ridge is deeply incised by V-shaped gullies and cañons. Toward the west the ridge is much lower and the crest line becomes more serrate, as would be expected where the ridge is reduced below the old surface. The correlation of this topography with that to the north is uncertain. The relief is greater than that on the summit ridge and the surface is certainly distinct from that developed when Mill Creek and Santa Ana cañons were floored with fanglomerate; it must occupy some intermediate position. This fact, together with the actual resemblance of the two surfaces, suggests that it belongs to the subcycle represented by the streams along the ridge west of Sugarloaf.

It has already been noted that the mountains have a general slope to the east. The western portion was probably raised the highest at each uplift, and hence must have developed the greatest relief as the streams approached base level. Therefore we find the second cycle well developed around Bear Valley, while to the east it is not so distinct, and still farther east, in the vicinity of The Pipes, large areas of the first cycle are preserved. It is therefore clear that a certain correlation of scattered remnants of any surface is exceedingly difficult and in some cases the evidence is hardly more than suggestive.

The valley southwest of Smart's Ranch probably belongs to the third cycle, for it is cut down sharply below the east end of Bear Valley and its walls are more rugged and rise more steeply.

A broad valley floored with fanglomerate lies southeast of Mound Spring. It forms the divide between separate drainage systems, and is therefore not a feature of the present cycle. The upper portions of the hills to the north are rounded and compare favorably with those around Bear Valley and the upper Santa Ana. On the crest of the ridge immediately to the south there is a large stretch of even topography extending nearly to the head of Antelope Cañon. This may well be a remnant of an earlier cycle or subcycle. The top of the ridge east of the valley is also flat. In both of these cases the tops of the ridges are quite distinct from the sides and in no way can they be considered merely the rounded hilltops of a topography of considerable relief, but rather the remnants of a very old surface. Because of the way in which it is cut down below these older rounded features the valley is believed to belong to the third rather than to the second cycle.

The valley east of The Pipes has almost identically the same relationships to the surrounding country as that near Mound Spring. It is floored with fanglomerate, and remnants of an older topography are found on the hills south and west of The Pipes and also to the east. Between this valley and Rock Corral there is a plateau which is remarkably like the Bluff Lake country. It is covered with low hummocks of granite which are being buried in their own detritus, and north of Saddlerock Spring for about two miles there are areas where the granite is completely buried recalling the panfan or end stage of desert erosion. The streams are meandering and of low gradient, but along the north front of the range they drop off precipitously, suggesting faulting. The bareness of the hummocks in the northern portion of the plateau is probably due to the removal of detritus by these streams. West of this plateau the hills rise rather abruptly, but not in a straight line as would be expected if due to faulting. This feature is far more likely due to one of the phases of desert erosion. Northwest of Negro Butte there is an extensive granite surface sloping very gently to the north and disappearing under the alluvium. Where it first emerges from the alluvium it is almost unbroken, but farther to the north numerous small gullies cut across it; and finally these gullies, while not deep, become conspicuous with low but rugged ridges between, identically like the plateau north of Saddlerock Spring. This platform ends rather abruptly against the hills west of Negro Butte. This sort of thing is common in the desert and will be considered further on another page. The important point to bring out at this time is that the surface between Saddlerock Spring and Rock Corral was probably evolved under desert conditions, and by further comparison it seems likely that this is also true of the Bluff Lake region. This is also indicated by the presence of several inclosed basins, such as are characteristic of the desert.

The ridge from Granite Peak eastward is a remnant of an old surface covered with huge boulders pitted and scarred by wind erosion. Although the country rock is a uniform granite, there are to be found here many angular fragments of polygenetic rocks, quartzite, schist, aplite, etc. Usually these are very hard, and quartzite is the most prominent. They prove that the surface was once extensive, for only under such conditions could these fragments be brought here. The ridge to Tiptop Mountain is part of the same surface, but it is somewhat different toward the east due to the nature of the country rock, which is limestone. It is rather even and rounded at the crest. Tiptop Mountain itself is not a simple peak, but consists of three rounded hills rising above the ridge. This area is at about the same elevation as some of the ridges around Bear Valley, and the whole may well have been continuous at one time.

Other remnants of the second and third cycles are probably to be found in these mountains, but their correlation is even less certain than some of those already described.

The Fourth Cycle

The mountain mass as a whole is now undergoing rejuvenation by uplift and the surfaces of the older cycles are rapidly disappearing. Bear Creek plunges down a youthful cañon which is gradually eating back into Bear Valley. All the streams along the north front of the range from Silver Creek to Arrastre Creek are cutting back to the south. Arrastre Creek itself has a rather uniform and not precipitous grade from the very head down to Smart's Ranch; but below this point it is precipitous. Rattlesnake Creek flows in a narrow cañon with steep sides often approaching the vertical. It has cut down to grade southward to the bend two miles southeast of the Rose Mine. Above this it is very steep.

The streams south and east of Rattlesnake flow in newly cut channels in their lower courses. This may be seen between Rock Corral and Rattlesnake. On the plateau the stream courses are so crooked and the grade so low that one hardly knows whether he is going up stream or down; but on the north side of the range they drop through steep juvenile cañons.

All the erosion going on at present cannot be considered as due to streams. Between Rock Corral and The Pipes typical desert erosion is active. The low granite ridges of this area are burying themselves in their own detritus except where the water is able to carry it away. There is no true exfoliation, i.e., no curved fragments are being formed. The detritus consists almost wholly of disintegrated granite with occasional angular or subangular harder fragments of pegmatite and aplite.

The streams along the south flank of the range flow in youthful cañons cut far below the mature surface of the third cycle, some parts of which form prominent benches above the streams. Such is the case at Banning Heights, which rise above the San Gorgonio Pass on the south and above the San Gorgonio River on the east. Morongo Valley opens to the east and was evidently excavated by drainage in that direction, but it has been captured by streams—Dry, Big, and Little Morongo creeks—cutting back from the south.

The youthful topography may also be seen in the higher parts of the mountains. In Santa Ana Cañon the general appearance of maturity is preserved, but in reality it is deeply incised by erosion, which is still active (pl. 20A). The main stream has cut into the fanglomerate to a depth of nearly five hundred feet. In Mill Creek Cañon erosion has gone farther and has almost completely removed the old valley floor. The smooth ridge just south of Raywood Flat is incised by V-shaped gullies (pl. 21B). Toward the east both the ridge and flat are giving way to a youthful rugged topography as the streams cut back. This same sort of thing may be seen in nearly all the cañons immediately to the north.

At the mouth of Mission Creek there are two terraces of fanglomerate between the present stream bed and the old surface on top of the ridge to the west. In all the cañons along the south, terraces are found ten to twenty feet above the stream beds. These probably represent changes in the humidity of the region, although those at the mouth of Mission Creek may possibly indicate halts in the upward movement of the mountain mass.

Glacial Features

Glaciation in the San Bernardino Mountains has been described by Fairbanks and Carey,[3] and the present writer can add but little to the record of their observations. Well preserved cirques and moraines constitute the evidence of the former period of ice action. This glaciation was of such a local character that the moraines do not extend far beyond the cirques and no typical glaciated valleys are found in the region. Practically all of the detritus is angular and no striated boulders were seen.

There is a typical glacial cirque on the northeast side of San Gorgonio Mountain. It is very nearly equidimensional, being about 500 yards long, 300 yards wide, and 400 yards deep. A moraine extends about 400 yards beyond the cirque and crosses the uppermost part of the north fork of the Whitewater River, thus inclosing a small irregular basin, which, however, is usually dry. After building up a moraine 250 feet high the ice retreated for 150 yards and then continued to drop its load, thus forming a semicircular ridge which rose 100 feet above the first. It again retreated, but made a short stop, during which it built a ridge 20 feet in height across the mouth of the cirque. The upper portions of the walls of the cirques are steep, and the surface is extremely irregular due to the plucking action of the ice, which removed great blocks of granite. The lower slopes of the walls are covered with talus.

On the northwest side of San Gorgonio Mountain there are two cirques facing north and northeast respectively and separated by a sharp ridge (pl. 17A, left of center). The walls of these cirques are ribbed vertically, probably due to the fact that the plucking action of the ice was influenced by a jointage system in the granite. Toward the north the ridge between the cirques has been so reduced that the detritus from the two forms a single large moraine extending about a mile beyond. It is three-quarters of a mile wide and forms a dam 400 feet high across the east branch of South Fork. This together with a small artificial dam retains a small body of water known as Dry Lake.

In the upper part of the west branch of South Fork there are several ridges of débris extending longitudinally down the cañon. The north side has a moderate slope and the head of the cañon rises

[3] Fairbanks, H. W., and Carey, E. P., Glaciation in the San Bernardino Range, California, Science, n. s., vol. 31, no. 784, p. 32.

to a saddle and can by no means be considered a cirque. Dollar Lake is retained by a moraine of parabolic contour, the lake itself being at the focus. One limb of the parabola extends up the cañon and the other is cut off by the precipitous south side of the cañon. This wall is very uneven and somewhat resembles the ice-plucked walls of the cirques, but, being of schist, this action cannot be so clearly recognized. Below the parabolic morainal dam and parallel to it are several other ridges of débris. Farther down they extend across the cañon and are fully 300 feet in height. These ridges are due to glaciation, and indicate a tendency for the ice to hug the south side of the cañon. The ice did not retreat directly up the cañon, but to the south side as well. This was probably due to ablation caused by the sun's rays striking the north side of the cañon.

A large amount of water is retained by the glacial till and numerout large springs flow from the slopes of the moraine. These springs carry out considerable quantities of débris which form mounds. Many springs were seen where no water is now flowing and during the writers short stay a new spring broke forth. This temporary nature of the springs can probably be accounted for by the extremely irregular arrangement of the débris, which must result in correspondingly irregular, and in many cases local, reservoirs. The streams from these springs water a long series of meadows in South Fork and farther down they unite to form a single large stream.

The most ideal example of glaciation is found at the head of Hathaway Creek. The writer can best quote Fairbanks and Carey.[4]

> It was a long narrow tongue of ice which reached downward a mile and left the most perfect moraines seen. Five semicircular terminal moraines cross the canyon and upon its eastern side is an ideally perfect marginal moraine. The middle one of the terminal moraines is formed of immense blocks of rock and looked at from below its curving front forms a great wall nearly 100 feet high. The lowest moraine, 1000 feet farther down the canyon, is formed of the finest material of any, as though when the first ice tongue came down it found the surface soft and deeply disintegrated. The phenomena here indicate that glaciation was of considerable duration, and that the history of the period was anything but simple. . . . . None of these glaciers appears to have descended much below 8500 feet, and it will be seen from the descriptions given that the conditions had to be just right for their appearance at all. Such conditions were a northward or northeastward facing alcove which headed sufficiently close to the crest to receive the snows which drifted over its summit.

[4] Fairbanks, H. W., and Carey, E. P., *op. cit.*, p. 33.

The Desert

The desert north of the San Bernardino Mountains has had a physiographic history so different from that of the mountains themselves that it will receive special attention. This difference is not the result simply of the difference between the effect of uplift and that of depression on the gradients of the streams, but is also a result of the difference in the climate and the processes at work.

South of Old Woman Springs there is a considerable area of basalt resting on a nearly flat granitic basement. This affords a clue for the correlation of part of the desert surface with that of the mountains, for, if the basalt is the same as that east of The Pipes, then the underlying granitic surface is probably the same in the two cases. Also, the flat surface on the two areas of basalt may be correlative. Three miles north of Old Woman Springs, there is a similar area of basalt resting on an old surface. Other small areas are found between this place and Negro Butte, and of course these all help to convey the idea that the pre-basalt surface was one of low relief and that the desert and present mountains were at that time a continuous geomorphic feature.

Following the period of lava extrusion there was considerable faulting throughout the region, and the comparison between the physiographic development in the desert and in the mountains becomes very difficult. Naturally the faulting increased the relief in the desert; but the movements were not great, for we still find remnants of basalt on Negro Butte and some of the nearby hills and also south of the hill east of Negro Butte. The vertical offsets of these high and low areas of basalt are not more than 500 feet. Fry Mountain is capped with basalt which slopes 15° to the north and is continuous with a fault area more than two miles in length. On the upper part of this hill, extending southeastward from the peak and just below the crest of the ridge, there are remnants of an old valley with stream beds of low gradient. This part of the drainage system of the hill is in marked contrast with the southwest margin, where the stream beds drop off precipitously through steep, narrow cañons. It is therefore certain that during the uplift of Fry Mountain there was a period of rest, and this was near the beginning of the movement. That the major movement of the mass is of comparatively recent date is proved by the geomorphic discordance. In consideration of this fact and of the preservation of the numerous areas of basalt, it seems probable that at no time since the development of the pre-basalt surface has the relief of this portion of the desert been much greater than at present. This statement probably includes the hills west of Rabbit Springs and around Means Wells, for the relief is of the same magnitude as in the vicinity of Fry Mountain and Negro Butte.

The topographic history of the desert cannot be separated into parts comparable to the second, third, and fourth cycles so clearly identified in the mountains. The changes which took place in the desert during the development of the second cycle in the mountains are still in progress, and a description of the processes now at work and the forms developed by them must suffice.

The erosional processes in the desert have certain distinguishing features occasioned by aridity: the rocks break down by mechanical disintegration rather than by chemical decay; no definite drainage system is maintained; the distance of transportation of products of disintegration is very limited. Another important consideration is that the rainfall, though small in the aggregate, is torrential when it does come. The topography consists of three elements: the rock masses, the alluvial fans, and the playas. Lawson[5] has discussed the development of the desert surface at length and certain rock forms which he develops from theoretical considerations are well exemplified in this region.

The exposed rock masses break down by mechanical disintegration and the products of this action are removed by rain wash and deposited on the lower slopes. As this goes on the face of the exposed rock mass retreats, leaving a bench protected by detritus. The retreating rock face has been termed "The Subaerial Front," and the bench "The Suballuvial Bench." It is an interesting fact that the subaerial front maintains its steep slope as long as it exists at all. The coarser material forming the alluvial embankment is on the higher slope and may contain angular boulders of considerable size. Farther down the material becomes finer and finally out on the playas it is fine silt.

The granitic hills west of Negro Butte are a good example of desert topography. They are extremely rugged, rather steep, and with the exception of the north side they are approached by alluvial fans right up to the bold rock masses. There are several isolated salients and the general outline of the hills is very irregular. The alluvial fans intersect those from other hills or end in playas. On the north side

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[5] Lawson, A. C., The Epigene profiles of the Desert, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, no. 3, pp. 23–48.

of the hills a considerable strip along the upper portion of the suballuvial bench has been laid bare by the removal of fanglomerate. Along its lower or northern edge this uncovered rock platform is rather smooth, but higher up to the south there are small gullies developed with portions of the flat surface between. Still higher the gullies become deeper and wider and the surfaces along the tops of the ridges become broken. It seems probable that this stripping has been brought about by an increased gradient due to a sinking of the area to the north. Had it been due merely to a local uplift of the hills, part of the bench on the south side would also be denuded. The hills to the east of Negro Butte exhibit the same general character.

The recency of the uplift of Fry Mountain has already been mentioned. The alluvial fans are in accordance with this, for they are poorly developed as compared with those around the hills to the southwest. The long hill three miles east of Fry Mountain has a well developed, alluvial embankment on the southwest side and the upper part of the suballuvial bench has been stripped and eroded in exactly the same manner as that west of Negro Butte. The northeast side of the hill is straight and steep, which leads to the conclusion that it is a fault scarp. This idea is further strengthened by the fact that it is in line with the northeast side of a similar hill four miles to the southeast. An interesting feature in connection with this hill is the way in which the wind has affected the alluvial embankment. On the east side it is perfectly normal fanglomerate, but on the west there is a great deal of finer wind-blown sand creeping high on the slopes. At the hill two miles to the southeast this material nearly reaches the top.

The two hills northwest of Means Wells are similar to Fry Mountain in that they are steep and have rather poorly developed fans. These observations naturally lead to the conclusion that they too are of recent uplift. Contrasted with these are the hills farther north, where again we have well developed fans and many isolated salients.

Extensive alluvial fans are being developed along the north front of the main mountain mass. These present certain peculiarities which show that the uplift has been by stages. On the north side of Blackhawk Mountain an old fan creeps high on the slope and extends more than three miles from the base of the mountain. It is composed almost wholly of fragments of limestone so recemented as to be nearly as firm as the original. This fan is now deeply dissected, probably due to increase in gradient by uplift.

East of Blackhawk Cañon many alluvial fans creep high on the hills and in two cases they have been faulted. One of these is about a mile west of the mouth of Rattlesnake Cañon and the other is about three miles east of Rock Corral.

West of Cushenberry Spring the fans are well developed but do not creep high on the hills in the same manner as those farther east. Another important difference is that more large boulders have moved far down the slope. In this connection it is well to note that west of a north-south line passing through Negro Butte there are numerous yucca trees, while to the east there are none; the vegetation there consisting of greasewood, sagebrush, catclaw, and mesquite. Even these are sparse, and five miles east of Old Woman Springs there is a great area of sand dune country. The significance of these facts seems to be that the rainfall is materially greater to the west. This, of course, would explain the difference between the alluvial fans.

Playas are the beds of intermittent, undrained lakes and are typical of a region so arid that no outside drainage is established. They are, of course, the places where the finest silt and dissolved salts in the run-off from the surrounding country are deposited. By far the larger part of the material is fine silt, but thin calcareous and gypsiferous seams are not uncommon. When these playas dry up, the surface is hard and smooth and light grey to white in color. At a distance they look like sheets of water.

A more or less continuous patch of green vegetation extends from Cushenbury Springs to Rabbit Springs. Numerous springs flow forth along a fault and the moisture has served to retain the finer dust, so that areas of fine loamy soil are found which are in marked contrast with the coarse fan material on all sides. To a less extent the same thing is found at Old Woman Springs.

Alluvial Fans in San Gorgonio Pass

Along the south front of the mountains the streams are building up alluvial fans. One at the mouth of Mission Creek is well developed and shows the features characteristic of these accumulations. Near the mouth of the cañon the material which constitutes the fan is hardly less than a mass of boulders. Some of these are well rounded, but most are subangular although worn fairly smooth. Toward the southeast the material is finer and finally, just north of Palm Springs station, there is a great deal of fine alluvium; but even here there are some large boulders, brought down doubtless during cloudbursts. The stream is constantly changing from one radiating channel to another across the fan.

Out from Millard Cañon the same thing is to be seen. At the mouth of the cañon the fan is a mass of subangular boulders, while at Cabezon the alluvium has been cultivated and planted to orchards. Again at Banning the upper part of the fan contains many boulders and south of the town the soil is rather heavy.

It is interesting to note that the fans spreading out from the cañons on the north side of the pass cross it and the streams actually wash against the bedrock on the south; in fact, the only alluvial fans on the south side are at the mouths of Snow Creek and Blaisdell Cañon, and these are protected by prominent salients. A study of the relative amounts of water coming down the cañons on each side of the pass seems to contribute to an explanation. Planimeter measurements show that the catchment area for Whitewater River is 60 square miles, while that for Snow Creek is only 32 and for Blaisdell Cañon it is only 7 square miles. For Potrero and Millard cañons it is 42 square miles and for the opposing streams from the south only 19 square miles. The total area draining into the San Gorgonio Pass from the north is 198 square miles and that from the south is only 74 square miles. It is therefore clear that with the same precipitation the streams from the north would be the stronger and build out the larger fans. There are reasons, however, for believing that the precipitation on the north is the greater. In this region the moisture-bearing winds are from the southwest and on striking the high mountains they drop a large part of their burden; hence the south and west slopes will receive the more. This being the case, the precipitation is probably much greater on the north side of the pass than on the south.

While the foregoing considerations explain the greater development of the fans on the north side, they do not fully account for the fact that fans on the south side are almost entirely absent. A factor which may be of importance in this connection is the effect of the fault on the north side of the pass. This fault is certainly very recent, for its topographic expression is still clear despite the fact that the rocks on the north, or upthrown side, are but loosely consolidated and therefore not resistant to erosion. The lowering of the south side would naturally cause the fans there to be buried by those from the north.

In addition to the extent of the fans there are other effects of the greater flow of water from the north. The slopes of the fans at the mouth of Blaisdell Cañon and Snow Creek are as high as 6°. They approach the ideal more closely than do those of the north in that the material of which they are composed is more angular. It has not been subjected very much to the action of running water, but has simply been carried out on the fans and deposited. No streams flow down over them except after the rains. On the other hand, the slope of the Whitewater fan is very gentle and much of the material is so rounded that it might well be called stream conglomerate. A considerable stream flows down throughout the year and as late as July it amounts to more than 2000 miner's inches. Comparison of other opposing streams reveals the same relationship though not with such a marked contrast.

To sum up the situation it seems that the fans from the north are the more extensive because of the greater amount of water contributing its load to them.

Summary

The four cycles of erosion in the San Bernardino Mountains show that the mountain mass has reached its present position of elevation by stages. To be sure, changes in aridity have had some influence in sculpturing the horsts, but in the main the record is of uplift.

Previous to the first movement and during the first cycle the region was reduced to a peneplain, and following it the broad graded valleys of the second cycle were cut below this erosion surface. Therefore the difference in elevation between the remnants of the surface of the first cycle and the broad valley floors of the second indicates the amount of the uplift. The summit ridge between San Bernardino and San Gorgonio mountains rises 4000 to 4800 feet above Big Meadows and the floor of Bear Valley. These figures approximate the maximum movement between the development of the first and second cycles of erosion.

The amount of the second uplift is not so clearly recorded as that of the first. After it was accomplished Santa Ana Cañon was cut below the floor of Bear Valley about 1000 feet, but this figure tells little since the stream had not reached base level before a change in humidity arrested its cutting action and caused the V-shaped cañon to be filled with débris. Along the south front of the range, however, it appears that there has been no important vertical movement on either the San Andreas fault or Mission Creek fault since the development of the third cycle. It would seem, therefore, that elevation of the valley floors of the second cycle above Banning Heights, which was probably at the base of the mountains at that time, is a measure of the uplift. This is approximately 3000 feet, somewhat less than the amount of the first uplift.

Since the most recent uplift is evidenced by rejuvenation, with no evidence of the streams having even approached base level, it is impossible to determine its actual amount.

Glaciation has locally modified the topography of the summit ridge extending from San Bernardino Mountain to San Gorgonio Mountain. Well preserved cirques and moraines are found along the north side. The record they afford shows that the period of ice action was of considerable duration and had a history of some complexity, one glacier having left five terminal moraines. The glacial till retains a considerable amount of water which feeds a large number of springs. These water several meadows and give rise to at least one important stream.

The physiographic history of the desert north of the San Bernardino Mountains differs considerably from that of the mountains themselves. Numerous areas of basalt, each resting on a nearly flat surface of granite or schist, because of their resemblance to similar areas in the mountains east of The Pipes, indicate that the desert and the present mountains were at one time a continuous surface of low relief. There has been considerable faulting in the desert as well as in the mountains, but the movements were much smaller and the topography does not bear the record of a history divisible into parts corresponding to the second, third, and fourth cycles in the mountains. The changes taking place in the desert during the development of the second cycle in the mountains are still going on. Because of the erosional processes peculiar to arid conditions, desert topography consists of three elements: rock masses of characteristic forms, alluvial fans, and playas. These elements are well developed in this area and display certain variations due to the fact that faulting has taken place at the same time.

Extensive alluvial fans are being built along both the north and south flanks of the main mountain mass. Those on the south flank spread out across the San Gorgonio Pass. They are much greater than the fans extending northward from the south side of the pass, the difference probably being due to a greater amount of water contributing its load to them.

GEOLOGY

General Statement

North and northwest of Cienaga Seca Creek the rocks are limestone and quartzite, presumably of Paleozoic age, intruded by granites. South and east the rocks are mostly schists and granites, some of which have been rendered gneissic, so intimately associated that they have not been differentiated. They were originally thought to be pre-Cambrian, but portions of the sediments to the north are so altered as to be indistinguishable from them. This raises a doubt as to the age of a large part of this southern complex, and, although parts of it may be altered phases of the rocks to the north, it will be discussed separately. The granitic rocks of the region represent several different intrusions, but no evidence of sedimentation between them has been found.

Along the south flank of the San Bernardino Mountains there are sandstones, shales, and fanglomerates of Tertiary and Quaternary age. Remnants of basalt flows are also found here. In the desert to the north, and also in scattered areas in the mountains, there are sediments and basalt supposed to be correlative in a general way with those along the south flank.

The rocks of this region have never before been described, and local names have been given them. The sedimentary formations involved are, in chronological order beginning with the oldest, the Arrastre quartzite, named after Arrastre Creek; Furnace limestone, after Furnace Cañon; Saragossa quartzite, after Saragossa Spring; Potato sandstone, after Potato Cañon; Lion sandstone, after Lion Cañon; Hathaway sandstone and shale, after Hathaway Creek; Santa Ana sandstone, after Santa Ana River; Pipes fanglomerate, after The Pipes, a watering place; Deep Cañon fanglomerate, after Deep Cañon; old desert deposits; Coachella fanglomerate, after Coachella Valley; Cabezon fanglomerate, after Cabezon Station; Heights fanglomerate, after Banning Heights; glacial till; alluvium. The igneous rocks are: a heterogeneous mass of granites; the Cactus granite, after Cactus Flat, of rather uniform characteristics over large areas; basalt.

Undifferentiated Schists

Extending south and east from San Bernardino Mountain to the San Gorgonio Pass and the lower portion of Whitewater River, and thence northward to Big Meadows and Big Morongo Creek, there is a great mass of contorted schists of variable character. Granite has invaded this area in many places and has been so subjected to deforming stresses that it also possesses a foliated structure and in many cases cannot be readily distinguished from the schists of sedimentary origin.

Because of their highly metamorphosed character and complex folding, as compared to the quartzites and limestones north of the Santa Ana River, these rocks were at first thought to be much older, probably pre-Cambrian. However, certain portions of the clearly recognizable sediments were found to be so altered as to be indistinguishable from the rocks, thus raising a doubt as to their relations. Before discussing this phase of the problem the rocks themselves will be more fully described.

Schists are exposed in the lower portions of Smith Creek northeast of Beaumont. The schistose laminae are folded and twisted in a very complex manner. The principal constituents are quartz, biotite, and a feldspar, but the rock is so decomposed that the feldspar was not determined. The schists are intruded by a granite mass on the north and are cut by apophyses of this mass. Both granite and schist are cut by pegmatite dikes containing crystals of muscovite more than two centimeters across.

On the west side of San Gorgonio River, two miles from its mouth, there is a peculiar rock exposed in a small gully which has cut down through the overlying fanglomerate. At first sight it has the appearance of a granite, but closer examination shows that it consists of slightly rounded pieces, one to fine centimeters in diameter, of greyish quartz with interstitial biotite; and it may be an altered pebble conglomerate. This overlies a dark, medium-grained plastic rock containing quartz, biotite, and muscovite. Both are cut by pegmatite dikes containing large crystals of pink orthoclase and varying in thickness from a few inches to nearly two feet.

On the opposite side of the cañon there is a rock containing much biotite presenting several variations. Near the bottom it is composed almost wholly of biotite as small flakes and is without schistosity. Higher up it is schistose and contains some muscovite in addition to the biotite. Still higher it resembles that at the bottom, except that it is much coarser. Above this biotite rock is a fine-grained quartzite containing small flakes of muscovite, but showing no bedding.

The schists two miles farther up the cañon are highly altered and it seems likely that some were originally igneous. On the west side the schistosity strikes N 30° E and dips 30° SE and the lower portion is largely black schist. Under the microscope it is seen to have a very fine texture and to consist of quartz with enough green hornblende to give the rock its dark color. A small amount of biotite is arranged in streaks with the hornblende. The rock also contains numerous small grains of titanite and a few small prisms of apatite. No feldspar could be seen. Above this there is a dark schist consisting largely of brown biotite, some muscovite and hornblende, and lenticular phenocrysts of orthoclase with carlsbad twinning, some of which are more than three centimeters across. Under the microscope these large crystals are seen to have irregular boundaries due to the other minerals jutting into them and flakes of muscovite are scattered through them. The ground mass contains considerable quartz and an altered feldspar, probably orthoclase, including a few needles of apatite. Numerous grains of titanite and a small amount of magnetite are also present. The rock is probably of igneous origin and it may have been intruded into that described above, but the schistosity imposed upon both of them has obliterated any positive evidence of such relationship. They have been cut by pegmatite dikes which still exhibit their characteristic graphic structure in spite of being much decomposed. Epidotization is common in the black schist and apparently progresses along fissures from which it extends out into the mass.

Nearly all the rocks on the ridge between Aker's Camp and Oak Glen are schistose. They strike approximately parallel to the ridge and dip 50° to 80° to the north and have been so metamorphosed that it is difficult in many cases to tell whether they are of sedimentary or igneous origin. That north of Oak Glen looks like a medium-grained gneissic granite and consists of quartz, biotite, and a feldspar. Much of the biotite has been chloritized. Near the crest of the ridge southwest of Aker's Camp a thin lens of marble was found which suggests sedimentation, although there still remains the possibility of calcite having been deposited in a fissure before schistosity was impressed upon the adjacent rocks.

The granites east of Mountain Home Creek show great diversity in both composition and texture. In several places there are darker rocks, high in biotite, having the appearance of inclusions and ranging in size from two to a hundred feet across. These rocks are usually ellipsoidal in form, but sometimes have one or more flat boundaries. Both granite and inclusions are crossed in all directions by pegmatite dikes from an inch to two feet thick. The whole rock mass has been repeatedly faulted.

On the south side of San Bernardino Mountain the schists strike west of north and dip 30° to the northeast. They are very heterogeneous, some being biotite schist with a few grains of magnetite and a decomposed feldspar, while other parts are rather high in quartz and are granitic, although this is somewhat masked by schistosity. At the peak there is a great deal of biotite schist having a silky, crinkled-ribbon appearance. On the east side of the peak there is a peculiar occurrence. A fine-grained biotite granite lies between schists. In the schist next to the granite there is a layer, about a foot thick, consisting of angular fragments of schist, granite and pegmatite all firmly held together by the granite. Lower down on the ridge epidote is to be seen everywhere.

The rocks around San Gorgonio Mountain exhibit great complexity. Medium-grained, biotite granites are found grading into distinctly schistose masses. These are intruded by granite with tongues branching into the schist. This sort of thing can be found on nearly any scale, some distinct apophyses being only a few inches thick and less than two feet long. The masses of schist in the granite are relatively small, only a few inches to a few feet across. A specimen from near the peak appears to consist practically wholly of biotite flakes about two millimeters across in parallel arrangement, but a microscopic examination reveals a few flakes of muscovite and scattered grains of magnetite, as well as a few grains of quartz containing small needles of apatite. Another specimen nearby consists of parallel light-colored bands of quartz and a small amount of orthoclase alternating with somewhat wider dark bands of biotite. In spite of the imposed schistosity a fine-grained granitic structure can still be recognized. The quartz and orthoclase are closely associated in interlocking crystals and the few small crystals of plagioclase, a rather acid oligoclase, show but a slight tendency toward automorphism. As is practically always the case in these schists, the quartz has undulatory extinction. Associated with the biotite is a small amount of muscovite and a few grains of magnetite and titanite. Another specimen taken half a mile southwest of the peak answers well to the above description, but in addition contains small areas of quartz and orthoclase in micrographic intergrowth.

These rocks correspond in every way to igneous rocks which have been rendered schistose. There are other rocks in this vicinity, however, which are of more doubtful origin. On the ridge two miles southwest of the peak where the trail turns suddenly down into High Creek there are schists dipping 30° NW sunken into the granite. The individual bands are rather long, although very thin. Under the microscope the rock appears to consist largely of quartz grains intimately intergrown. Orthoclase is the only feldspar present and is in small amount. Biotite is abundant and with it is a little muscovite and a few grains of titanite. Small patches of schist are seen the rest of the way down the slope imbedded in the granite and usually isolated from each other. They appear to partake of the nature of roof pendants rather than inclusions, since they have, for the most part, approximately the same attitude, striking N 60° E and dipping 30° NW. In the lower portions of the first little gully east of the ridge forming the divide between Mill Creek and Whitewater there are schists, quartzite, and limestone sunken into the granite. They are in conformable sequence, the quartzite being at the bottom and overlain by schist and this by limestone, a relationship entirely normal for these rocks. The thickness of the limestone is 30 feet, the schist 10 feet, and only 30 feet of quartzite is exposed. This quartzite is of vitreous rather than sacchroidal variety. One specimen, which appeared rather pure in hand specimen, was found on microscopic examination to contain a few flakes of biotite and muscovite. The quartz grains are intimately intergrown and exhibit undulatory extinction. A few crystals of feldspar are present, but so altered as not to be determinable with certainty. They are probably orthoclase and oligoclase. Another specimen, somewhat darker in general and showing dark and light streaks, was found to contain more biotite. The quartz grains have a tendency toward elongation parallel to the streaks of biotite. A few grains of titanite and magnetite are present as well as some round crystals which are isotropic and highly refractive, probably garnet. There are also a few prisms of apatite. The limestone is much broken and is entirely recrystallized; in it are developed contact minerals: epidote, garnet, and tremolite. They are best developed along fissures, and in some cases they follow planes of stratification. The schist between the quartzite and limestone at first looks like a fine-grained sandstone containing considerable biotite. Under the microscope it has somewhat the appearance of a fine-grained granite, largely due to its granoblastic texture. It contains orthoclase, albite, oligoclase, possibly a more basic feldspar, and considerable quartz, although less than feldspar. There is also some titanite, apatite, and a few rounded highly refractive, isotropic crystals, probably garnet. In a general way this description answers well for an igneous rock, but the field relations clearly show that the rock is an altered sediment. One point worthy of note is that the biotite does not show a strong tendency to cut across the other minerals, but is usually between them.

The ridge north of Raywood Flat is of banded schist intruded by granite. A specimen of the dark grey quartz-mica schist examined under the microscope was found to contain a small amount of orthoclase and albite-oligoclase and a few flakes of muscovite. Grains of magnetite and prisms of zircon and apatite are also present. On the ridge to the southeast there are hornblende gneisses which are peculiar in that they contain patches of hornblende less than a quarter of an inch thick over areas four inches square.

A large part of the schist along the south side of the mountains has a ribbon-like appearance, as is well shown in Hathaway, Potrero, and Millard cañons. In the upper part of the latter, granite and granite-gneiss predominate and are cut by pegmatite and aplite dikes. Epidotization is common, pure epidote often being found in fissures in the gneiss while in other cases the rock has been gradually replaced. No large crystals of epidote were seen. East of Millard Cañon the schists and small areas of granite are intimately associated and frequently the granite grades into distinctly schistose rock. The whole mass is intruded by pegmatite dikes and on top of the main ridge west of Deep Cañon there are several transverse ridges of pegmatite made prominent by differential erosion. Much of the granite is so decomposed that a pick can readily be driven into it and even some of the pegmatite crumbles to a powder between the fingers.

From Deep Cañon to Whitewater River the schists are largely of banded or ribbon-like varieties. In a general way they strike east and west and dip 20° to the north, but locally dips may be found in any direction. This can be seen in Stubby Cañon, where the range of strike is from N 45° W to N 50° E and the dip from 40° north to 20° south. On the west side of Whitewater River nearly vertical dips are common. Here several quartz veins stained with limonite cut the schist and some of them have been prospected for gold. Painted Hill consists of schist striking N 30° E and dipping 30° N. Much of it is badly altered and was probably mineralized, as it is now colored in streaks with limonite and hematite, presenting the striking appearance that gives the hill its name.

Similar schists in Dry Morongo appear to be made up of long continuous bands alternating grey, white, and black. These usually exhibit much contortion and crumbling. Because of the evenness of the banding, the individual bands showing but little tendency to pinch out, they at first appear to be sedimentary; but that similar well defined bands may be formed in another manner, may be seen near the head of the cañon. Small pegmatite dikes less than an inch to three inches thick are found ramifying through the schist. From this simple relation gradations may be followed to schistose rocks in which these small dikes have been drawn out into long bands. The continuity of these for distances of 20 to 30 feet and the resemblance of the mass to altered sediments is truly remarkable.

These schists extend northward to Big Meadows and Big Morongo Creek, where they are cut off by granites. The line between the granites and schists is not definite, but the schist area by an increasing amount of granite becomes a granite area.

As a whole, this great mass of schists has little in common with the limestone and quartzite to the north. Their general aspect—their high degree of metamorphism, intense folding, and intimate association of sediments with granitic rocks so altered as to resemble them—all are indicative of a vastly older complex. Furthermore, these granites are of many varieties while most of the granite intruding the limestone and quartzite is of much the same general character. True, there are small areas of other varieties cutting these sediments, but there is no proof that they are the same as the great heterogeneous mass so intimately associated with the schists. In Burns Cañon the granites and small areas of schist are cut by so many pegmatite dikes that from a distance their prominence, due to differential erosion, gives the whole mass the appearance of a sedimentary formation. Lindgren[6] believes that in the Cordilleras this association is confined to pre-Cambrian rocks. On this criterion there is a possibility that some of the schists to the southwest may also be pre-Cambrian.

On the other hand, as already mentioned, there are parts of the quartzites and interbedded schists so altered that they duplicate a great many varieties of the schists to the south. East of Baldwin Lake the Saragossa quartzite has a general dip of about 40° southwest and individual strata may be followed, almost without a break, for six miles; but locally portions of the same mass are crumpled and folded in such a complex manner as to come up to the ideal conception of

6 Lindgren, Waldemar, Dana commemorative lectures on problems of American geology, Yale University, December, 1913, p. 241.

Archaean sediments so commonly pictured from the sections of the Great Lakes region (fig. 2). The local nature of all this formation is striking, for within a hundred yards one may pass from the clear-cut uniformly dipping strata to the contorted mass. These occurrences are usually found near an intrusion of granite which itself has often taken on so similar an appearance that positive identification is difficult or even impossible. A specimen from this ridge which was thought to be a fine-grained intrusive proved under the microscope to be a

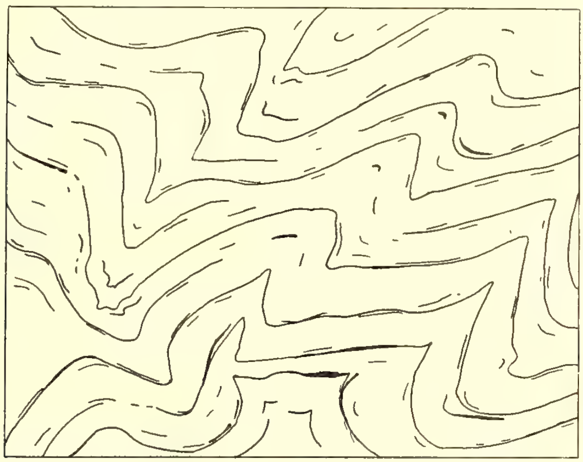

Fig. 2. Metamorphosed and contorted Saragossa quartzite at east end of Baldwin Lake.

quartz-mica schist. It is a mosaic of quartz containing small flakes of sericite, green and brown biotite, and a few grains of titanite and magnetite.

Farther southeast in the section exposed by Arrastre Creek the quartzites, particularly the more impure layers, have been altered to schists and these are cut by granites and later by many pegmatite dikes. In lower Arrastre Creek the Arrastre quartzite has been altered and intruded by granites and cut by pegmatite dikes in such a manner as to be quite comparable to the most complex relations found in any part of the great schist area on the south side of the range, and even a microscopic examination shows fully as great changes from the original sediments. (See Arrastre Quartzite.) This mass extends east beyond Rattlesnake Cañon, where it is dispersed by intrusions of granite. East of Rattlesnake Cañon, three miles south of Mound Spring, the schist forms the end of a syncline in which limestone rests. Here again the schist is cut by granites which also have a well developed schistosity. Pegmatites and other granitic rocks have cut the whole, resulting in a complex mass similar to those described above.

Small areas of schist are found included in the granites east of Big Morongo and Rattlesnake cañons and also outcropping with the granite in the desert to the north. The largest of the latter is on the southeast side of the hill three miles west of Old Woman Springs and another forms the small hills four miles northeast of Rock Corral. Smaller masses are found in the hills west of Means Wells.

Summary.—A great mass of schists extends northward from the San Gorgonio Pass to Big Morongo Creek and Santa Ana Cañon. Because of their great complexity as compared to sediments of ancient date found farther north and because of their association with granites bearing evidence of pre-Cambrian age these rocks might be considered pre-Cambrian. Similar complex structures, however, have been found in certain portions of the old sediments, and this raises a doubt as to the age of the great schist mass. It may all be of the same age as the quartzites, schists, and limestone in the Bear Valley region, or it may all be much older. Again, certain portions may be of the same age and other portions older.

The Older Sediments

The old sediments north and northwest of Cienaga Seca Creek embrace, in ascending order, the Arrastre quartzite, the Furnace limestone, and the Saragossa quartzite. The floor on which the Arrastre quartzite was laid down has been destroyed by intrusions of granite. Northeast of Horsethief Flat the quartzite is conformably overlain by the Furnace limestone, the whole series dipping 35° to the southwest. Conformably above the limestone lies the Saragossa quartzite, as is clearly shown in a section along the road a mile northeast of Doble, where both are found dipping 20° to the southwest.

The structure of the region is so involved that the mere position of the limestone and quartzites in space can hardly be considered as proof of their age relationships; i.e., so far as structure is concerned the section as given may be upside down and the apparent order of succession due to an overturn. However, cross-bedding in the Saragossa quartzite shows conclusively that the sequence is as stated above, as will be described farther on.

Arrastre quartzite.—The Arrastre quartzites are the oldest sediments positively identified as such in the region. The general nature of these rocks is best seen in a section northeast of Horsethief Flat, where they lie conformably below the Furnace limestone. Both formations at this point dip 35° to the southwest. The limestone grades down into calcareous mica schist about ten feet thick, below this is a stratum of massive quartzite six feet thick, which in turn is underlain by black and grey mica schists with quartzose layers grading down into rather thin-bedded quartzite; i.e., individual strata are seldom six inches thick. As one crosses the strike by going down Arrastre Cañon for half a mile the dip increases to 65°, and a rough estimate of the thickness of the quartzite from these data is about 2500 feet. The total may be much greater, but this cannot be more accurately determined, as the sediments are badly broken up by intruding granites. The impure quartzite is so altered and the granite is so gneissic that the two are often indistinguishable. The granites themselves are very heterogeneous and, together with the sediments, form a mass so complex as to defy description. A block consisting of quartzite intruded by lamprophyre was seen sunken into a dark hornblende granite. Irregular pegmatite dikes cut the mass and they in turn are cut by other granites.

A comparison of the Arrastre and Saragossa quartzites brings out several important differences. Most of the Arrastre is thin-bedded, individual beds being less than six inches thick, and there are no beds up to five and ten feet of pure quartzite such as found in the Saragossa. There is no pure sacchroidal quartzite, no great variety such as coarse angular grits, pebble conglomerate, cross-bedding, etc., all of which are prominent features of the Saragossa.

From Arrastre Creek the Arrastre quartzite can be followed to the southeast as far as Rattlesnake Cañon. The contact with the granite on the south is so straight that it at once suggests faulting. Apophyses from the granite cut the quartzite, but these may well have been faulted off from the main mass. The best evidence is the contact just north of Granite Creek, where it seems impossible that any other than a fault contact could follow down the hill in such a straight line. Along the northern boundary of the quartzite the association with the intrusive granitic rocks is so intimate that one can hardly tell where to draw the line of demarcation; numerous blocks of quartzite, some several hundred feet across, are isolated by the intrusives.

East of Rattlesnake Cañon, three miles south of Mound Spring, quartzose schists form the end of a syncline in which limestone rests. They are intruded by granitic rocks on which schistosity has also been impressed. The mass as a whole is very complex, but, since it agrees with parts of the Arrastre quartzite farther northwest and its general relations to the limestone are identical, it is believed to be a part of the same formation.

There is a strip of quartzite sunken into granite and striking N 30° E along the hills north of Antelope Cañon three miles southwest of Saddlerock Spring. It is massive and rather pure, though it contains occasional grains of magnetite and flakes of biotite. Other areas of altered sediments are similarly sunken in the granite to the north and northeast and all may be remnants of the Arrastre quartzite. This may also be the case with some of the undifferentiated schists on the south side of the range, but, as blocks of the Saragossa quartzite might be isolated in a similar manner, positive identification is impossible.

The Arrastre quartzites have undergone considerable metamorphism since their original deposition as sandstones, and portions containing impurities show this particularly well. A medium fine-grained grey quartzose schist from Rattlesnake Cañon, just below Mound Spring, appeared under the microscope to be practically free from feldspar, only a very small amount of orthoclase and a few grains of plagioclase, probably oligoclase, being present. Some of the quartz occurs as a fine aggregate as if secondary. The quartz and feldspar show undulatory extinction. The rock contains a large amount of biotite as scattered flakes and in small aggregates. There is considerable muscovite with the biotite and both are often bent. Numerous small hairlike tufts of a colorless mineral are present, usually associated with the biotite. Its optical properties could not be definitely determined, but the occurrence and general form suggests tourmaline. There are a few small grains of titanite, and a small amount of green hornblende is seen going over to a colorless amphibole.

A fine-grained grey quartzite from Rattlesnake Cañon three and a half miles below the branch to Viscera Spring was found to consist almost wholly of small quartz grains interlocked by secondary additions to the original fragments. Numerous fine flakes of biotite, a few flakes of muscovite, and many small grains of magnetite are also present.

On the north face of the range the quartzite is rather impure. A specimen from a mile and a quarter east of the mouth of Arrastre Creek is a fine-grained schistose rock mostly yellowish-white in color but with discontinuous dark streaks high in biotite, the flakes being arranged parallel to the schistosity. It is largely composed of quartz grains elongated in the same direction. A little orthoclase is present, but no plagioclase; also a little titanite and a few grains of magnetite.

Furnace limestone.—In a section on the northeast side of Horsethief Flat the Furnace limestone conformably overlies the Arrastre quartzite with a dip of 35° to the southwest. In color this rock varies from white to nearly black and in texture from coarsely crystalline, individual crystals often being half an inch in diameter, to fine and compact. An irregular mass sunken into granite nearly surrounds Horsethief Flat and continues southeast to the Rose Mine with a strike parallel to the general trend of the outcrop. It passes under the Saragossa quartzite to the southwest, generally with a dip of 40° to 60°; but in some places within the mass itself the dip is vertical. On the northeast it is intruded by granite. In the vicinity of the Rose Mine the limestone is penetrated by numerous small granitic dikes and with these are associated ores of gold, copper, and lead.

South and east of the Rose Mine the granite cuts the limestone into numerous small isolated masses. A long tongue stretches eastward and its eastern extremity lies in a trough of quartzose schists.

Two miles up Antelope Creek from the Burns Cañon road there is a somewhat broken strip of limestone extending to the southeast. Along the northern side there are small remnants of schist. Both schist and limestone are intruded by granite and contact minerals have been developed, particularly along fissures in the schist. Epidote and garnet are the most abundant with occasionally some tremolite. In some places these minerals are traversed by quartz veins. At the contact with granite the limestone is entirely recrystallized, the average size of the crystals being about two millimeters across, and is usually white.

A large isolated area of limestone is found east of Broom Flat, and south of this, sunken into the granite, are many small areas which, for the most part, have been altered to coarsely crystalline white marble.

North and northwest of Sugarloaf Mountain there is a considerable area of limestone. The eastern portion forms an anticline whose axis is about a mile north of the peak and whose south limb dips 20°, passing beneath the Saragossa quartzite which forms the higher portion of the ridge. The western half of this area is nearly surrounded by intrusive granite and on the south side the latter has sent out many large apophyses into the limestone. One point of interest in connection with this area of limestone is the occurrence of graphite in the cañon half a mile northeast of Sugarloaf Peak. It is present as a stratum in the limestone and is usually impure, sometimes grading imperceptibly into the limestone. It is of variable thickness, from one to four feet, but on the whole is remarkably continuous. A seam of graphitic limestone, believed to be a portion of the same, was seen more than two miles farther west.

At the mouth of Grapevine Cañon the limestone overlies the metamorphosed quartzite and dips 40° southwest while the quartzite is nearly vertical. The contact could not be closely examined because of the large amount of talus, but, in view of the conformable relationship near Horsethief Flat, it is probably a fault. Both are intruded by an acid granite and some of the limestone is silicified; some is also streaked with colors, brilliant red, orange, yellow, and slaty blue. This may well be due to mineralization associated with the granite and later modified by meteoric water. Similar silicified and colored limestone is also found along the contact of the limestone with the granite in Blackhawk Cañon where gold was formerly mined.

On the north side of the range from Grapevine Cañon westward beyond Crystal Creek, the limestone dips in all directions, generally at angles of less than 45°, in some cases lying horizontal. Just within the cañon south of Cushenbury Springs the limestone is much broken and altered, forming colored streaks similar to those in Blackhawk Cañon. A large proportion has been recrystallized to a coarse-grained white marble. In Furnace and Wild Rose cañons granite has intruded the limestone with the development of contact minerals, tremolite, garnet, epidote, wollastonite, pyrite, chalcopyrite, and gold.

West of Crystal Creek the limestone is limited by a heterogeneous mass of intrusive granites. A large body of limestone branches off to the southwest to Greenlead Camp, where contact deposits were once extensively mined for gold. The main part of the formation crosses Holcomb Valley to Bertha Peak and thence eastward to Van Dusen Cañon. On the southwest side of the valley the limestone is intimately associated with an area of Saragossa quartzite, both dipping about 75° to the southwest. To the west and south they are cut by intrusive granite. Several smaller masses cut the limestone along the south flank of the ridge east from Bertha Peak and in Van Dusen Cañon later masses separate it from the Saragossa quartzite.

The thickness of the limestone can only be roughly estimated. Between Crystal Peak and Marble Cañon there is a limestone scarp 3000 feet high. West of Furnace Cañon the limestone has been warped a great deal, but its general attitude is horizontal. The height of the scarp therefore represents part of the thickness of the limestone unless there has been step faulting. South of Smart's Ranch and west of where Arrastre Creek enters the valley the distance across the strike of the limestone is 4700 feet and the dip about 60° to the southwest. As calculated from these figures the limestone is 4300 feet thick (fig. 3). In neither of these two cases do we find the bottom of the limestone definitely limited, and 4500 feet is therefore a conservative estimate of its total thickness.

Saragossa quartzite.—The relation of the Saragossa quartzite to the Furnace limestone is clearly seen in a section a mile northeast of Doble, where both are found dipping 20° to the southwest. The limestone grades up into a soft decomposed biotite schist about 50 feet

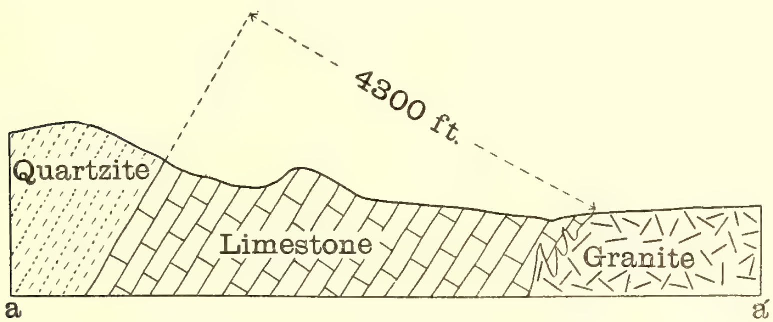

Fig. 3. Section south of Smart's Ranch.

thick, and then comes 120 feet of white and pink quartzite so recrystallized as to have lost all semblance of its original clastic structure. This is overlain by several feet of quartzite pebble conglomerate. The pebbles vary in size from half an inch to an inch in diameter and are usually well rounded. They are imbedded in a coarse schistose matrix containing considerable muscovite and some biotite.

The pebble conglomerate is overlain by 200 feet of schists. The bedding is rather thin, from a fraction of an inch up to a foot, and the material varies from fine biotite schist to coarse, gritty quartz-biotite schist. Toward the top it becomes free of dark constituents and finally grades into sacchroidal quartzite. The details of some of the bedding are important in showing the true sequence of deposition; for the mass as a whole has been so tilted here and elsewhere that mere position in space is not a conclusive criterion of the sequence of deposition. Figure 4*a* shows cross-bedding of coarse sacchroidal quartzite which has been truncated and covered over by a very coarse sand containing angular fragments as much as three-fourths of an inch across. It is very difficult to conceive of the reverse order. In that case the cross-bedding would have to be laid down sharply abutting the underlying beds. In all forms of cross-bedding known, however, the bedding grades into the contact below along curves. In figure 4*b* cross-bedding of coarse quartzite has been cut obliquely and a thin stratum of medium-grained quartzite has been laid down. Above this, cross-bedding of coarse material was again developed. The whole has been truncated and very coarse grits deposited. This case is similar to that described above but repeated several times; but in addition we have another important piece of evidence. It is a matter of actual field observation that cross-bedding is always concave upward, and here we find the bedding curving in agreement with the upper side as determined from other data.[7]

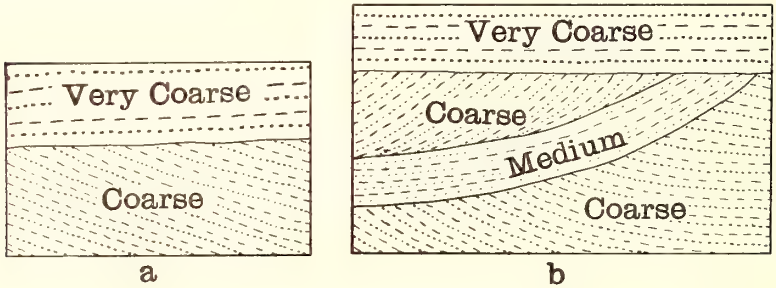

Fig. 4. Bedding in Saragossa quartzite showing order of succession.

Above the gritty schists and quartzite there is a series of soft biotite and muscovite schists and above these are very heavy-bedded quartzites, which, however, contain occasional strata of schist. Continuing to the southwest, the dip of the rocks flattens somewhat, and at Gold Mountain the quartzite dips 8° to the northeast. This upper portion is nearly all heavily bedded and largely sacchroidal. As estimated from this section the thickness of the quartzite is about 3500 feet (fig. 5), but since the upper limit is unknown the total thickness may be much greater.

The quartzite extends northward to Burnt Flat and to the southeast beyond Cienaga Seca and Broom Flat. Although well exposed in many places, over a considerable area it is found only as fragments, due to its brittle nature and the rounded topography. Over a large part of the country the soil is sufficient to support a heavy growth of timber, but usually the fragments of quartzite are so abundant as to leave little doubt as to the nature of the underlying rock.

[7] Cf. Lawson, Andrew C., The Archean geology of Rainy Lake re-studied, Mem. Geol. Surv. Canada, vol. 40 (1913), pp. 62–63.

About a mile east of Doble a small mass of granite intrudes both the Furnace limestone and the Saragossa quartzite. From this point the contact between the two formations can be readily followed southwestward to Round Valley, although somewhat complicated by faulting, and in many places the limestone can be seen dipping beneath the quartzite at angles of from 20° to 60°. Along the side of the old road one mile and a half northwest of the Rose Mine is exposed a section in which the quartzite, schist, and limestone are found repeated in section. It exemplifies the degree to which faulting has affected the region and how complex some of the detailed structure must be.

On the ridge which forms the northwestern limit of Round Valley the quartzite is separated from the limestone by a few feet of chlorite

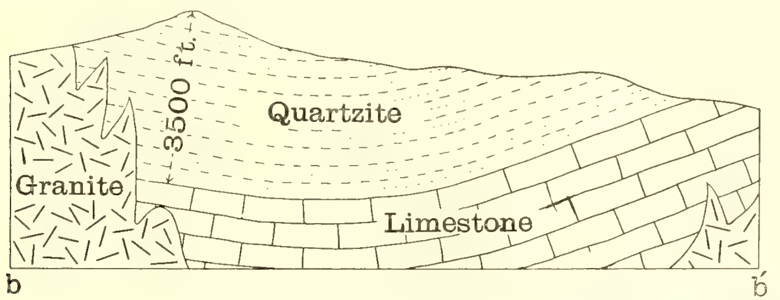

Fig. 5. Section through Gold Mountain showing thickness of Saragossa quartzite.

and biotite schist and the whole series dips 35° to the southwest. Just south of this place the quartzite is intruded by a tongue of granite which has forced its way through the limestone. East of Broom Flat the quartzite again is found resting on limestone. From here southward to Cienaga Seca and thence westward two miles beyond Sugarloaf the quartzite is intruded by granite. North of Sugarloaf it rests on limestone, but here again the contact is often obscure and may be somewhat complicated by faulting.

Northeast of Baldwin Lake the quartzite extends over into Holcomb Valley, where it is intruded by granitic rocks. In many places near the contacts the bedding of the quartzite is entirely obliterated and inclusions of quartzite are found in the granite. Near Burnt Flat it is in contact with the limestone, but it is not known whether this contact is one of sedimentation or is a fault.

On the south side of Baldwin Lake the quartzite has a granular appearance for the most part and is hard and brittle like glass. It varies considerably in color: white, yellowish white, light and dark grey, all in well-defined beds. Some of the bedding planes exhibit a distinct sheen resembling schist. Fractures are common in all directions, some of which are filled with quartz containing cubes of limonite pseudomorphic after pyrite.

Between Baldwin Lake and Round Valley the quartzite, with its interbedded strata of biotite and muscovite schist, has been intruded by pegmatite, biotite and hornblende lamprophyres, and granites. As is usually the case, the extremely acid and basic rocks occur as rather limited dikes. Some of the granite has a marked gneissic structure, and, as this is parallel to the schistosity of the surrounding rocks regardless of the shape of the intrusive mass, it is clearly due to deformation since solidification, rather than to the flow of intrusion. There are also large irregular masses of biotite granite which retain the original structure. The quartzite itself presents many phases. Some is very pure quartz without a trace of bedding. From this extreme there is a gradation to well-bedded pure quartz varieties, then quartz with muscovite or biotite or both, and finally to a muscovite-biotite schist.

There is a small area of quartzite south of Bear Valley. The whole slope is forested and, as is usually the case in country of low relief, no solid outcrops of quartzite could be found, but the hillsides are covered with angular fragments. Many of the low ridges just south of Pine Lake are almost free of soil, but even here no solid outcrops were seen.

Another small area is found southwest of Holcomb Valley. It appears to dip beneath the limestone and it may be that both are overturned. They are intruded by granite to the west.

One of the interesting features of the quartzite is the way in which it has been affected by deformative forces and the intruding granite. It has already been noted that some of the impure strata have been rendered schistose, and even in some of the pure varieties a distinct sheen can be seen on the quartz grains parallel to the bedding. East of Baldwin Lake the general dip is 40° southwest, and this is uniform throughout a considerable portion of the mass. But locally, particularly near granitic intrusions, these beds have quite a different character. They are crumpled and folded in a very complex manner and the rock itself resembles more nearly a granitic gneiss than sediments (fig. 2). This is a matter of considerable importance, for it shows that extreme alteration and complexity may not necessarily indicate greater age than more simple rocks even within a restricted area.

In the section exposed in Arrastre Creek above the limestone this formation has suffered much the same sort of disturbance as the Arrastre quartzite in lower Arrastre. Some has been metamorphosed so as to greatly resemble the associated granitic gneiss and the whole mass is cut by pegmatite dikes. Along the south side of Sugarloaf for about 1500 feet from the top of the ridge the quartzite retains its true character, but below this there is a more or less continuous zone where the quartzite has been highly altered by the intruding granite, as in Arrastre Creek.

A thin section was made of a piece of pinkish grey sacchroidal quartzite from west of Round Valley. The quartz grains are rather intimately intergrown, possibly due to secondary deposition of silica, but the original outlines of the fragments cannot be recognized. Most of the quartz exhibits undulatory extinction. A few grains of magnetite and titanite are present, and also flakes of muscovite and biotite. While the quartzite is so variable that even a large number of sections would not be wholly adequate to describe it, this specimen is typical of by far the larger part of the formation.

Age of the Older Sediments

No fossils were found in the limestone or quartzites and any statements as to their age must be based entirely on their relations to the granites and their lithological resemblances to other rocks of known age. They are cut by granites belonging to two periods of intrusion, one of which is probably late Jurassic. The age of the other is unknown. These relations, however, alone are sufficient to suggest that the sediments are of ancient date, probably Paleozoic.

Hershey[8] has described a quartzite-limestone series at Oro Grande and because of its lithologic resemblance to the lower Cambrian series of Inyo County described by Walcott[9] has classed it as being of the same age. This series is by no means so thick as that in the San Bernardino Mountains, for Hershey says that the thickness of the limestone is "probably no more than 200 feet" as compared to the 4500 feet of Furnace limestone. Darton[10] describes a series of Cambrian and Carboniferous limestones, quartzites, and shales in the Iron Mountains north of Cadiz, about 60 miles east of the northeast corner

[8] Hershey, C. H., Some crystalline rocks of Southern California, Am. Geol., vol. 29 (1902).

[9] Walcott, Chas. D., Lower Cambrian rocks in eastern California, Am. Jour. Sci., vol. 49 (1895), p. 141.

[10] Darton, N. H., U. S. G. S., Bull. 613, Part C, Santa Fé Route, 1915.

of the San Gorgonio Quadrangle. Clark[11] has amplified this description. The total thickness of the series is 1280 feet, the upper half being Carboniferous limestone, the next 120 feet, middle Cambrian shale, and the lower portion, lower Cambrian limestone, shale, and quartzite. The assignment of the sediments to their respective ages is supported by characteristic fossils. It is a noteworthy fact that no Ordovician, Silurian, nor Devonian rocks are included in the section and that there is no pronounced unconformity between the upper Cambrian and the Carboniferous.

Noble[12] has found limestone in the San Gabriel Mountains to the west. He says:

> A very characteristic feature of the granite and gneissoid-granite belt is the presence of bodies of white, crystalline, metamorphic limestone. . . . . Seemingly they are inclusions which have sunk down into the granite. In one of the limestone bodies a few poorly preserved gastropods were obtained which resemble forms found in the Ordovician Pogonip limestone of eastern California. The limestone bodies are to all appearances the same rock as the metamorphic limestones associated with granite in the neighboring Tehachapi and San Bernardino ranges.

With these facts before us the problem is to assign the old sediments of the San Bernardino Mountains to their proper places in the geologic column. From Noble's account it would seem most likely that at least part of the Furnace limestone is Ordovician. Part of it may also be Cambrian corresponding to that in Inyo County described by Walcott and to that in the Iron Mountains described by Clark. Then the Arrastre quartzite might well be considered as Cambrian, probably lower Cambrian. If Hershey is right in assigning the quartzite of Oro Grande to the Cambrian, this correlation receives further justification. Also, Clark reports Cambrian from the Iron Mountains. That the conditions existing in this region in Cambrian time prevailed over an extensive area is further shown in Arizona. Noble[13] describes 285 feet of sandstone at the base of the Cambrian in the Grand Cañon section. Above this lies about 300 feet of shales and 450 feet of limestone, also of Cambrian age. At Bisbee,[14] near the Mexican border, there is a similar section. At the base lies the Bolsa

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[11] Clark, C. W., Lower and Middle Cambrian faunas from the Mojave Desert, Bull. Dept. Geol., Univ. of Calif., vol. 13, pp. 1–7.

[12] Noble, L. F., Personal communication to R. E. Dickerson, September 8, 1917.

[13] Noble, L. F., The Shinumo Quadrangle, Grand Canyon District, Arizona, U. S. G. S., Bull. 549.

[14] Ransome, F. L., Geology and ore deposits of the Bisbee Quadrangle, Arizona, U. S. G. S., Professional paper no. 21.

quartzite, 430 feet in thickness. Above this is the Abrigo limestone, which is 770 feet thick and contains middle Cambrian fossils. Across the Mexican border at Cananea[15] are the Capote quartzite and the Puertecitos limestone, which are believed to be correlatives of the Bolsa and Abrigo respectively. Again in the Clifton-Morenci[16] district we find a similar sequence. The lowermost sedimentary formation is the Coronado quartzite of Cambrian age and above it lies the Longfellow limestone, which is Ordovician. Quartzite is also found at the base of the section at Globe,[17] but, as the oldest fossils above it are of Devonian age, its correlation is less certain.

The upper age limit of the limestone and the age of the Saragossa quartzite is only conjectural. No Ordovician, Silurian, or Devonian rocks are found in the Iron Mountains, and yet the structural break between the Cambrian and Carboniferous is not marked. This may have been due to a slight uplift which prevented deposition during that time. A similar uplift in the San Bernardino Mountain region may have merely brought about a change to near-shore conditions which would permit the deposition of the Saragossa quartzite. If the Furnace limestone is partly Ordovician as suggested, however, this uplift must have been later in the San Bernardino Mountain region than in the Iron Mountain region. This would mean that the Saragossa is Silurian or Devonian.

Conclusion.—From the evidence available at present it seems probable that the Arrastre quartzite was deposited in lower Cambrian time. During upper Cambrian and Ordovician time the Furnace limestone was laid down. The Saragossa quartzite is probably Silurian or Devonian.

Granites

Granites are the most widespread rocks in the region. Nearly all the rocks outcropping in the portion of the Mohave Desert included in this area are granites. The largest area in the mountains extends from Cienaga Seca Creek and Rattlesnake Cañon eastward beyond the limits of the San Gorgonio Quadrangle. Another large area extends from Bear Lake southward to Little San Gorgonio Creek and southeastward beyond San Gorgonio Mountain. Besides these masses there are

15 Emmons, S. F., Cananea Mining District of Sonora, Mexico, Economic Geology, vol. 5 (1910), pp. 312–356.

16 Lindgren, Waldemar, Copper deposits of the Clifton-Morenci district, Arizona, U. S. G. S., Professional paper no. 43.

17 Ransome, F. L., Geology of the Globe Copper district, Arizona, U. S. G. S., Professional paper no. 12.

numerous others of smaller dimensions cutting the old sediments northeast of Cienaga Seca Creek and the undifferentiated schists south of Santa Ana Cañon; in fact, nowhere are there any considerable areas entirely free from granites. Because of their complex relationships to the altered sediments and to each other they afford many problems. There may be two or more periods of intrusion, and in further describing the rocks special attention will be given to evidence supporting this statement. It is unfortunate that the most positive evidence, sediments laid down on granite and intruded by another granite, is lacking. Still there are several reasons for believing in intervals of some importance.

About two miles up Big Morongo Creek pegmatite dikes and inclusions of schist in granite gneiss were found drawn out and contorted with it into acute folds and the whole mass intruded by later granite. This shows that granite was intruded into schist. Some time later pegmatite intruded the mass, probably as an end action of that particular granitic intrusion. After the mass had cooled it was subjected to great stresses to which it yielded with the formation of acute folds. That the mass had cooled is shown by the sharp boundaries of the broken fragments of the pegmatite dike as it was sheared diagonally by the regional forces. This sequence of events then represents, though possibly only in part, the importance of the interval between two granitic intrusions, for another granite clearly cuts across the whole complex mass. Nor is the case cited by any means rare; on the contrary, essentially the same thing may be found recorded in many boulders scarcely two feet across on almost any of the alluvial fans along the south front of the range.

Great masses of granite have intruded the quartzites, schists, and limestone north and northwest of Santa Ana Cañon. Most of this is of much the same general type, being a medium-grained muscovite-biotite granite which is only rarely gneissic. Pegmatite dikes, while hardly rare, are not at all conspicuous. South of Santa Ana Cañon and east of Rattlesnake Cañon the granites are variable in character, single areas of any one kind usually being only a few hundred yards across. Pegmatite dikes are abundant and in some cases constitute nearly half of the rock mass. The granites are usually gneissic and often acutely interfolded with schists which they have penetrated. As already stated, these are frequently cut by later granites.

In lower Arrastre Creek the Arrastre quartzites and Furnace limestone are intruded by a heterogeneous mass of granite; but clearly cutting the whole mass rises the granite of Granite Peak. It extends northward to Grapevine Creek and thence westward. The rock is a medium coarse-grained granite whose general appearance is pinkish to yellowish grey. A specimen from one mile northeast of Cactus Flat was examined in thin section and its principal constituents found to be nearly equal amounts of quartz and pink orthoclase with Carlsbad twinning. Part of the quartz and orthoclase occurs as numerous rounded areas of vermiculate, radiate intergrowths. Some albite-oligoclase is present. The principal accessory is biotite, but there is also a small amount of muscovite. Many small prisms of apatite are scattered through the rock as well as a few grains of magnetite and rounded colorless crystals with high index of refraction and low birefringence. The latter may be due to strain, for both the orthoclase and quartz show undulatory extinction. In that case the mineral may be garnet. Because of its prominence in the vicinity of Cactus Flat granite of this period will be referred to as the Cactus granite.

A small area of dark medium-grained granite cuts the limestone near the point where the above specimen was collected, but is itself intruded by the larger granitic mass. It consists of albite-oligoclase, and a very little orthoclase and even less quartz, with biotite and dark green hornblende in about equal amounts and in sufficient quantity to give the rock its dark color. Titanite is unusually abundant and some rather large crystals are to be seen. A little augite, a large number of small apatite prisms, and a few grains of magnetite were also found. A very small amount of quartz and orthoclase are in micrographic intergrowth. Decomposition is under way, the feldspar going over to muscovite and kaolin. This rock is not strictly a granite, but is really a biotite-hornblende diorite.

North of Baldwin Lake there is an area of granite which seems to differ somewhat from the larger part of the mass and yet both seem closely related in the field and look somewhat alike. This rock contains equal amounts of quartz and orthoclase with Carlsbad twinning, but also considerable oligoclase twinned on the albite, pericline, and Carlsbad laws. Biotite is the most important accessory and along with it is a little muscovite. A few grains of magnetite and titanite, small prisms of apatite, and also rounded crystals, similar to those believed to be garnet in the main mass, are also present.

The main mass of granite ends on the surface about a mile west of Cactus Flat, but rises through the limestone and quartzite farther west in Van Dusen Cañon, at Union Flat, and also northwest of Union

Flat, and in the vicinity of Fawnskin Valley. Thence it branches to the north and south. At the head of Holcomb Creek a large dike intrudes the limestone and the latter is silicified near the contact. A large mass of dark granite extends southwestward from Greenlead Camp beyond Delemar Mountain. It weathers more readily and to smoother forms than the more widespread lighter granite. North of Greenlead Camp the latter swings down to the north slope of the range where it intrudes several other varieties of granite, forming a complex area near the east side of the quadrangle. The Cactus granite is exposed in many places along the north front and at some of the contacts, notable in Furnace Cañon, characteristic minerals have been developed. A medium coarse-grained pinkish yellow granite from Arctic Cañon was found in thin section to consist principally of equal amounts of quartz and orthoclase with Carlsbad twinning. It also contains a little albite-oligoclase and the principal accessory is a small amount of biotite, some of which has been leached green. Other minerals present are a few grains of magnetite, titanite, and a few prisms of apatite. A specimen from Blackhawk Cañon was found to be essentially the same. It contains equal amounts of orthoclase and quartz, flakes of biotite, and a few crystals of albite-oligoclase; also a few grains of magnetite and titanite, small flakes of ilmenite, and a few stout prisms of zircon. Both of these rocks are thus practically the same as that described from near Cactus Flat.

From Granite Peak the granite extends southeastward to the Rose Mine intrusive between the Furnace limestone and Terrace quartzite. Thence it swings to the south and southwest to Big Meadows, beyond which a more heterogeneous mass predominates. In the southwest corner of Round Valley the granite cutting the limestone has been rendered gneissic; but under the microscope it is seen to be practically the same as that farther to the north. In general appearance it is a light yellowish-grey, medium-grained granite containing equal amounts of quartz and orthoclase and biotite as the principal accessory. There are also present numerous small areas of orthoclase and quartz in micrographic intergrowth, and a little oligoclase. A few flakes of muscovite as well as a few grains of magnetite and prisms of apatite are scattered through the rock. Small grains of titanite occur with the biotite and also rounded crystals with high refractive index, probably garnet. The whole section presents a crushed appearance and the quartz exhibits undulatory extinction. A specimen from the north side of the triangular limestone area east of Broom Flat is identically the same, except that it does not possess the evidence of strain. The granite just beyond the east corner of the limestone is pale yellow in color, fine-grained, and composed almost wholly of orthoclase and quartz with the orthoclase predominating. No plagioclase is present and only a few flakes of biotite, and this is leached to a pale green. A few grains of magnetite and titanite occur, usually with the biotite.

The rock around Chaparrosa Spring is similar to that of Granite Peak. It consists of equal amounts of orthoclase and quartz with biotite as principal accessory, and small amounts of muscovite. Of course, being isolated from the main mass to the west, there is no way really to check its identity, but it is believed to belong to the Cactus period of intrusion.

The area of granite around Fawnskin Valley extends southward to Lake Creek and thence eastward beyond Elsie Caves. For the most part it is the same medium-grained biotite granite so common in the region, but south of Pine Lake there are several varieties, and one is inclined to place them with the older masses of similar nature into which the larger uniform masses of Cactus granites are included. One of the most prominent varieties is a porphyritic granite which presents several variations in texture. In some places the rock seems to be a solid mass of large orthoclase crystals to the exclusion of ground mass and there is often a tendency to a flow structure, in which case the crystals in the ground mass assume a parallel arrangement, but the large phenocrysts do not.

This area extends across the cañon to Martin Glen and up to San Gorgonio Mountain. Along Mountain Home Creek the rocks show great diversity in both composition and texture. They are true granites, the orthoclase content being high and the plagioclase unimportant. All contain considerable quartz and both biotite and hornblende are abundant as the ferromagnesian constituents. The texture varies from medium to very coarse and in a few cases is porphyritic, some of the orthoclase phenocrysts being five centimeters across. There are some darker masses, probably inclusions, and the whole is crossed in all directions by pegmatite dikes from an inch to two feet thick.

Several varieties of granite are found at San Gorgonio Mountain. That on the north peak is a fine-grained light pinkish grey rock consisting of equal amounts of quartz and pink orthoclase with biotite as the most prominent accessory, but it also contains considerable muscovite. A small part of the quartz and orthoclase occur in micrographic intergrowth. Only a small amount of plagioclase, oligoclase, is present. Most of the biotite is bleached green. Small grains of magnetite and numerous rods of apatite are scattered through the rock. A medium-grained porphyritic granite of similar mineralogical composition occurs to the south. Part of the orthoclase is twinned on the pericline law and some of the phenocrysts are more than a centimeter across. No plaglioclase is present. A few stout prisms of apatite occur, but small rods are by far the more numerous. Another rock near this is a medium-grained yellowish grey granite with a ''salt and pepper'' appearance due to the fineness of the biotite flakes. As is the case with the others, the orthoclase and quartz in this rock are in equal amounts and small areas in micrographic intergrowth are found. A little oligoclase, muscovite, apatite, and magnetite are also present.

Besides the granites with original structure there are some in this locality which have been subjected to great stresses and rendered gneissic. In some cases the one grades directly into the other. To add to the complexity, other granites have cut the whole mass, sending out many apophyses, large and small, into the older rock. The rock on the ridge just below the south knob of San Gorgonio Mountain is a medium-grained granite with the biotite in schistose arrangement, the individual streaks, however, not being continuous for more than a few centimeters. Orthoclase is very prominent, many of the crystals being more than five millimeters across. Quartz is somewhat less abundant than orthoclase and only an occasional grain of albite or albite-oligoclase occurs. A small amount of quartz and feldspar is present in micrographic intergrowth. Some muscovite occurs with the biotite and both often have bent cleavages. Another evidence of strain is the undulatory extinction of the quartz. A few colorless garnets are associated with the biotite; also grains of magnetite and titanite.

The most prominent rock of San Gorgonio Mountain and the one which seems to intrude all others extends to the southwest from the peak. It is a medium-grained granite with equal amounts of orthoclase and quartz, a few large crystals of oligoclase, and green biotite. Scattered throughout are smaller amounts of muscovite, magnetite, and small rods of apatite. At the head of the gully just east of this ridge there is a granite which differs from those described above in that it contains a large amount of dark green hornblende and only a little biotite. Titanite is also somewhat more abundant, although only as small grains. The structure differs in that the quartz and orthoclase have the same degree of automorphism and present a mosaic effect. Lower down in this gully another granite intrudes a mass of sediments: limestone, schist, and quartzite. Quartz and orthoclase are in equal amounts, some in vermicular intergrowth. Oligoclase is present and a little microcline. Green biotite is in moderate amount. The few grains of magnetite are red around the edges, evidently due to alteration to hematite.

To the south and east of this mass of granites stretches the great area of undifferentiated schists. Throughout these there are small patches of granites and granite-gneisses; but not until we reach Big Morongo Creek do we find the characteristic granitic rocks predominating. A specimen from the north side of Little Morongo Creek just above Morongo Valley is medium coarse-grained, with the feldspars often more than five millimeters across. The biotite, however, is rather fine, the individual flakes seldom exceeding a millimeter. Orthoclase predominates over both quartz and the plagioclase, oligoclase, but the rock is still to be classed as a quartz monzonite. Apatite is exceedingly rare and present only as the finest needles. Magnetite grains are also small and scattered. Farther to the northeast on the west side of the valley just before reaching the divide the granite is rather varied as to texture, but the mineralogical content seems to be fairly constant. One variety of fine-grained, yellowish granite has a "salt and pepper" appearance due to the fine flakes of biotite. Under the microscope this biotite is found to be of a greenish color. Quartz and orthoclase showing Carlsbad twinning make up the mass of the rock, with the latter in excess. Small areas of micrographic intergrowths are common and a little oligoclase is present. Apatite is unusually abundant both as small needles and stout prisms, but magnetite is scattered rather sparingly. Another specimen from a little farther north presents quite a different appearance in the hand specimen, as it is somewhat coarser, but in thin section it is almost identically the same, even to the amount of apatite both as needles and stout prisms.

On the opposite side of Morongo Valley is a medium coarse-grained granite with equal quantities of quartz and orthoclase and a small amount of albite. The most prominent accessory is biotite, and even that is rather scattered. Prisms of zircon and more slender ones of apatite are present; also a few grains of magnetite and titanite. The occurrence of the latter is peculiar in that it forms some rather large crystals.

The rocks around Chaparrosa Spring have been described as greatly resembling those intruding the sediments farther west, but beyond these, along Pipes Creek, the granites form a heterogeneous mass intruded by a few pegmatite and aplite dikes, which are particularly prominent in some places where the intruded granite is badly decomposed, in fact just north of The Pipes they at first appear to be the principal country rock. In the upper part of Burns Cañon most of them dip 20° to 50° east and are so numerous that from a distance they look like sedimentary strata. They vary in thickness from less than an inch to more than three feet and in texture from fine aplite to very coarse pegmatite, with masses of orthoclase and quartz over a foot long. Some of the larger ones are fine near the margins and increase in coarseness to the center. Many rather peculiar features were observed and an occurrence a quarter of a mile west of Burns Spring is particularly interesting. On the north side of the cañon is a pegmatite dike 3.5 feet thick, 2 feet being nearly solid orthoclase with a little quartz and the other 1.5 feet being nearly solid quartz with a little orthoclase. It has many branches ramifying into the granite below in contrast to the general tendency of the dikes to be clean cut. The granite varies a great deal as to its biotite content and hornblende granite is comparatively rare.

Four miles north of Burns Spring there is a great area of fine-grained granitic gneiss light yellow in color somewhat resembling an aplite. Quartz and orthoclase are in equal amounts and are interlocked and elongated in the same general direction and show undulatory extinction, these characteristics no doubt being due to flow under great stress. The rock contains a little oligoclase and only a very small quantity of pale green biotite. Magnetite is rare. One peculiarity is that some of the titanite crystals are as large as those of feldspar. This rock intrudes a schist which at first might be taken for altered sediments, but under the microscope it is seen to contain as much orthoclase as quartz. The other constituents are a little oligoclase-andesine, considerable biotite, scattered prisms of apatite, and a few grains of magnetite and titanite. In some places this rock is cut by lamprophyre dikes, and a specimen from one of these was examined in thin section. It consists essentially of deep green hornblende and less than half as much plagioclase, oligoclase-albite showing albite and pericline twinning. This rock, therefore, is camptonite. A large part of the hornblende has been altered to a colorless amphibole. A few grains of titanite are associated with the hornblende and the feldspar includes rods of apatite. Magnetite is sparsely distributed, usually with the hornblende.

This granite mass stretches to the front of the range on the north, Rattlesnake Cañon on the west, and beyond the quadrangle to the east. For the most part this is a rather heterogeneous mass in which the order of intrusions is hard to decipher, but clearly cutting this mass are relatively smaller areas of uniform coarse-grained granite with orthoclase crystals up to two centimeters across. The quartz and orthoclase are about equal in amount and the principal accessory is biotite, which is rather prominent. The largest of these areas extends two miles to the south from Saddlerock Spring. The older granite is crossed by many aplite and pegmatite dikes. One of these, right at Saddlerock Spring, is eight feet thick and near the center are individual masses of orthoclase more than two feet across, but near the sides the texture is fine like that of an aplite. The quartz in the coarser portions occurs as small stringers parallel to the trend of the dike.

Farther north is a broad hummocky plateau extending nearly to Rock Corral. On the south side of the hill two miles north of Saddlerock Spring the older heterogeneous granite cut by numerous pegmatite dikes clearly forms the roof of an intrusive mass of grey granite similar to the large mass farther south. Numerous examples of this relationship are found to the west, but because of the small size of the greater part of these intrusions only the larger ones were mapped.

Two and a quarter miles southeast of Rock Corral there is an interesting dike of pegmatite striking N 60° E and dipping nearly vertically. It is about two feet thick and for the most part is rather fine-grained, but it contains lenticular patches of coarser rock up to six inches thick and two feet long. These consist mostly of quartz, some pieces of which are more than four inches wide by eight long. The peculiar thing about the rock is that this quartz possesses a cleavage so pronounced that fragments glistening in the sun might easily be mistaken for amblygonite. The surrounding heterogeneous rock is traversed by numerous smaller dikes, but this one cuts straight across them all.

Along Rattlesnake Creek just below Mound Spring a very complex mass has been formed by various igneous rocks intruding the Arrastre quartzite. To add to the complexity, some of the intrusives themselves resemble the quartzite at first sight because of their light color and imposed schistosity parallel to the quartzite which they have invaded. A specimen of this intrusive, which is whitish grey when fresh but weathers yellowish, was examined in thin section and found to be a very fine-grained granitic rock consisting of equal amounts of quartz and orthoclase and a little plagioclase, probably basic oligoclase. Other minerals in small amounts are biotite, muscovite, magnetite, and titanite. Another rock of similar nature differed in having a few prisms of zircon and in containing no plagioclase. The general attitude of the schistosity is horizontal, but undulatory rather than flat. Both the quartzite and the granites are cut vertically by numerous lamprophyre dikes. A specimen of coarse texture, with individual crystals more than six millimeters across, was found under the microscope to be largely hornblende with a much less amount of plagioclase, probably oligoclase, showing pericline and Manebach twinning. A few grains of magnetite are also present.

Farther down the cañon these dikes cut light granitic rocks in all directions and in some cases have been mixed with them and so drawn out by regional movements as to resemble dark strata between lighter. A specimen of the darker rock near the branch to Viscera Spring was found to be essentially the same as those described above. These basic rocks are so numerous as to constitute a very significant part of the country rock, but no less remarkable is the occurrence of the acid rocks into which they are intruded. A thin section of light yellow granitic rock from about two miles below the turn to Viscera Spring contains equal amounts of quartz and orthoclase with a little biotite having a tendency toward parallel arrangement. No plagioclase was seen in the section, although it is exceptionally large. Several grains of titanite are present. The magnetite is partly altered to hematite and limonite, as evidenced by the red color on the thin edges by transmitted light and yellowish brown stains. This rock is an aplite such as is usually found as rather limited dikes traversing granite; but here the mass is of considerable area, extending more than three miles along Rattlesnake Cañon.

Four miles below the branch to Viscera Spring the aplite and lamprophyre complex is intruded by a large mass of dark rather coarse-grained granite high in biotite. Orthoclase predominates over the quartz, but only a little plagioclase, oligoclase, is present. Minor accessories are magnetite, titanite, and apatite. The intrusive nature of this rock is clear, for it contains many inclusions of the others. This mass extends nearly to the mouth of the cañon, but does not remain constant in its mineralogical composition. A specimen from just south of Twohole Springs, megascopically resembling that described above, in thin section was found to contain micrographic intergrowths of quartz and orthoclase, small quantities of deep green hornblende, rather large crystals of titanite, small flakes of ilmenite, and stout prisms of zircon. This is cut by pegmatite and aplite dikes. One of the latter was examined under the microscope, but was not found to differ greatly from others in the region. It consists of equal amounts of orthoclase and quartz, some being in micrographic intergrowth, very little biotite, some oligoclase, and a few grains of magnetite.

In the Mojave Desert north of the mountains numerous hills rise above the desert débris, and these are in most cases composed of granitic rocks. As in the mountains, two periods have been recognized. All heterogeneous masses consisting of several granitic rocks have been considered as older, while large uniform masses of light-colored granite containing equal amounts of orthoclase and quartz and rather little biotite have been considered younger. Wherever the two were found together the contact relations justified this interpretation.

The rocks north of Means Wells are varied in character and with them are schists, but on the ridge to the west the younger granite has intruded the older and extends northwestward off the quadrangle in a somewhat broken ridge. At the highest part of the crest there is a remnant of the older granites which greatly resembles those on the plateau north of Saddlerock Spring.

Fry Mountain is a complex mass cut by numerous pegmatite dikes and also considerably epidotized in some portions. Younger granites form the hills on either side of Negro Butte. The granites west of Rabbit Springs are cut by numerous coarse pegmatite dikes containing quartz far in excess of orthoclase. Because of the weathering of the granite they are particularly prominent and appear to constitute a significant part of the mass.

The ages of the various granitic intrusions are somewhat conjectural. The abundance of pegmatite dikes in the vicinity of Burns Cañon has already been referred to as indicative of pre-Cambrian time. It is a significant fact that granites belonging to that period in the earths history occur at Cadiz, about sixty miles to the east. Darton[18] says:

> The Iron Mountains present a considerable variety of rocks, including pre-Cambrian granite. . . . . The granite . . . . is overlain . . . . by rocks of Cambrian age, consisting of a basal quartzite with a thick body of overlying limestone and shale. . . . . The granite has a wave-worn surface, and the beds were deposited on this surface when it was a sea bottom, a fact which establishes the age of the granite as pre-Cambrian.

[18] Darton, N. H., Santa Fé Route, U. S. G. S., Bull. 613, Part C, 1915.

This statement has been verified by Clark,[19] who has gone a step farther by finding lower Cambrian fossils above the eroded granite. Now, since granitic intrusions are not usually local phenomena, but, on the contrary, partake of the nature of widespread revolutions, it seems quite likely that the complex granitic mass of the San Bernardino also contains rocks contemporaneous with that near Cadiz.

At the close of Jurassic time there was a great invasion of granitic rocks throughout the Sierra Nevada, and these have been traced down into the San Gabriels. It therefore seems fitting to assign the latest granites of the San Bernardino Mountains, herein referred to as the Cactus granite, to the same age. We have seen that there are older granites than these, which, however, also cut the limestone and quartzites. Do these belong to an earlier part of the same great period of intrusion or to an earlier period which, were the record complete, would be found separated by denudation and sedimentation? A post-Carboniferous invasion of granites in the Sierras has been mentioned by Lindgren and Turner.[20] Could it not be, then, that we have the same granites represented here in the San Bernardino Mountains? These are questions which naturally rise in the mind of the student of west coast geology, but for their answer we can only look to the future.

The Tertiary Formations

The Potato sandstone.—The portion of the ridge between Potato Cañon and Mill Creek east of Wilson Creek consists of a very hard sandstone entirely different from any other rock in the district. For the most part it is a well-bedded, coarse, angular arkose with angular boulders of schist and granite. A yellowish variety predominates, but there are also finer greenish and some red varieties. A few thin beds of shale are found between the sandstone strata. The bedding of the formation is somewhat variable in thickness, ranging from a few inches to more than thirty feet.

At its eastern limit the sandstone is probably in faulted contact with the granite. A sharp fault contact was not seen, since the whole mass is so sheared that it resembles a schist at a short distance. At this point the dip is about 60° to the west, but farther west it quickly flattens out and lies practically horizontal. The top of the ridge is 1500 feet above the bottom of Mill Creek, and, since the bottom of the

[19] Clark, C. W., Lower and Middle Cambrian faunas from the Mohave Desert, Univ. of Calif. Publ., Bull. Dept. Geol., vol. 13, no. 1, pp. 1–7.

[20] Lindgren, Waldemar, and Turner, H. W., Geologic atlas of the United States, Smartsville Folio, no. 18.

sandstone is not exposed and the top has been eroded away, this represents a minimum estimate of its original thickness.

The age of this sandstone has not been definitely determined. The intense shearing and induration indicate that it is older than the Hathaway formation or the Santa Ana sandstone. Its position relative to the Saragossa is obscure, but its freedom from intrusive rocks and the fact that much of it is unaltered, except that it is well indurated, suggest that it is younger. Lithologically it resembles many of the Tertiary sandstones of the Coast Ranges; for example, the Puente Sandstone of Miocene Age in the Santa Monica Mountains. As other considerations are not adverse to this, the formation will tentatively be considered as Miocene.

The Lion sandstone.—About half a mile from the mouth of Lion Cañon there is a branch to the northwest which, near its upper end, cuts across the Hathaway formation, a series of land-laid deposits; shaley playa beds, coarse sandstone, and fanglomerate, all dipping from 20° to 70° to the north. Overlying them in angular discordance is a flow of basalt. This also dips to the north, but not quite so steeply. On the third ridge west of Lion Cañon there is a small outcrop of sandstone, about a quarter of a mile long, dipping 45° north. Its exact relationship to the land-laid series is not clear. The southern limit of the latter, east and west of this point, is a fault, but the rocks are so similar and their detritus so intermingled that the contact on this ridge is obscure. If the fault is in line with the better exposures on each side, then it passes south of the small sandstone outcrop. This would mean that the sandstone has been faulted with the Hathaway formation and, since it dips toward the latter, it probably passes beneath and therefore underlies it. If the fault passes north of the sandstone, however, the latter is separated from the Hathaway but may be thrust from below. In either case the sandstone is the older. It is not likely that the sandstone has been dropped from above, for in that case we should expect to find it elsewhere.

This sandstone contains a small marine fauna consisting of forms found by Kew[21] in the Carrizo Creek region. The most important of these are: a *Turritella* compared to *altalira,* a *Spondylus, Pecten subnodoses,* and some other pectens not yet described. Of the Carrizo Creek fauna Kew says: "The echinoderm fauna seems to indicate a comparatively late age, as several of the forms are very closely related to the species living in the Gulf of California at the present time, and

[21] Kew, W. S. W., Tertiary echinoids of the Carrizo Creek region in the Colorado Desert, Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, no. 5, pp. 39–60.

these species are presumed to change relatively rapidly.'' Vaughan[22] has recently made a rather exhaustive study of the Carrizo Creek locality and concludes that the beds ''are not older than Lower Pliocene.''

The fauna from the Lion sandstone is of great importance, since it is the most definite evidence afforded in the whole region for the age of the sediments along the south front and for the age of uplift of the mountain mass; and in considering these questions it will be referred to again. It is also important to note that the fauna belongs to the Gulf of California rather than to the Southern California coast. Hence the Gulf of California probably extended into the region of the present San Gorgonio Pass at the time of the deposition of the Lion sandstone.

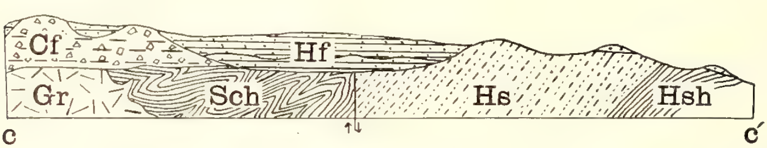


Fig. 6. Section west of San Gorgonio River. Gr, Granite; Sch, Schist; Hsh, Hathaway shale; Hs, Hathaway sandstone; Cf, Cabezon fanglomerate; Hf, Heights fanglomerate.

Hathaway formation.—A light grey shale, containing hard calcareous streaks, outcrops with a dip of 15° to the north near the mouth of the cañon west of San Gorgonio River. Farther up in the cañon the dip becomes greater and about two hundred yards from the mouth of the cañon this shale is conformably overlain by a grey sandstone, both having a dip of 45°. The sandstone is light grey in color and contains many streaks of angular pebbles derived from the igneous and metamorphic rocks to the north. The admixture of coarse and fine material and the general poor definition of the beds suggest very strongly that the deposit was land-laid. The shale below is identical with the material found in the playas in the desert north of the mountain range. Near the sandstone-shale contact the shale contains strata of sandstone similar to that overlying it, thus showing a gradation of one into the other. Near the head of the cañon the sandstone projects through the flat-lying fanglomerate with a strike of S 60° W and a dip of 45° NW (fig. 6). On the west side of San Gorgonio Cañon, at its mouth, the sandstone outcrops with the same dip and strike.

[22] Vaughan, T. W., The reef-coral fauna of Carrizo Creek, Imperial County, California, and its significance, U. S. G. S., Professional paper 98-T.

In the cañon two miles west of San Gorgonio River, the sandstone is faulted against the schist on the north and west and is overlain by fanglomerate on the east.

At the mouth of Hathaway Cañon, on the west side, the sandstone overlies the shale and both are warped to dips as high as 45°. They are overlain by basalt and fanglomerate. A small area of similar sandstone is overlain by volcanic material on the little hill one mile west of Millard Cañon.

Between Millard and Stubby cañons there is a strip of sediments which are believed to be correlative with the Hathaway formation because of lithologic similarity and also because of their position beneath a basalt flow. Portions of this mass, however, are somewhat different from any found west of the San Gorgonio River, but if, as has already been suggested, these are land-laid deposits, this local variation is to be expected.

On the west side of Deep Cañon both sandstone and shale are found together, but the beds are vertical and so faulted that their true relationship cannot be deciphered. On two small ridges east of this cañon both were found striking nearly east and west and dipping 50° to 70° north beneath the basalt. A narrow strip of shale could be followed along the south side of the sandstone. The shale and finer portions of the overlying sandstone are cut by numerous faults and along these gypsum and calcite have been deposited. In some places nodules were found within the mass.

West of Lion Cañon a small mass of fossiliferous Lion sandstone projects up through the Hathaway sandstone, but the nature of the contact is obscure. Just east of this point a light buff-colored sandstone lies beneath the bluish grey sandstone so characteristic of the Hathaway formation. These sandstones are separated by 5 to 20 feet of rhyolite fragments seen nowhere else in the whole region. The buff sandstone is similar to the grey in that it consists of angular unsorted material and contains many poorly defined strata in which some of the boulders are more than a foot across. The whole series dips to the north at about 45 degrees. The shale is not seen here, but half a mile east of Lion Cañon it again outcrops and is rather continuous for more than a mile.

Along the south side of this strip of shales and sandstone there is a large mass of fanglomerate. Because of the loosely consolidated nature of this material the contact is usually obscure. On the ridge west of Lion Cañon it is clearly a fault (fig. 7), but at the mouth of Deep Cañon it is depositional, the fanglomerate overlying the sandstone and shale. On the north the sediments are faulted against the old schists and the nearly vertical contact can be seen in nearly every small cañon which cuts across it.

The total thickness of the Hathaway formation is unknown, but in the small cañon just west of San Gorgonio River 1800 feet of sandstone and 800 feet of shale are exposed dipping to the north, the sandstone at 45° and the shale at 15° to 45 degrees. Neither the top nor bottom of the series could be seen, and these figures therefore represent a minimum estimate of the whole.

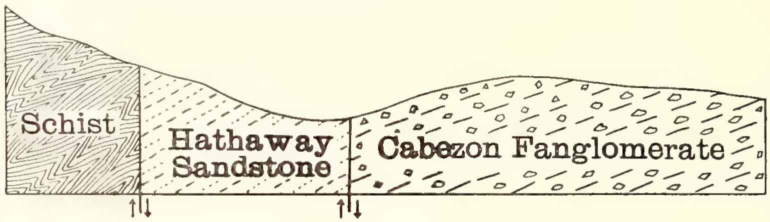


Fig. 7. Section of ridge west of Lion Cañon looking east. Scale 1″ = 2000′.

The Lion sandstone, which, if correlated with the beds at Carrizo Creek, "is not older than lower Pliocene," projects up through the Hathaway, apparently dipping beneath, but the contact is rather obscure and there is a bare possibility of it being a fault. Even so, the Lion sandstone would be likely to be faulted from beneath, as it is not exposed anywhere else in the region, and if it were the younger, we would certainly expect to meet with it elsewhere. Then if the Hathaway formation is younger than the Lion sandstone, it must be younger than lower Pliocene. It can hardly be upper Quaternary because of the evidence of time since its deposition: extrusion of basalt, uplift with development of different erosion surfaces, and deposition of great masses of fanglomerate. Hence the conclusion that it is either upper Pliocene or lower Quaternary.

Santa Ana sandstone.—The low topography along the Santa Ana River is carved from a fanglomerate beneath which lies a sandstone and shale formation. Near Seven Oaks, sandstone predominates in the sandstone-shale member. For the most part it is medium grey in color, although brown and reddish streaks are present. It also includes strata of coarse granitic detritus up to five and six feet in thickness between which are finely laminated shales and occasional calcareous seams. Compared to the sandstone along the south front of the range it is uniformly finer, contains fewer pebbles, and has a better defined bedding. The general attitude of the formation is flat-lying with minor warping, the dip locally being as high as 45°.

About a mile below the houses in Big Meadows and on the south side of the stream the sandstone again outcrops from beneath the fanglomerate. Here it lies horizontally. Just below the junction of Fish Creek and the Santa Ana River it strikes north and south and dips 22° west.

The formation cannot be correlated with much certainty with any other in the district. That it is now in an abnormal position is strongly emphasized by the fanglomerate, containing huge blocks of granite over eight feet across, which overlies it unconformably and which, of course, is the type of deposit one would expect to find between two high ridges. The sandstone and shale may possibly have been formed at the same time as the Hathaway formation on the south side of the range, since their lithologic similarity indicates somewhat similar conditions of deposition; i.e., they were both deposited in a region of low relief and, therefore, must certainly have been laid down before the uplift of the mountain mass. Their degree of deformation also suggests synchronous deposition. The present position of the evenly bedded sandstone and shale in the bottom of a deep cañon can only be explained by faulting. The nature of this faulting will receive further attention in discussing the structure of the mountain range.

Pipes fanglomerate.—On the hill half a mile southeast of The Pipes there is a flat-lying sedimentary deposit having a total thickness of about 50 feet. The lower fifteen feet is a sandstone containing many rounded pebbles. This grades up into a conglomerate consisting for the most part of rounded granite, aplite, and quartz pebbles ranging in size up to six inches in diameter. The upper part contains considerable angular material. The lower sandy portion is grey in color, but the upper is reddish due to the presence of hematite, probably derived from the overlying basalt. The larger part of the mass is rather well cemented and more resistant to weathering than the underlying granite, so that it forms a distinct bench near the top of the ridge.

At the table-topped hill directly east of The Pipes the basalt rests on sandstone and fanglomerate having a thickness of 60 feet on the south side but less than 20 on the north. The fanglomerate consists for the most part of coarse granitic material, the larger fragments attaining a diameter of about six inches. Below this there is about 15 feet of soft sandstone also consisting of granitic material.

As noted above, the fanglomerate is somewhat thinner on the north side of the hill. On the next hill to the north the basalt rests directly on the granite, and it therefore seems evident that, at the time the detritus was deposited, the country sloped to the south.

Between the basalt flows a stratum of similar material occurs, but it is rather small and pinches out to the northwest.

The Pipes fanglomerate is believed to be upper Pliocene or lower Quaternary because it is older than the basalt flows; yet it cannot be much older, for it is parallel to them and similar material is found between them.

BASALT

Areas of basalt are found along the south flank of the San Bernardino Mountains, in the vicinity of The Pipes, and in the desert to the north. They are merely the remnants of flows which probably extended over a much larger part of the region previous to the uplift of the mountain range. Several varieties are found and it is impossible in any case to check different areas as portions of the same flow.

Olivine basalt overlies the Hathaway sandstone between Hathaway Cañon and San Gorgonio River. Due to alteration it has a reddish color, but a few rounded grains of olivine can still be recognized. It dips to the west and is overlain by horizontal beds of fanglomerate. On a small hill one mile west of Millard Cañon volcanic rocks rest on sandstone and are overlain by fanglomerate. For the most part the volcanic material is basalt, the upper portion of which is vesicular. Above this there is a thin stratum of soft, white, decomposed tuff. Both are nearly horizontal.

Between Millard and Deep cañons the basalt lies across the eroded edges of the Hathaway sandstone. The basalt and sandstone form an anticline here, the south limb of which disappears before it reaches Deep Cañon, possibly due to faulting, while the north limb continues east of Deep Cañon for about half a mile. Fanglomerate overlies the basalt and has been tilted with it.

Red Dome in Whitewater Cañon is an outcrop of olivine basalt. About half a mile to the northeast there is a small area of schist exposed to view by the stripping of the overlying fanglomerate and on this there are several small patches of basalt. Practically all of this is of a deep reddish color due to weathering and the resultant oxidation of iron. Near the upper portions of some of these small masses of basalt there are amygdules of chalcedony.

On the south side of Mission Creek near its mouth basalt outcrops from beneath the fanglomerate. The weathered surface appears at first sight to be a fine agglomerate, but on breaking off the outer crust the material is found to be a somewhat decomposed basalt. One peculiar thing about this outcrop is that at its eastern end it exhibits the fluted forms so typical of badland erosion. East of Hog Ranch another strip more than half a mile long is exposed in the side of the cañon. As in other cases it also is overlain by fanglomerate.

A small body of olivine basalt is found in one of the little gullies on the north side of Little Morongo Creek, about a mile and a half from its mouth. This is evidently a neck, for it is cut by erosion and extends to a considerable depth despite the fact that it is not more than seventy feet across. Immediately surrounding the basalt proper is a shell of altered basalt mixed with fragments of granite torn from the walls of the pipe.

The flat-topped hill two miles east of The Pipes (pl. 17b) is almost wholly of basalt, the underlying fanglomerate forming only a comparatively thin bed. On the north side of the hill this fanglomerate nearly pinches out and is seen to rest on granite. The basalt mass consists of several flows from ten to thirty feet thick, the total aggregating a little over 200 feet. The vesicular character of the upper portion of the individual flows usually serves as a distinct line of demarcation.

The lowermost flow is about ten feet thick and is a dark brownish, nearly black, rock. It contains many rounded olivine phenocrysts, some of which are as much as a millimeter in diameter. These are light greenish in color with light brownish limonite stains around the borders. Tabular crystals of plagioclase up to three millimeters in length are present and under the microscope were determined as labradorite near andesine. This seems to form a large part of the rock with all gradations in size from the smallest in the ground mass to the largest phenocrysts. The ground mass is dark and compact and, in addition to the needle-like crystals of labradorite, consists of numerous grains of augite and magnetite. The augite is partially altered to chlorite and distinct reddish rims of hematite can be recognized around some of the magnetite.

A specimen fifty feet from the base differs somewhat from the above. Large euhedral olivine phenocrysts and laths of basic bytownite are imbedded in a ground mass of small laths of basic labradorite and grains of colorless augite. Many blades of hematite and some rounded grains of magnetite are also present. The rock is altered and considerable calcite forms a filling between the original constituents. A specimen thirty feet higher is similar except that the feldspars are more acid, the phenocrysts being basic labradorite and the ground mass andesine.

A very dark greenish rock near the top of the section contains grains and small granular masses of olivine which are prominent even to the naked eye. Under the microscope it is seen to possess a typical ophitic structure, laths of labradorite being imbedded in large tables of augite. A considerable quantity of magnetite is present as small blades.

About three miles northeast of The Pipes there is a similar basalt-capped hill, but here the lava rests directly on granite instead of on sediments. As in the other case, there are many flows represented in the mass. A dark purplish grey compact rock from near the top of the hill contains abundant rounded phenocrysts of olivine. Large laths of bytownite containing needles of apatite are also present. The ground mass consists of small needles of labradorite with interstitial grains of colorless augite; also a considerable number of small grains of magnetite.

Resting on the fanglomerate on top of the ridge half a mile southeast of The Pipes, there are several small areas of basalt. A dark compact variety is so coarse that the striations on the plagioclase may readily be seen in the hand specimen. Secondary calcite is present as the filling of small cracks. Under the microscope labradorite and augite exhibit an ophitic structure. The amount of augite, however, seems to be small and the feldspars rather crowded. Euhedral grains of olivine are rather prominent in the rock. It also contains numerous blades of magnetite.

On the ridge two miles south of the point where the Burns Cañon road crosses Antelope Creek, there are three small areas of basalt. It is a very compact greenish-black rock containing grains of olivine and also granular masses more than a centimeter across. Under the microscope the small isolated grains are found to be euhedral and all have rims of hyalosiderite. The ground mass consists of basic labradorite microlites with considerable magnetite. Grains of augite are also present. Two miles farther west there are two other small areas.

South and west of Old Woman Springs there is a large area of basalt. Just west of the springs and also a mile and a half southeast low rounded knobs of granite project up through the lava. The northeast limit of the basalt is an escarpment, but to the west and south it disappears under fanglomerate. At its eastern extremity it is immediately overlain by a thin stratum of coarse sandstone above which lies fanglomerate. The basalt is compact and very dark grey, nearly black, in color. In thin section it is seen to contain large euhedral augites, the outer portions of which have a violet tint and are slightly pleochroic. Smaller euhedral crystals of olivine with hyalosiderite rims are more abundant. The ground mass is composed of small laths of basic labradorite, considerable magnetite, and very small grains of colorless augite.

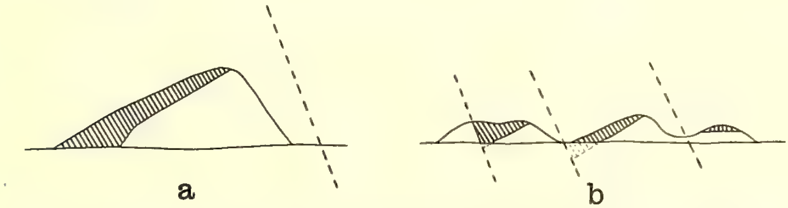


Fig. 8. *a,* Negro Butte; *b,* three low hills two miles east of Negro Butte, showing probable position of faults.

Three miles north of Old Woman Springs a series of basalt flows rests on granite which is exposed on an escarpment overlooking a playa on the north side. Two and a half miles to the west there is a small patch of basalt on a hill of granite. Just south of this hill there are several small areas.

Negro Butte is a small granite hill, the southwest slope of which is covered with basalt dipping 30° to the southwest (fig. 8a). Because of the generally flat-lying attitude of the basalt in the region this slope is believed to be due to faulting. About two miles to the east there are three similar areas of basalt also tilted to the southwest (fig. 8b).

Fry Mountain is capped with basalt which slopes 15° to the north and is continuous with a flat area more than two miles in length. At the base of this basalt cap there is a vesicular layer which has been oxidized to a deep red and this is offset by a north-south fault.

Three important points are to be noted regarding the basalt: although the areas are small, it is widely distributed; wherever there is evidence of the nature of the surface on which it rests, this is found to be flat or of very low relief; the basalt is now found at places of considerable difference in elevation and there is abundant evidence of its having been faulted. It is therefore evident that the basalt was extruded anterior to the uplift of the present mountain range with the attendant deposition of fanglomerates along its flanks. On the other hand, it is younger than the Hathaway formation, which is late Pliocene or early Quaternary. Therefore it is probable that the basalt is of early Quaternary age.

Quaternary Fanglomerates

The basalts are the youngest rocks of general distribution in the region. Some time after their extrusion the present mountains began to rise between faults along the north and south sides, and with this uplift streams began to rapidly dissect the mass and bring down great quantities of débris. In discussing the physiography we have seen that in an arid climate this material is characteristic, the bulk of it being coarse and angular. In some cases, however, small perennial streams contribute to them and beds of pebbles, so rounded as to be termed "stream conglomerates," are often present.

Alluvial fans are still being deposited along both the north and south sides of the range, but quite distinct from these are older deposits of similar nature. Since these were deposited during an uplift of the region and were themselves subject to movement, they contain unconformities. During the uplift there were definite halting periods and probably also changes in the humidity of the region. These periods and changes are evidenced partly in the physiography and partly in the deposits of fanglomerate.

It is impossible to correlate all the different fanglomerates at any one place with those of another, but in some cases there is strongly suggestive evidence of identity or equivalence. They are considered Quaternary in age, for the general conditons under which they were deposited still exist. Present information justifies a partial classification and naming of these formations, as appears in the following descriptions.

Deep Cañon fanglomerate.—On both sides of Deep Cañon the basalt is overlain by fanglomerate and both have been warped and faulted together. Across their upturned and eroded edges later fanglomerate has been deposited. The older detritus greatly resembles the Hathaway formation which underlies the basalt. While the bulk of the Hathaway is rather fine for fanglomerate, in this vicinity the upper portion, that immediately below the basalt, is rather coarse.

The detrital rocks above and below the basalt are similar in that they consist largely of angular and subangular boulders derived from the older rocks to the north. They contain a notable proportion of rounded material, but this, since it may be true locally of any fanglomerate, is unimportant. The upper also contains strata of sandstone quite comparable to that in the Hathaway.

In consideration of the foregoing facts it seems probable that the fanglomerate above the basalt was laid down under conditions somewhat similar to those which controlled that below, i.e., before the uplift of the mountain mass, or before this uplift had become of great importance.

The older desert deposits.—In the desert along the north side of the range there are isolated outcrops of sedimentary rocks whose age is rather uncertain. They have been cut by recent erosion and in some cases, where the nature of the material indicates the conditions of deposition, the time with regard to the uplift may be inferred.

Horizontal sediments are exposed on the east side of the hill a mile west of Cushenbury Springs. In the lower fifty feet the deposit consists of grains of quartz and flakes of biotite in a fine earthy matrix of light brownish color. Toward the top there are a few strata of coarse detritus, the larger fragments being about two inches in diameter. This is unconformably overlain by nearly horizontal beds of coarse fanglomerate, some portions of which are firmly cemented with lime, but on the whole similar to that now being deposited along the foot of the mountains. The sequence indicates that the lower strata were laid down before the uplift of the mountains to the south and the uppermost strata after this uplift was well advanced. The finer material could hardly have been laid down at the base of a steep scarp, but rather in a country of low relief, while the fanglomerate is typically laid down in such a position.

East of Old Woman Springs the basalt just before it disappears is overlain by coarse sandstone containing fragments of quartzite. Above this there is a soft sandy shale and still higher a fanglomerate which makes up a large part of the bench as it continues to the southeast. The sandstone immediately above the basalt has a dip to the south of 5° to 15°. Just north of the basalt similar strata dip to the north at about the same angles. The outcropping basalt does not dip beneath them, but abuts against the strata, so that either there must be a fault or the basalt was much eroded before the deposition of the sediments. In considering the structure other evidence will be presented which seems to indicate faulting. These finer beds were evidently laid down before the mountain mass to the south attained its present height, but whether before the beginning of the uplift or after the second cycle or one of the subcycles is an open question. The overlying fanglomerate is similar to that being deposited at the present time and therefore must have been laid down after the uplift.

The basalt disappears about a mile northwest of Old Woman Springs, but the bench, though inconspicuous, continues for nearly two miles farther. It consists of desert deposits: playa silts, somewhat calcareous and gypsiferous, and fanglomerate. The extent of these beds is not known, but they are found in several places to the west, where the small washes cut down through the more recent fanglomerate. Two miles west of Box S Springs sediments are exposed which are lithologically identical to those described above. These beds were evidently laid down under conditions similar to those existing in the desert today, and must have been deposited before the mountains to the south reached their present elevation, but it is impossible to say just how long before.

Coachella fanglomerate.—On the east side of Whitewater Cañon, from Painted Hill four miles northward, there is a clastic rock having all the characteristics of a fanglomerate. For the most part the fragments are angular and show but little sorting; though the material seems to vary somewhat throughout the mass. Along the crest of the ridge the strata dip 20° to 40° eastward, but flatten somewhat toward the east.

Opposite Red Dome the fanglomerate consists mostly of sharply angular fragments varying in size up to three feet across. By far the largest part of this is porphyry, but other rocks, granite and basalt, are also present. Some strata contain sufficient volcanic material to color them red and give them the appearance of flows somewhat shattered, but the presence of other rocks shows their fragmental character. Some rather large boulders are present, one porphyry block being more than eight feet across and a block of basalt six feet across. Some of the finer material is so broken down as to resemble soil. This particular mass differs somewhat from that to the southeast in its coarseness, extreme angularity, and high basalt content; but such differences are to be expected in deposits of this sort even within short distances. It is not certain whether they represent different horizons which have been faulted into juxtaposition or local variations of the same formation.

The fanglomerate as seen two miles southeast of Red Dome is typical of the greater part of the mass. The strata are light and dark grey and rather persistent except where cut by faulting (pl. 24A). The material is coarse gravel and subangular polygenetic pebbles two inches to a foot in diameter, probably derived from the old rocks to the north. At a distance it might be mistaken for sandstone, but closer examintaion reveals its true character. While similar to this as regards the general nature of the material, a great part of the fanglomerate at Whitewater Cañon shows practically no bedding. About a mile north of Painted Hill there is a great deal of volcanic material present and on weathering the iron colors the rock a deep red.

Just north of Painted Hill the fanglomerate contains fragments ranging up to more than two feet in diameter. The general appearance of the mass is that the fragments are waterworn, but in reality it contains fully as much angular and subangular material. This is unsorted and for the most part displays no evidence of stratification, although there are occasional distinct beds of sandstone. The whole deposit is well consolidated and on the east side of the hill it is firmly cemented.

The relations of this accumulation to the adjacent rocks are quite clear. North of Painted Hill it overlies the old schists and gneisses. To the east it dips under more recent fanglomerate which differs from it in being more uniform and massive and in lying nearly horizontal. Furthermore, the later deposit is of yellowish color as contrasted to the grey and purplish grey of the Coachella. The latter outcrops on the west side of Mission Creek half a mile below Hog Ranch and also on the south side of the hill south of the Whitewater-Desert road. Here the strata form a low anticline whose axis strikes S 30° E and whose limbs dip about 6°.

The Coachella fanglomerate is of such nature that it must have been deposited near the base of a mountain mass. It contains many basalt fragments. It is therefore probable that this detritus was deposited after the mountain mass had begun to rise, but probably only shortly after, as there was still considerable basalt available to contribute to it.

Cabezon fanglomerate.—We have already seen that during the development of the second cycle fanglomerate was deposited in Bear and Holcomb valleys.

The largest area in Bear Valley is the broad flat between Rathbone Creek and Erwin Lake. The material is almost wholly unsorted angular and subangular quartzite brought down from Sugarloaf Mountain to the southeast. This area once extended farther west, but only a few low ridges are left. Just west of Pine Lake there is an outcrop of rather well cemented fanglomerate dipping 10° to the north and containing unsorted angular boulders up to eight inches in diameter. Its exact significance is not known, but it lies beneath the other fanglomerate and may represent an earlier phase of the same deposition. On the north side of the valley, between Poligue and Van Dusen cañons, there is considerable fanglomerate, but it is of recemented limestone fragments, the same sort of material to which the Spanish term "caliche" is applied.

Holcomb Valley is nearly surrounded by flat ridges of fanglomerate. Those on the south and east sides are particularly conspicuous and consist of limestone, granite, and quartzite from the surrounding hills. The quartzite, because of its greater resistance to erosion, is the most prominent constituent over a large part of the area. On the north side of the valley from Caribou Creek northwestward for a mile this fanglomerate has been worked for placer gold.

The nature of the erosion of the fanglomerate deserves particular attention. The flat between Rathbone Creek and Erwin Lake is cut up with gullies, but there are no alluvial fans at their mouths. In some of these gullies there are grassy meadows and the floor of the valley is loamy meadow land. In Holcomb Valley the same condition obtains. It thus appears that the erosion here is more of the nature of that taking place under humid conditions than that which is active along the flanks of the mountains or was active in the mountains at the time the fanglomerate was deposited. The dependence of this on the uplift of the mountains has already been discussed and needs no further mention.

The fanglomerate in Bear and Holcomb valleys is only a local representative of a widespread deposition during the third cycle of erosion. Similar fanglomerates are found in many other valleys and cañons and along the flanks of the mountains.

In Santa Ana Cañon fanglomerate unconformably overlies the sandstone-shale formation and, although deeply incised by recent streams, it still has the general appearance of being the valley floor. It consists largely of somewhat angular granitic and gneissic boulders, some of which are as much as eight feet across, from the ridges on either side, with a matrix of similar material differing only as to size of fragments. The whole mass is but loosely consolidated and the color is usually reddish or yellow. The fanglomerate extends high up on the sides of the cañon and on the south side there are numerous talus cones along the upper edge. This is an important feature in that it bears out a previous statement that aridity prevailed during this period. The same conditions existed in Mill Creek Cañon, but all that remains of the fanglomerate at present are some low hills and a terrace. On the north side of the cañon at Akers Camp there is a fanglomerate bench which is no doubt a remnant of the old valley floor. A similar occurrence is found at the mouth of Potato Cañon.

Fanglomerate forms the main valley floors around the headwaters of Whitewater River, and Raywood Flat is a remnant of just such an old floor. This consists of unsorted angular and subangular fragments of granite and schist from the neighboring ridges. In some places it shows a rude stratification with lenses of sand free from pebbles. These lenses, however, are usually small, only five to ten feet in length. The gravel consists of small rock fragments with muscovite, biotite, and even feldspar, as well as quartz. Near the head of the north fork of Whitewater the fanglomerate is over 200 feet thick. At first sight it appears to be entirely without stratification, but viewed from a few hundred feet distant a rude horizonal bedding can be recognized. One subangular boulder was seen which was about 20 feet across in its greatest dimension and others 10 feet in diameter are not uncommon. This material, being at such an altitude, might be taken for glacial débris; especially owing to the presence of huge boulders. But there are some things to be noted which rule out this possibility altogether. Most of the deposit, even the coarse material, exhibits a rude bedding. When the whole mass is viewed from a vantage point it is seen to form large even-graded areas filling in old depressions and grading harmoniously into the surrounding hills. There is true glaciation on the north side of this same ridge, but the moraines do not extend so low as this detritus on the south side by fully 2000 feet. Yet the limit of glaciation must be lower on the north side where glaciers would have been more protected from the heat of the sun. The lithologic similarity of the mass to the fanglomerate in Santa Ana Cañon and in Mill Creek is very striking, and this alone is sufficient to suggest a similarity in origin.

At the upper end of Mission Creek, just below the divide, are remnants of fanglomerate having the same relation to the surrounding topography as that in the Santa Ana Cañon and like it consisting largely of angular boulders.

Just below Pine Bench is a fanglomerate which, because of its elevation and location (see map), looks as though it were once continuous with Banning Heights and simply separated by erosion. This is more apparent in the field when looking southward from Pine

Bench. It bears the same physiographic relationship to the surrounding country as that at Raywood Flat and in Santa Ana Cañon, and the material is also very similar. The same kind of fragmental rock is found at the mouth of San Gorgonio Cañon on both sides. On the west side it forms part of the bench and rises above the more recent sediments. A mile and a half from the mouth of the cañon it is again seen as two small hills on the bench. It therefore seems probable that the older fanglomerate was continuous with that below Pine Bench, and that its deposition is referable to the same period as those of Raywood Flat and Santa Ana Cañon. In Cherry Cañon and Little San Gorgonio there are extensive benches corresponding to Banning Heights and in some places the streams have cut down into an old fanglomerate greatly resembling that described above. It is quite distinct from the overlying fanglomerate in that it is nearly always of a reddish color and contains many boulders so decomposed that a pick may be driven into them as easily as into the matrix.

Along the south flanks of the range there are several areas of fanglomerate. These are correlated by reason of their lithologic similarity on the assumption that the conditions favoring the deposition of fanglomerate were very likely general.

At the mouth of Hathaway Cañon fanglomerate is found on both sides. On the east side the base of this deposit cannot be seen, but on the west side it rests on basalt and the old schists. The southern half of the valley at the head of the cañon is floored with similar material resting on a smooth surface, carved from the older rocks, which is continuous with the northern portion of the valley floor.

The hill at the mouth of Millard Cañon is entirely of fanglomerate, some of the boulders of which are more than five feet across. As is generally the case, the freshly exposed material is yellowish in color, but the portions which have been exposed for any considerable time are red. Similar material is also found on the east side of the cañon, where it overlies shale, sandstone, and basalt. High up on the ridge just north of this area there are horizontal strata of gravel and fanglomerate. The San Andreas fault lies between these two areas and they may have been continuous at one time.

A rather large area of fanglomerate extends from Deep Cañon to Stubby Cañon. Its general attitude is horizontal, but in some places it has been warped considerably. On the east side of Deep Cañon nearly all the detritus is sharply angular and very coarse, blocks eight feet across being common. Not the slightest trace of bedding is recognizable. About a mile farther east the material is not so coarse and has a rough bedding which is best seen where streaks of sand are present. It is tilted, in some places to angles as high as 40°, and also somewhat faulted. It seems that from this point eastward to Stubby Cañon the northern portion is warped with dips up to 20° and 30° to the north, while along the southern edge the beds are practically horizontal.

The contact with the sandstone and shale on the north is not easy to follow because of the fact that these rocks yield readily to weathering and the detritus from both becomes mixed. On the east side of Deep Cañon the fanglomerate overlies the sandstone and shale, but two miles farther east the contact is a fault. On the west side of Stubby Cañon it is clearly faulted against the old schists, the movement here being on the San Andreas fault. On the east side a small block is isolated on the north side of the fault by a slice of schist which has been faulted up between it and a narrow strip a little to the south. Two other small areas are found between this point and Cottonwood Cañon along the edge of the hills and two others project above the alluvial fan about half a mile south of Cottonwood.

Between Cottonwood Cañon and Whitewater River a large rectangular block of fanglomerate is faulted against the schist to the north. The material is very similar to that now being deposited at the mouth of Whitewater. It contains a great deal of small angular and subangular débris, and also some larger boulders over eight feet in diameter. The bedding is poorly developed and its general attitude is horizontal.

On the east side of Whitewater, near its mouth, there is a large area of fanglomerate which swings around east of Painted Hill and northward, overlying the east edge of the Coachella fanglomerate. A small strip extends along the bank of Whitewater River west of Red Dome and another along the east bank northwest of Painted Hill.

Fanglomerate lies between Whitewater River and Mission Creek. That between Red Dome and Hog Ranch is nearly horizontal and overlies the Coachella fanglomerate, basalt, and the old schists. A mile north of Red Dome the situation is not so simple. Here horizontal fanglomerate is found overlying lithologically identical beds which have dips up to 35°. While ordinarily such a discordance would demand a separation, the fact that both were laid down near the great Mission Creek fault is sufficient to explain this break, even though the general conditions of deposition remained the same and the time was short. West of Hog Ranch the fanglomerate rests nearly horizontally on the basalt and schists. At the mouth of Big Morongo

Creek there is a small area jutting sharply into the schists; the south and east boundaries are faults.

A strip of fanglomerate extends along the southwest side of Morongo Valley. There is also a small area at the divide shown on the edge of the map and another on the divide between the valley and Dry Morongo Creek. All three of these may possibly be remnants of a more extensive area that once filled the Morongo Valley.

In the valley east of The Pipes there is a great stretch of fanglomerate into which the present streams have cut. In many places this fanglomerate grades into the slopes up to the flat-topped hills. The open valley southeast of Mound Spring is also floored with fanglomerate. In discussing the physiography of the region, both of these valleys were considered as probably contemporary with Bear and Holcomb valleys. It therefore seems reasonable to believe that the fanglomerate is also of about the same age as other widespread deposits having the same relationships to the topography.

Heights fanglomerate.—Several areas of fanglomerate are found in this region which were laid down under the same conditions as obtain at the present day, but they have been uplifted and are undergoing dissection. Banning Heights is floored with such an accumulation which overlies schists and granite, the Hathaway shales and sandstone, and the Cabezon fanglomerate. Along the south front of the range there has been a recent movement which has raised the floor of the Heights more than 500 feet above the San Gorgonio Pass, where similar material is now being laid down and with which it was formerly continuous. The San Gorgonio River has cut down through the uplifted sediments until it is now on a grade with the Pass.

In Hog Cañon, Little San Gorgonio Creek, and Cherry Cañon there is an extensive fanglomerate at the same general elevation as Banning Heights. It is of the same sort of material and bears the same relationships to the surrounding topography, even to the scarp which forms the southern limit, with the difference that it is much lower.

On the north side of the range there are several areas of fanglomerate which are probably of about the same age as those described above. One such area forms a bench extending from Marble Cañon to Silver Creek. The material is the same as that now being deposited but somewhat more consolidated, and it has also been uplifted and incised by the present streams. A similar uplifted area is found two miles west of Two Hole Springs and another two miles east of Rock Corral.

A large mass of "caliche" or limestone fanglomerate lies between Cushenbury Springs and Grapevine Creek and extends northward three miles from the mouth of Blackhawk Cañon. It has been extensively dissected, but remnants still extend high on the steep slope. In some portions of this mass there is considerable limonite, so that it appears to form the cementing material for the limestone fragments.

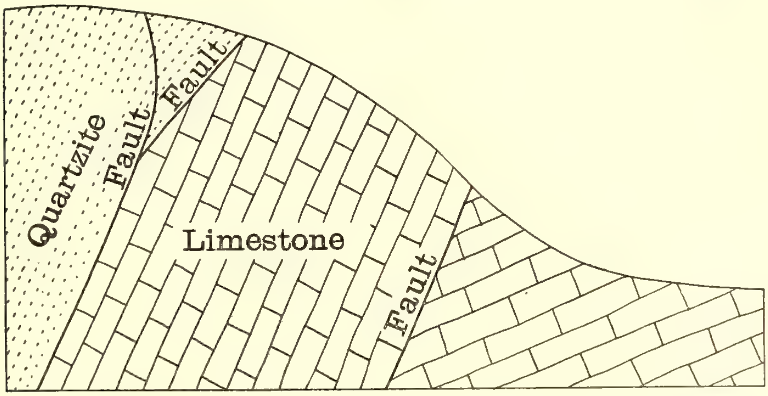


Fig. 9. Section three-quarters of a mile southeast of Smart's Ranch.

Alluvium

Alluvial fans are being deposited in the San Gorgonio Pass on the south side of the range and also along the north flanks and in the Mohave Desert. Since they not only represent sedimentary deposits but are important as physiographic features, they have been discussed in that connection and need no further description.

Smaller areas of alluvium are found in Bear and Holcomb valleys, Santa Ana Cañon, Morongo Valley, Cienaga Seca, Broom Flat, and other swampy places in the mountains.

Structure

Folds modified by intrusions and faults.—The older sediments of the region, the Arrastre quartzite, Furnace limestone, and Saragossa quartzite, have been folded and faulted and the resulting structure further complicated by granitic intrusions. The axis of a northwest-southeast syncline passes a little to the west of Doble (fig. 5 and section B–B′). The northeast limb can be followed southeastward to Round Valley. Throughout this distance the limestone dips toward the Saragossa quartzite at angles of from 20° to 60°, but does not always pass beneath it, as may be seen south of Smart's Ranch, since the simple relations are disturbed by strike faulting (fig. 9).

Northeast of the limestone the underlying Arrastre quartzite is isolated by a large mass of granite and only in one place, northeast of Horsethief Flat, does it come in contact with the limestone. Here its concordance with the dip and strike of the latter shows that in reality it is part of the same syncline. At Round Valley the Furnace limestone swings around and continues southward as small masses sunken into the granite and isolated from the Saragossa quartzite; still its distribution is in agreement with the general synclinal structure.

The southwestern limb of the syncline cannot be clearly recognized so far along its strike as the northeastern. At Gold Mountain the Saragossa quartzite dips 8° to the northeast and south of Baldwin Lake it is nearly flat. The Furnace limestone is found west of Gold Mountain, but is separated from the Saragossa quartzite by a small mass of granite. It was probably faulted up to its present position, as the dip of the quartzite is too flat to account for the limestone outcropping from beneath it so near the axis of the syncline.

North of Sugarloaf Mountain the limestone forms a small east-west anticline, the south limb of which passes beneath the Saragossa quartzite. The north limb is covered over with fanglomerate. The relations of the limestone to the Saragossa quartzite on the east are rather obscure, but in consideration of its stratigraphic position it is believed to pass beneath.

On the west side of Holcomb Valley there is a small mass of Saragossa quartzite which appears to dip beneath the limestone, but the rocks are so broken by faulting and the intruding granite that the significance of this observation is uncertain. It may represent a portion of an overturned anticline, a thrust fault, or the block of quartzite may merely have been dropped down into the limestone. North of Holcomb Valley between Wild Rose Cañon and Crystal Creek the general attitude of the limestone is horizontal with numerous minor folds whose limbs have local dips of more than 45°. Several dikes of granite traverse the limestone and west of Delemar Mountain, Greenlead Camp, and Crystal Creek granite is the predominating rock.

On the south side of the hill two miles north of Saddlerock Spring the older heterogeneous granite is clearly seen to form the roof of a younger mass of grey granite. A few small apophyses of the latter have followed along cracks between blocks of the former. Ridges of the older rock strike across the plateau N 50° E and in one of the small gullies an angular block of this roof rock was seen hanging down into the younger. It therefore seems probable that these parallel ridges are the result of some sort of jointage system that existed before the intrusion of the younger granite.

South of Antelope Creek and Santa Ana Cañon the older sediments are so broken and contorted by folding, faulting, and granitic intrusions that a general statement of the structure is scarcely possible, and what has been said under the description of these rocks must suffice. This statement also applies to the rocks in the desert to the north.

At its eastern limit the Potato sandstone dips nearly vertically or very steeply to the west, but farther west it flattens considerably and at the mouth of Mill Creek Cañon, about two miles off the map accompanying this paper, it is nearly horizontal.

The unaltered sediments along the south side of the range have been somewhat warped and faulted. Between Deep Cañon and Stubby Cañon the Hathaway formation dips from 20° to 70° to the north. On a ridge about half a mile east of Deep Cañon the Lion sandstone appears to lie at the base of the Hathaway with a dip of 45° north, but there has been so much faulting that this is not clear.

Between Millard and Deep cañons basalt overlies the eroded edges of the Hathaway sandstone. It seems to form an anticline, the south limb disappearing before reaching Deep Cañon, possibly due to faulting. The north limb continues half a mile east of Deep Cañon and is overlain by the Deep Cañon fanglomerate which has been tilted with it. Along the south side of the Hathaway formation between Deep and Stubby cañons there is a large mass of Cabezon fanglomerate, but owing to its unconsolidated nature the contact is usually obscure. On the ridge west of Lion Cañon it is clearly a fault (fig. 7), but at the south of Deep Cañon it is depositional, the fanglomerate overlying the sandstone and shale.

The unconformity between the Hathaway formation and the basalt can be seen at the mouth of Hathaway Cañon on the west side, where the former is tilted to dips as high as 45° and is overlain by the latter with a dip of about 30° to the west. This in turn is overlain by nearly horizontal Cabezon fanglomerate.

Near the mouth of the cañon west of San Gorgonio River the Hathaway formation has a dip of 15° to the north, but farther up it gets steeper and about 200 yards from the mouth of the cañon the dip is 45°. Near the head of the cañon the sandstone projects through the flat-lying fanglomerate with a strike of S 60° W and a dip of 45° NW (fig. 6). In the cañon two miles west of San Gorgonio River the sandstone is faulted against the schist on the north and west and is overlain by nearly horizontal fanglomerate on the east.

The general structure east of Whitewater River is simple, but in detail it is somewhat complicated by faults which have cut the Coachella fanglomerate into numerous blocks variously tilted (pl. 22A). Along the crest of the ridge the strata dip 20° to 40° to the east, but flatten out toward the east and dip beneath the Cabezon fanglomerate. North of Red Dome horizontal beds of Cabezon fanglomerate overlie lithologically identical beds which have dips up to 35°. This is probably due to their proximity to the Mission Creek fault, which might bring about structural complexities, even though the general conditions of deposition were unchanged and the time short.

Quaternary faults.—A notable feature of the geologic structure of the San Bernardino Mountains is a great system of Quaternary faults whereby the mass has been uplifted and divided into several blocks. Along the north side of the range is a prominent fault, the expression of which, as a degraded scarp, is particularly bold between Blackhawk Cañon and Silver Creek (pl. 22B). From the head of Arctic Cañon the general relations can be seen clearly. To the south is the rounded topography of Holcomb Valley. Immediately to the north is the rugged, steep slope beyond which is the Mojave Desert. The rounded topography of the second cycle, as exemplified by the country around Bear and Holcomb valleys, represents late maturity; the width of the valleys and the gentle slopes which prevail indicate that the streams which excavated them must have nearly reached base level. Its present position, therefore, is discordant with its geomorphic development and can only be explained by uplift. This fact, together with the actual scarp, indicate the presence of a fault which is readily traceable to the west beyond the quadrangle and to the east as far as Blackhawk Cañon.

Just out from the base of the scarp and extending from Silver Creek to Cushenbury Springs there is a more or less dissected bench consisting partly of fanglomerate and partly of granite and limestone. At the mouth of Furnace Cañon, on the west side, this is represented by a long flat-topped granite ridge. The interpretation of this is somewhat uncertain. It may mean that the uplift of the range was along the face of this bench and that erosion cut back from the fault and developed the surface of the bench. A recent movement would have elevated it to its present position. There is also the possibility that the surface of the bench represents an uplifted portion of the old desert floor and that there has been step-faulting.

Extending southeast from the mouth of Blackhawk Cañon nearly to Rattlesnake Cañon there is a scarp as prominent as that to the west (pl. 23A). Because of its resemblance to the other and the fact that the line of uplift could hardly stop short, this also must represent a fault. Its eastern limit is poorly defined due to the degradation of the scarp.

It seems that there has been a rather recent uplift along the north front of the hills near Two Hole Springs. To the south a straight wall of granite and schist rises, but on following this westward a mile beyond Rattlesnake Cañon a large alluvial fan is found to be broken along the same line with uplift on the south. The upper portion of this fan extends southeastward into the hills and was evidently the mouth of Rattlesnake Cañon in former times. It is now being rapidly dissected, but its original features are still preserved and the break along the north flank is still clear (pl. 23A).

From Rock Corral a scarp extends to the southeast beyond the limits of the quadrangle and to the northwest two miles beyond Old Woman Springs. The stream channels on the plateau southwest of Rock Corral pursue very tortuous courses until they nearly reach the top of the escarpment, where they plunge down precipitously. This discordance is equally clear southeast of Old Woman Springs, where a flat bench of granite and basalt rises suddenly above the desert floor. Old Woman Springs are on this line and the water from them is warm, about 20° C. While this temperature is not very high, it is sufficient to indicate a deep source such as a fault might tap. Another spring is found on the same line about a mile northwest of Old Woman Springs. All this evidence is in agreement and points to the same thing: the scarp is the result of a movement on a fault.

It is interesting to note that in the desert there are several faults parallel to that just described. One of these extends from Box S Springs northwestward beyond Rabbit Springs. That this is a fault is suggested by the numerous springs located along the line. Furthermore, the physiography shows a slight uplift on the southwest side.

Another scarp extends along the northeast of the long hill six miles northeast of Old Woman Springs. The southwest approach to this hill is very gentle, but on the northwest it presents a steep granite wall. It is also of importance to note that this lines up with another long hill six miles farther southeast and with a group of hills three miles south of Means Wells. These last also have a gentle approach from the southwest, but drop off steeply on the northeast. Besides the evidence which it in itself presents we must also consider the fact that this scarp parallels that from Cushenbury Springs to Rabbit Springs and that through Old Woman Springs. It therefore fits in with a general system of northwest-southeast faults.

Another fault which may belong to this system is found along the southwest side of Fry Mountain. This mountain is capped with basalt which slopes 15° to the north and is continuous with a flat area more than two miles in length. At its highest point the basalt is about a thousand feet above other areas to the south and in the vicinity of Negro Butte to the southwest. But this uplift did not take place as one progressive movement. On the upper part of this hill, extending southeastward from the peak and just below the crest of the ridges, there are remnants of an old valley with stream beds of low gradient. This part of the drainage system of the hill is in marked contrast with the southwest margin, where the stream beds drop off precipitously through steep narrow cañons. It is therefore certain that during the uplift of Fry Mountain there was a period of rest, and this was near the beginning of the movement. That the major uplift is of comparatively recent date is shown by the geomorphic discordance.

The big hill two miles northwest of Means Wells is probably a recently upthrust block. This conclusion is based partly on its physiographic resemblance to Fry Mountain. Although no remnant of an old surface was seen near the top, the precipitous nature of the drainage on all sides is very similar. Furthermore, its alluvial fans are poorly developed while those in the hills to the northeast are very large even though the hills themselves are small. So, this hill can hardly be an erosional remnant of an extensive block, but must represent a recent local uplift.

Several other small faults are shown by offsetting of areas of basalt. Negro Butte is a granite hill with a basalt covering sloping about 30° southwest. Two miles farther east three small areas of basalt resting on granite also dip to the southwest in such a manner as to suggest faulting (fig. 8). The hill four miles northwest of Old Woman Springs is capped with basalt which lies horizontally and just south of this hill and 300 feet lower there are two other small areas. This relationship is probably due to faulting. The age of this faulting is hard to determine, but it is probably earlier than that described above. This is suggested by the development of an old surface just below the top of Fry Mountain. This indicates that the uplift was in two stages and the first was of about the same amount as the offsetting of the basalt to the southwest. There is also a nearly north-south fault through Fry Mountain by which the basalt cap has been broken, so that it is possible that all of this minor faulting was effected at an earlier period than the uplift of the old surface on Fry Mountain.

The most interesting fault in this region is the San Andreas, since it has been the locus of many movements resulting in severe earthquakes, notably those of 1857 and 1906.[23] About twenty miles west of this quadrangle the fault cuts diagonally between the San Gabriel and San Bernardino ranges and then skirts the south side of the latter, as is evidenced by the steep wall which the mountain mass presents

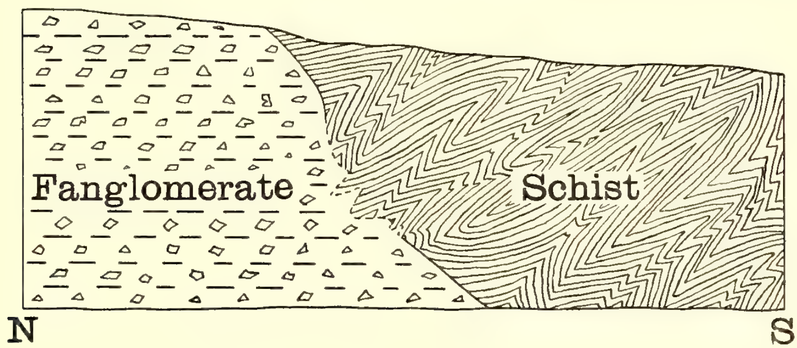


Fig. 10. Overthrust on the east side of Stubby Cañon at its mouth.

to the San Bernardino Valley. The physiographic expression (see map) can be readily followed along Potato Cañon to Oak Glen and thence a mile east of Pine Bench. Here the trace of the fault is lost from sight for nearly two miles, but is again seen on the north side of the valley at the head of Hathaway and Potrero cañons and along the West Branch of Millard Cañon.

Crossing Millard Cañon, it is again lost until about two miles west of Stubby Cañon, where definite displacement can be seen. Here the Hathaway sediments abut upon the schists with a nearly vertical contact; but just west of Stubby Cañon the dip of the fault plane is 70° to the north, so that the schists on the north override the fanglomerates on the south. Since the schists are the older, it is apparent that the fault is a thrust. On the east side of the cañon a block of gneiss on the south has been faulted up against Cabezon fanglomerate resting on gneiss on the north. From Stubby Cañon eastward to Cottonwood Cañon the position of the San Andreas fault cannot be exactly determined. Only in a few places can the more recent sediments be seen

[23] Report of the State Earthquake Investigation Commission upon the California earthquake of April 18, 1906, Carnegie Institution of Washington, D. C., 1908.

faulted against the schist, and these are south of the main fault according to its alignment east of Cottonwood Cañon and west of Stubby. They do, however, line in with another fault on the east side of Stubby Cañon south of the main fault. By another small fault farther south schist has been overthrust on the fanglomerate from the south at an angle of about 40° (fig. 10). The schist has been badly crushed and slickensided within itself and only at the bottom of the exposure is the contact sharp. It thus appears that there are several minor blocks along the fault zone.

Between Cottonwood and Whitewater cañons two straight streams mark the line of dislocation. North of this sharp line the rocks are schists and gneisses, while fanglomerate is found on the south side. The rocks south of Painted Hill have been displaced, but because of their lithologic similarity the exact nature of the disturbance was not determined.

There is an east-west fault between San Gorgonio and Millard cañons just north of the two hills at the mouth of Hathaway Cañon. Along this, between Hathaway and Millard cañons, the schists and gneisses on the north have been raised into juxtaposition with the Cabezon fanglomerates on the south. East of Millard Cañon the Deep Cañon fanglomerate and Hathaway sediments have this same relationship. Two miles west of Stubby Cañon the fault joins into the San Andreas fault.

At the head of Hathaway Cañon is a large open valley formed, at least in part, by faulting. The line of dislocation on the south is marked clearly by the straight eastern branch of Hathaway Creek, which separates the high ridge of schist on the south from the low south-dipping Cabezon fanglomerates on the north. Furthermore, the parallel streams flowing to the south indicate tilting. On the north side of the valley is the San Andreas fault. The western limit of the block is perhaps just west of Hathaway Creek and the eastern the east side of Potrero Cañon; but these relations are not entirely clear. The floor of the northern part of the valley is of schist and gneiss and is rather rolling. In a region of such rugged topography it is difficult to conceive of such a valley as formed by erosion. In consideration of other signs of faulting it is far more probable that a portion of an old surface has been dropped downward with respect to the surrounding country.

There is evidence of a fault along the south front of the hills from a point two miles east of Whitewater Cañon to a point two miles west of San Gorgonio Cañon. North of this, Cabezon fanglomerate lies above the floor of the San Gorgonio Pass. If this were entirely due to erosion we should expect to find similar rocks at the same elevation on the south side of the pass, but such is not the case. The alignment of the south side of the fanglomerate hills is even more suggestive, the rectangular outline of the block west of Whitewater Cañon being particularly noticeable. The absence of such an area immediately east of Stubby Cañon is probably due to the down-faulting of a block. Further evidence of this fault south of Banning Height lies in the fact that all streams wash the opposite side of the pass. The bench has not been produced merely by streams cutting the pass down and leaving the bench as a terrace. Also, on the opposite side of the pass, south of Beaumont, the slope of the pass grades into the hills, just as those on the bench grade into the surrounding hills. If the scarp were purely an erosional feature, we would expect to find one on the south side of the pass similar to that on the north.

The evidence thus adduced indicates, not only the presence of the fault, but that there has been rather recent movement with downthrow on the south side. This is of little importance, however, as compared to earlier movements by which a great block was raised to form the San Jacinto Mountains. South of Whitewater these present a bold scarp rising about 9000 feet above the floor of the pass. Toward the west the height of this scarp gradually diminishes and south of Beaumont it is insignificant. The San Jacinto Mountains slope to the southwest, the sloping surface being of low relief and in marked contrast to the rugged declivity to the north. It therefore appears that the San Gorgonio Pass was formed by a narrow graben between the San Bernardino and San Jacinto mountains. Since the degradation of the fault scarp on the south side of the pass the down-dropped block has risen somewhat with respect to the San Jacinto block. Therefore the present floor of the pass is to the south of the original.

The south side of the range east of Mission Creek is a degraded fault scarp, as is shown by its remarkable straightness and the fact that when the line is continued to the west the fault itself may be seen. Looking east from the crest of the ridge a quarter of a mile northeast of Hog Ranch, a decided depression may be seen between the fanglomerate and the schists. On the west side of the first small ridge the fault is distinct and on it the schists have been overthrust on the softer fanglomerate, the dip of the fault plane being 65° to the north (fig. 11). On the west side of Mission Creek the fault trace follows up a cañon with fanglomerate on the south and schist on the north and descends the west side of the ridge through a similar cañon.

On the east side of a small ridge three miles west of Mission Creek fanglomerate dips sharply down against a vertical contact with the schists which have been raised on the north.

Farther west this fault is in alignment with a branch of Whitewater River and then with Mill Creek, which is remarkably straight despite the heterogeneous character of the rocks on either side. The ridge on the north has a long even crest regarded as a remnant of an old surface. That on the south side is also rather even, but is 2000 feet lower. The crest has gently rolling hills and inclosed basins which are certainly abnormal in their present position. Headward erosion could hardly reduce a ridge to such an extent still maintaining an even crest. Of course there is the possibility that at an earlier

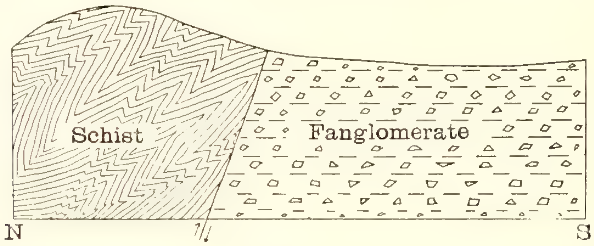


Fig. 11. The Mission Creek fault northeast of Hog Ranch showing schist overthrust on fanglomerate.

date in the history of the topography of the mass this outer edge of the block was reduced nearly to base level before the northern ridge was attacked. Bearing in mind the other evidence of faulting, however, it seems probable that it was never raised to the same height as the north side. If, then, the present relationship is due to faulting, differences in elevation on the map show that the ridge between Potato Cañon and Mill Creek has been raised 3000 feet, and the ridge north of Mill Creek 5000 feet above the floor of the San Bernardino Valley, which lies to the west just off the map. This valley floor is not a portion of the surface which was once continuous with the crests of the ridges, but consists of sediments from the surrounding mountains. The old surface itself is probably buried beneath them. It is therefore evident that the elevations of the ridges above the present valley floor do not represent the total uplifts of the blocks nor can these be exactly determined.

The divide between Mill Creek and Whitewater was examined for evidence of displacement of rocks by faulting, but as the whole country rock is schist these observations were not entirely satisfactory. Comparing the rocks on either side of Mill Creek at this point, it is to be observed that those on the north strike N 35° E and dip 40° NW while those on the south strike N 45° W and dip 50° SW; the schists on the north seem almost entirely fine-banded while some strata on the south are as much as two feet thick; the general color effect presented by those on the north is a medium dead grey while those on the south have a decided bluish cast. These differences, particularly those of strike and dip, are such as can best be explained by faulting.

At the mouth of Big Morongo Creek there is a triangular block of fanglomerate jutting into the range. That it has been dropped in by faulting is evident; for the fault contacts with the schists are easily seen on the north and east sides. The northern fault cuts across Big Morongo Creek and dips 75° north so that the schists are overthrust on the fanglomerate, which here dips 5° to 10° to the north. Farther east the latter is warped so that the dips vary from horizontal to 28° south. The southeast side of this block is along the Mission Creek scarp and it seems likely that it is the result of a subordinate movement associated with the greater fault.

The Mission Creek fault is of further interest because of its association with the San Andreas. In the uplift of the ridge between San Gorgonio and San Bernardino peaks there has been movement on both faults while to the northwest only the San Andreas was active and east of Dry Morongo Creek only the Mission Creek. It thus seems probable that the latter represents the eastern continuation of the same line of weakness in the earth's crust as the San Andreas. Details of the adjustments between these two faults are not clear, but there is reason to believe that there is a fault down Stubby Cañon and another down Whitewater, and there may be others.

Stubby Cañon is remarkably straight and lines up with another which drains to the north. In consideration of the heterogeneity of the rocks, this, while not conclusive, suggests faulting. No actual displacement could be observed in any strata, but on the other hand no particular mass of rock could be followed across the cañon. There is even more evidence of a fault down Whitewater Cañon. On the west side the metamorphic rocks rise rather abruptly to a considerable height above the basalt and Coachella formation on the east. Furthermore, the latter is itself much faulted (pl. 22A).

In Santa Ana Cañon there has been faulting the nature of which is not entirely clear. The presence of the Santa Ana sandstone-shale formation at the bottom of a deep cañon with steep walls of granite and gneiss cannot be explained in any other way since such sediments are deposited only in a country of low relief. This formation consists largely of beds of coarse sandstone of granitic detritus from 5 to 6 feet thick, between which are finely laminated shales and some calcareous streaks. That these are in an abnormal position is shown by the fanglomerate, containing huge blocks of granite over 8 feet across, which overlies them unconformably, and is the normal accumulation to expect in this position. The sandstone and shale have been tilted to dips up to more than 30°, and this consideration alone is proof of some sort of orogenic disturbance. There are two hypotheses as to the nature of the faulting by which these sediments reached their present position: first, the whole mountain range is an overthrust block and the sandstone is exposed through a "fenster"; second, the sandstone is part of a graben. The evidence at hand favoring the overthrust hypothesis is very meager. An overthrust block of sufficient magnitude to bring the sandstone to the bottom of Santa Ana Cañon from either the north or south sides would require a strong backing; but the San Bernardino Mountains rise rather abruptly with no such support on either side. On the other hand, the possibility of the sandstone having been faulted downward has much in its favor. All the large faults in the region are practically vertical. The mountain range itself has been raised between faults on the north and south sides. The faults in the desert to the north are also vertical. Since vertical faulting is so prominent a feature in the structure of the range, it seems most probable that in some way the Santa Ana sandstone-shale formation has been dropped relative to the schists and gneisses on either side. This has been shown on the map by a simple fault on each side of the cañon, but in reality there may be a very complicated system of faulting.

There is some evidence of a fault along the north side of Bear Valley. As compared to the south side and to the sides of Holcomb Valley, it is rather straight. The most suggestive fact, however, is that Holcomb Valley, which resembles Bear Valley in its topographic development, lies 600 feet higher. Van Dusen Cañon and the cañon just east of Poligue have cut back from Bear Valley with steep gradients and now tap Holcomb Valley. These facts certainly point to faulting as explanation, although they do not actually prove the case.

The nature of the faulting of the region may best be understood from a consideration of the topography. This clearly points to a progressive movement by several stages. The several fanglomerates along the south front of the range with their unconformities confirm this record.

In addition to the faulting there is another structural feature of great importance, a general uplift or doming of the whole region. The upper portion of the mountains, the pass on the south, and the desert on the north all slope gently to the southeast. The Lion sandstone is of marine origin and not older than lower Pliocene, but it now lies at an elevation of about 2000 feet. This merely proves that the uplift is later than lower Pliocene, but other considerations indicate that it is probably very recent. Such orogenic disturbances as general uplift and faulting usually go together. The youthful nature of the mountain mass shows that the faulting must be very recent and therefore suggests that the general uplift of the region is also recent. The divide in the San Gorgonio Pass is at Beaumont. To the west is San Timoteo Cañon, which has cut back until it taps the pass a mile from the town. Several other cañons have reached the pass from the south in a similar manner. This cutting still continues with the aggressiveness of youth, while if the uplift were of ancient date this upper part of the pass would have been cleaned out. It therefore seems probable that the general uplift of the region as well as the faulting which has given rise to mountains must be recent, and, indeed, it may still be under way.

Summary.—The older sediments of the region have been folded and faulted and then intruded by granitic rocks. The resulting structure has been further complicated by other granitic intrusions. In Bear Valley, and immediately to the north and east, there are considerable areas of the older sediments, some of which were probably roof pendants. Farther east, on the Saddlerock plateau, the older granites are found in such relationships to the younger as to suggest that they formed a roof over the latter at the time these invaded the country. South of Antelope Creek and Santa Ana Cañon the structural relationships of the older rocks are too complicated for description.

The unaltered Tertiary sediments along the south flank of the mountains are considerably folded and faulted and dips as high as 70° are found.

The San Bernardino Mountains owe their existence as such to a great system of Quaternary faults, which also extends into the Mojave Desert to the north. Most of these faults are evidenced by scarps, some of which are rather imposing. On the north side of the mountains a fault extends eastward from Silver Creek to Blackhawk Cañon and another from Blackhawk Cañon southeastward to Rattlesnake Cañon. North of the latter a somewhat smaller fault, striking east-west, passes through Two Hole Spring. Another passes through Old Woman Springs and southeastward beyond Rock Corral. Approximately parallel to this are several others: one extending from Box S Springs to Rabbit Springs; another along the southwest side of Fry Mountain; another extending northwestward from a point one and one-half miles southwest of Means Wells; one just north, and three about two miles east of Negro Butte.

The San Andreas fault skirts the south flank of the main mountain mass, passing in a southeasterly direction along Potato Cañon to Pine Bench, and then on to the mouth of Lion Cañon, thence nearly due east beyond Whitewater River. South of this fault, and striking nearly east-west, there is another bordering the lowermost foothills. Between these two faults are several of less importance. North of the San Andreas fault, and approximately parallel to it, is the Mission Creek fault extending entirely across the area mapped. The eastern portion borders the south flank of the mountains and is of some importance, while immediately to the south the San Andreas ends. Thus it may be that the Mission Creek fault, as it continues eastward, marks the same line of weakness as does the San Andreas to the northwest. Between the two are smaller faults probably representing adjustments.

The Santa Ana Cañon was, in part, formed by faulting, the exact nature of which has not been fully worked out. The lines mapped merely represent the general effect, but the actual faulting was probably somewhat complex. The outlines of the structure are indicated in the stereogram, figure 12.

Another important feature is a general uplift, or doming, of the whole region. This is best evidenced by the youthful aggressiveness with which erosion is removing the floor of the San Gorgonio Pass at the heads of several small cañons west and south of Beaumont.

Geological History

In pre-Cambrian time there was a great invasion of granites in the country now occupied by the San Bernardino Mountains and the portion of the Mojave Desert immediately to the north. Erosion removed nearly all the overlying rocks and in lower Cambrian time the ocean advanced over a granite floor upon which were deposited sands now represented by the quartzite in the Iron Mountains and near Oro Grande. The Arrastre quartzites in the San Bernardino Mountains are believed to be of the same age.

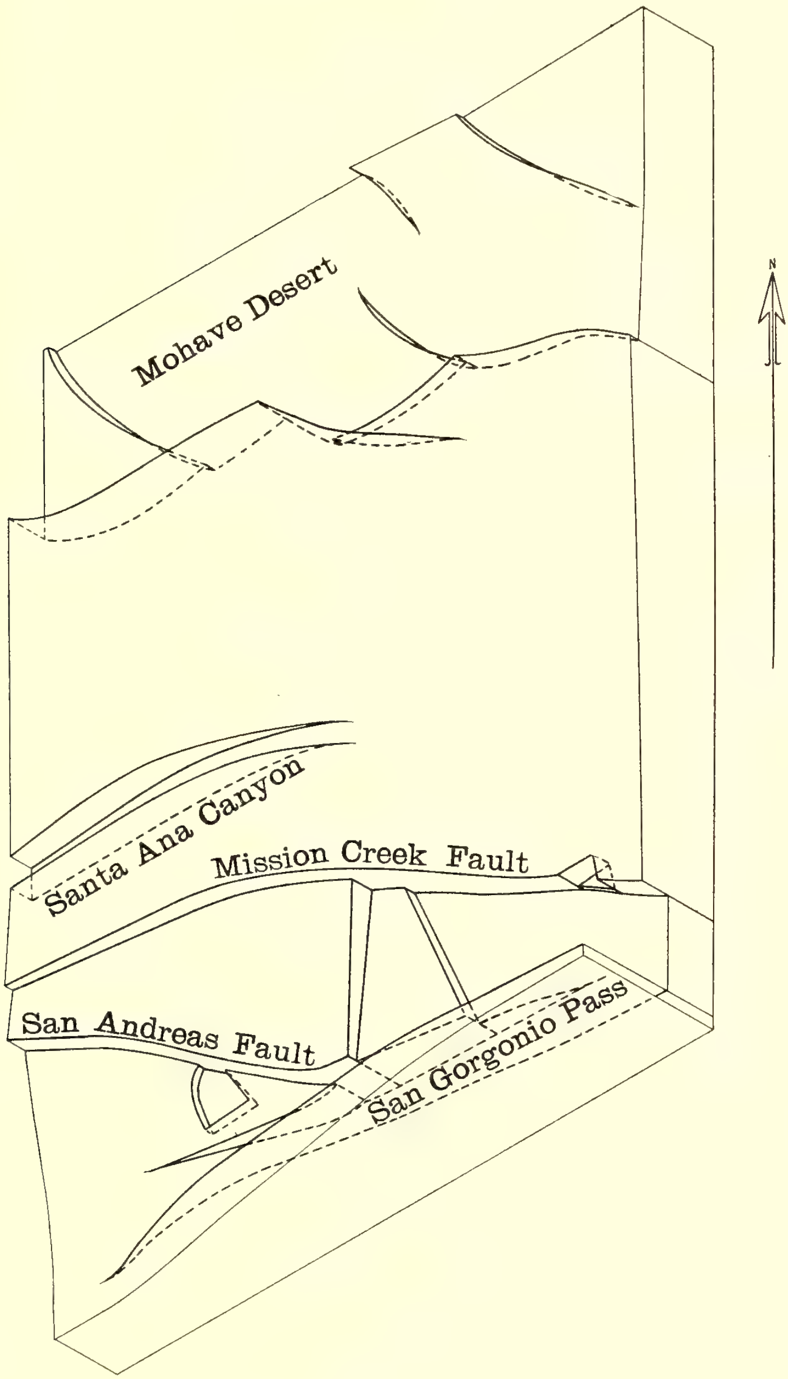


Fig. 12. Stereogram of San Bernardino Mountains.

During upper Cambrian and Ordovician time the area of deposition was far from land and the Furnace limestone was deposited. In Silurian or Devonian time there was a general uplift followed by continued sinking and deposition of sands, grits, conglomerates, and other shallow water sediments.

The next events of which we find any record were granitic intrusions of two periods, one possibly post-Carboniferous, the other Jurassic. The latter was accompanied or closely followed by mineralization along many of the contacts between the igneous and the sedimentary rocks. Some of the mineral deposits contained ores of gold, copper, lead, zinc, and tungsten and will be described on another page. Along with the granite intrusions were profound movements and intense metamorphism of the involved rocks.

There is no record of Cretaceous or early Tertiary sedimentation, probably because erosion was taking place which removed the covering from great areas of granite. It is barely possible that in Miocene time the Potato sandstone was laid down. In Pliocene time, probably in lower Pliocene, the Gulf of California extended northward into the region of the present San Gorgonio Pass and sandstone was deposited. By uplift this became isolated from the sea and the lower depressions became playas. As the movement continued fanglomerate from the neighboring hills covered the playa silts. The whole region was reduced to a surface of low relief and basalt flowed out over the level surface.

In Quaternary time the country was subjected to stresses to which the rocks yielded by faulting and a great block began to rise which eventually became the San Bernardino Mountains. The uplift was not continuous but by progressive stages with periods of rest, some of which are still to be found recorded in the topography. Simultaneously the streams cut deep cañons in the block and great beds of fanglomerate, consisting of the transported débris, were deposited along the flanks of the range. The mountains reached a great height and, despite the fact that the general climate of the region was arid, by their intercepting the moisture in the upper atmosphere they received a precipitation equal to that of a humid climate. Glaciers were even developed along the north side of the crest of the highest ridge, but they were of short duration because of the increasing mildness of the climate; but even yet a little snow remains on the higher slopes throughout the year.

ORE DEPOSITS

In the late sixties the search for gold in California led a few prospectors far from the better known fields of the Sierra Nevada and some eventually found their way to the San Bernardino Mountains. Gold was found in the gravels of Holcomb Valley and resulted in a sudden inrush of miners for its exploitation. It is said that more than $7,000,000 worth of the precious metal was taken out, and that this small valley once had a population of more than three thousand. It is now practically deserted.

Naturally the enthusiasm of these pioneers led them to search for the original source of the gold and many tunnels were driven into the surrounding hills; but, although gold can be found in many places, no real mines were discovered. Only a few of the prospects were examined by the writer. A small quartz vein in the granite on the southeast side of Union Flat contains small amounts of pyrite and galena and also a little gold. In Van Dusen Cañon gold is associated with pyrite, chalcopyrite, galena, and sphalerite near a contact between granite and limestone.

On the SE ¼, Sec. 30, T. 3 N, R. 1 E, gold is found in quartz veins with pyrite, galena, and sphalerite. The country rock is limestone striking N 60° W and dipping 40° SW, and is cut by granitic dikes with which the veins are associated. In one case a fine-grained hornblende-diorite dike nine feet thick follows the bedding of the limestone a short distance and then dips more steeply, thus cutting diagonally across it. Along the under side of this dike is a quartz-galena vein about six inches thick, the galena being in the central part. The gold is often found in some of the veins in calcite as pellets weighing as much as two grams. In contrast with most California gold, that found in this region, both in the veins and in the gravels, is remarkably free from silver, seldom containing as much as 2 per cent.

In Wild Rose Cañon there has been considerable mineralization along a granitic dike. Wollastonite and especially tremolite are common, some fibers of the latter attaining a length of more than four inches. Other minerals present are pyrite, chalcopyrite, and a little gold. Some malachite and azurite are found in the shallow oxidized zone.

A quartz vein just below Monarch Flat has been prospected for ore. A specimen from the dump consists of an almost solid mass of pyrrhotite and galena in equal amounts with smaller quantities of pyrite and chalcopyrite.

Greenlead Camp was once a prosperous mining camp, but it is now abandoned. Gold was mined from deposits along the limestone-granite contact, where it was found in quartz veins with pyrite, chalcopyrite, and galena.

A somewhat different occurrence of gold is found half a mile northwest of Doble, where a quartz vein over forty feet thick cuts the Saragossa quartzite. All through the vein there is slickensiding parallel to the dip which is 54° SW, the strike being N 40° W. The quartz contains limonite, some of which is in the form of cubes, evidently pseudomorphic after pyrite. The ore is free-milling and runs about $3 per ton, but the quantity is limited by a low-dipping fault which cuts off the vein about fifty feet below its outcrop on the summit of the small hill.

The Rose Mine is in the Furnace limestone, which at this locality is nearly vertical and is cut by dikes of fine granitic rock containing quartz, biotite, and a feldspar so decomposed as to be indeterminable. These dikes vary in thickness from less than a foot to more than twenty feet (pl. 23B), and the adjacent limestone is often pure white and coarsely crystalline, individual crystals being a centimeter long. The ore occurs as veins and irregular discontinuous bodies following the general trend of the dikes sometimes wholly within and more often without, but never far from the contact. The minerals in the ore bodies are quartz, pyrite, chalcopyrite, cuprite, azurite, malachite, galena, hematite, and gold. The value is gold, which often occurs as beautiful delicate moss and fernlike masses in cavities in the quartz. The tailings have recently been reworked and ran from $3 to $4 per ton, thus showing that some of the gold was in too intimate association, probably with the pyrite, to be entirely free-milling. The mine was sunk to a depth of a thousand feet, but the nature of the lower levels is not known.

Numerous small tunnels are also found in this vicinity, and it is said that mines were worked here under the Spanish rule. On the southeast side of Round Valley there are about a dozen arrastres now overgrown with brush, and their presence lends support to this statement.

Contact minerals are found on the east corner of the triangular area of limestone two miles south of the Rose Mine. Most of these deposits occur as irregular patches of different sizes up to eight feet long by four feet thick along the contact between the granite and limestone. The latter overlies the granite and is somewhat broken up and dips in all directions but at low angles near the largest contact deposits. The minerals are garnet, quartz, a little biotite, and epidote, the latter usually being the most prominent. A specimen examined in thin section was found to contain about equal amounts of quartz, epidote, and calcite with small granules of a uniaxial mineral having a high refractive index and birefringence. This answers to the description of scheelite, and some of the crushed material was panned for further examination. A white concentrate was obtained which turned canary yellow upon the addition of hydrochloric acid. It turned blue when boiled with tin, thus verifying the conclusion from the optical tests that the mineral is scheelite. This paragenesis is of particular interest in that it is unique, no other of similar nature having been reported heretofore.

The deposits are usually right at the contact and quartz is most strongly developed on the granite side, but in one place the deposit was wholly within the granite and the quartz was found on both sides. Several small pegmatite dikes cut the granite, and it seems that where these come in contact with the limestone the scheelite is most abundant. It was noticed that in some cases the pegmatite extends a short distance into the limestone and along these dikes the contact minerals are found even when the pegmatite is hardly more than a stringer. No tremolite was found actually in these deposits, but in fissures in the limestone near by.

There is a small mine on the north side of the small hill east of Rattlesnake Cañon where it turns north. It has been driven into the schists and follows small stringers of quartz containing free gold.

PLATES 17–23

A.—Summit ridge from San Gorgonio Mountain to San Bernardino Mountain as seen from Gold Mountain. Part of Bear Valley in the foreground.

B.—Basalt-capped hills east of The Pipes.

A.—Hills south of The Pipes.

B.—Profile of hill south of The Pipes.

Bear Valley showing east end of Bear Lake.

A.—Remnant of old valley floor in Santa Ana Cañon one mile west of Seven Oaks.

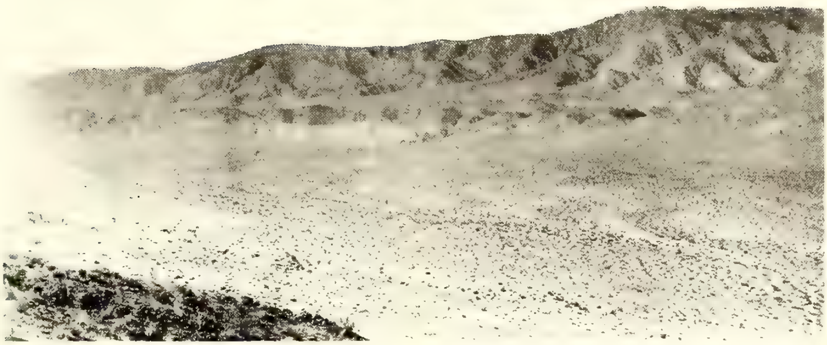
B.—Rocky ridge in the Bluff Lake country, showing rugged nature of the ridges between the meadows.

A.—Ridge and remnant of valley floor south of Raywood Flat.

B.—Ridge south of Raywood Flat.

A.—The Coachella fanglomerate; looking up Whitewater Cañon.

B.—Scarp on north front of the range between Crystal Creek and Silver Creek.



A.—North front of the range west of Rattlesnake Cañon; showing two approximately parallel fault scarps.

B.—Prospect southwest of the Rose mine; showing fine biotite granite intruding limestone.

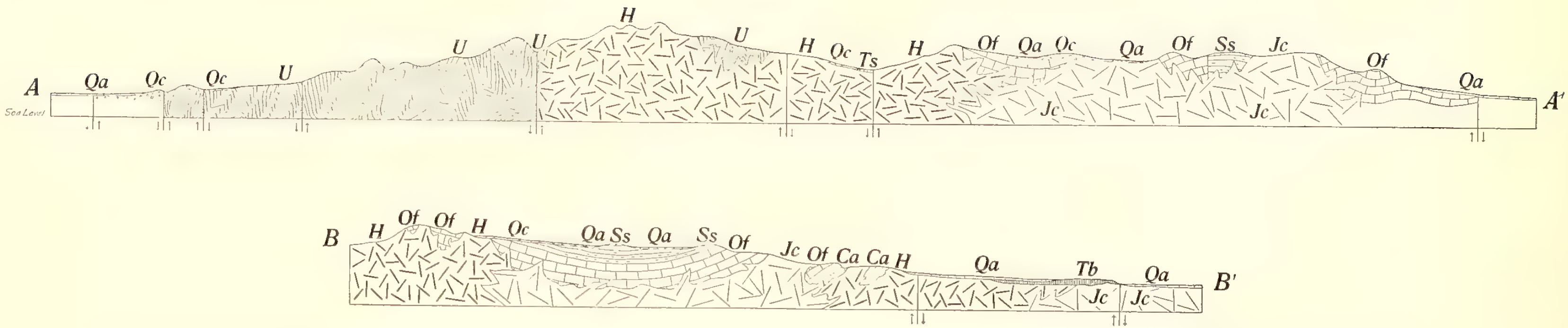


Fig. 13. Geologic structural sections through the San Bernardino Mountains along the lines *A–A′* and *B–B′* indicated on the geological map.

Qa: Alluvium.
Qc: Cabezon fanglomerate.
Ts: Santa Ana sandstone.
Ss: Saragossa quartzite.
Of: Furnace limestone.
Ca: Arrastre quartzite.
U: Undifferentiated schists.
Tb: Basalt.
Jc: Cactus granite.
H: Heterogeneous granite.

Scale: 1/4 inch = 5280 ft.

GEOLOGICAL MAP OF SAN BERNARDINO MOUNTAINS

By FRANCIS EDWARD VAUGHAN

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NEW SPECIES FROM THE CRETACEOUS OF THE SANTA ANA MOUNTAINS, CALIFORNIA

BY

E. L. PACKARD

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NEW SPECIES FROM THE CRETACEOUS OF THE SANTA ANA MOUNTAINS, CALIFORNIA

BY
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CONTENTS

INTRODUCTION

The rich invertebrate fauna collected by the writer in the Santa Ana Mountains of Southern California contains a number of molluscan species that appear to be new to science. These 34 species are herein described together with a few notations on other forms from the same region.

The general geologic and palaeontologic features of this region have already been presented by Dickerson,[1] and in 1916 a detailed discussion of the Cretaceous strata and contained fauna was published by the writer.[2]

Three faunal zones were recognized within the Chico of this region, by the writer, and were named after distinctive fossils: the Tellina ooides zone, the uppermost horizon, the Turritella pescaderoensis zone, the middle horizon and the Actaeonella oviformis zone the lowermost horizon. The oldest fauna ranges through about 350 feet of coarse sediments, the next oldest occurring within the overlying 900 feet of strata and the youngest ranging through the uppermost 300 feet.

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[1] Dickerson, R. E., The Martinez and Tejon Eocene and associated formations of the Santa Ana Mountains, Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, pp. 257-274, pls. 26–28, 1914.

[2] Packard, E. L., Faunal studies in the Cretaceous of the Santa Ana Mountains of Southern California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, pp. 137-159, 1 map, 1916.

THE CRETACEOUS FAUNA OF THE SANTA ANA MOUNTAINS

The fauna obtained from the Cretaceous of the Santa Ana Mountains includes aproximately 136 forms: 62 determined species and varieties of pelecypods, 22 of gastropods, 1 scaphopod, 3 cephalopods, and 2 echinoderms, besides 45 undetermined forms belonging to those groups and to the Molluscoidea, Vermes, Arthropoda, and Vertebrata. To this number we may add 17 more that have been reported from this region by other workers.

DESCRIPTION OF LOCALITIES

Univ. Calif. Loc.

2130 Four miles SE of B. M. 1271, Corona sheet. About ¼ mile north of Joplin's house on the west side of the cañon. Elevation 2200 feet.

2134 One mile N 45° E of B. M. 1271, Corona sheet. On crest above the reservoir in Harding Cañon. Elevation 1850 feet.

2135 One-quarter mile N 15° E of B. M. 1271, Corona sheet. In a small gully on the right side of Santiago Cañon. Elevation 1300 feet.

2136 Two miles N 38° E of B. M. 1271, Corona sheet. Near crest of ridge nearly north of fork of road in the cañon.

2138 About one-half mile NNE of B. M. 1271, Corona sheet. Right bank of Williams Creek, about 100 feet above Modjeska Springs (Mr. Burson's house). Just above basal conglomerate.

2141 Two and three-quarters miles N 6° W of B. M. 1271, Corona sheet. Left side of Silverado Cañon, in sandstone just above the basal gray conglomerate. Elevation 1200 feet.

2142 Two and one-quarter miles NNW of B. M. 1271, Corona sheet. Left side of Silverado Cañon, in shales undercut by the stream about 200 feet southeast of the road.

2143 Two and five-eighths miles N 10° W of B. M. 1271, Corona sheet. East side of Silverado Cañon, opposite the first house below the narrows in the cañon. Elevation 1200 feet.

2144 Three and one-quarter miles N 9° W of B. M. 1271, Corona sheet. East side of first north cañon from the house near the basal conglomerate in Santiago Cañon. Just below the lower Chico shales. Elevation 1400 feet.

2149 One and five-eighths miles S 70° E of B. M. 610, Corona sheet. On ridge between Santiago and Sierra cañons. Elevation 1100 feet.

2151 One-half mile N of B. M. 1271, Corona sheet. Ridge southeast of the cañon occupied by a road. Specimens possibly from a piece of Chico float. Elevation 1600 feet.

2155 Three and three-eights miles S 65° E of B. M. 610, Corona sheet. One-half mile from mouth of Black Star Cañon. Chico float.

Univ. Calif. Loc.

2157 Santiago Cañon, Corona sheet. Chico float from stream bed just above Williams Cañon.

2158 One and seven-eighths miles N 4° W of B. M. 1271, Corona sheet. On crest of ridge on north side of a small cañon about 600 feet from Pleasant's house. Elevation 1650 feet.

2162 Four and one-eighth miles N 11° W from B. M. 1271, Corona sheet. Roadside on the west side of Baker Creek where the road crosses the creek west of the house at the end of the road. Elevation 1100 feet.

2166 Three and three-quarter miles S 70° E of B. M. 610, Corona sheet. One thousand feet from the road in the first cañon north of the bee-house in Black Star Cañon. Elevation 1100 feet.

2167 Two miles N 10° W of B. M. 1271, Corona sheet. At a gate about one-half mile below Modjeska Springs in Williams Cañon.

2168 Three-fourths mile S 52° E of B. M. 1271, Corona sheet. On the top of a hill about one-half mile north of the road at the Santiago-Aliso divide. Elevation 1400 feet.

2169 One-half mile S 50° E of B. M. 1271, Corona sheet. On crest of Santiago-Aliso divide, about one-fourth mile north of the road.

2171 Four miles SW of Corona, Corona sheet. At clay mine, 200 feet up the cañon from a cabin.

2177 Three and one-half miles N 53° E of B. M. 610, Corona sheet. On left side of Sierra Cañon at junction with a small cañon.

2179 One mile N 20° W of B. M. 1271. Froat from creek bed.

2209 Sucia Islands, San Juan County, Washington.

DESCRIPTION OF SPECIES

Class **PELECYPODA**

Family Parallelodontidae

Genus CUCULLAEA Lamarck

CUCULLAEA PONDEROSA Whiteaves

Cucullaea ponderosa Whiteaves, Geol. Surv., Canada, Mesozoic fossils, vol. 1, p. 393, 1876–1903.

Cucullaea truncata Gabb, Palaeontology of California, vol. 1, p. 196, pl. 25, fig. 82, 1864.

This species is represented in the Santa Ana fauna by a single fragmentary specimen. This specimen is less ventricose, has broader umbones, and is relatively thicker-shelled than the typical *C. truncata,* resembling more closely the large form figured by Gabb and called *C. ponderosa* by Whiteaves.

CUCULLAEA (?) CORDIFORMIS, n. sp.

Plate 24, figure 1

Type specimen 12311, Coll. Invert. Palae., Univ. Calif., loc. 2158.

Shell large, trigonal in outline, equivalve, nearly equilateral, height greater than length; widely separated, with narrow acute, incurving beaks. Anterior extremity broken, probably rounded, resembling the broadly rounded posterior end; base arcuate. Umbones very prominent. Dorsal area broad. The chevrons marked by widely separated diverging lines. Hinge line relatively short. Length, 64 mm.; height, 75 mm.; diameter, 70 mm.

The only other specimen (no. 12312) comparable to the type was obtained in beds stratigraphically lower at locality 2149. That form was much smaller and differed from the type in having adjacent beaks. This new species differs markedly from other known West Coast members of this family in the ventricose character of the umbones.

Horizon.—Chico group, Turritella pescaderoensis zone.

CUCULLAEA LIRATA, n. sp.

Plate 24, figure 2; plate 25, figure 3

Type specimen 12314, Coll. Invert. Palae., Univ. Calif., loc. 2149.

Shell large, elongate, inequilateral. Anterior extremity short, evenly rounded; posterior extremity pointed (?), accentuated by a prominent umbonal ridge; ventral margin straight. Umbones small, widely separated by a dorsal area. Posterior dorsal area flat. Shell sculptured by numerous radial striae and prominent concentric growth lines. Hinge line short, with dentition typical of the genus. Height, 53 mm.; length, 75 mm.; convexity, 28 mm.

Several specimens of this species have been found at three collecting localities. The species quite closely parallels both in form and sculpture *Trigonarca telugensis* Stoliczka from the Trichinopolophy group of India. The lack of spinose ribs will distinguish it from the Indian species even if the hinge is not visible.

Horizon.—Chico group, Actaeonella oviformis and Turritella pescaderoensis zones.

CUCULLAEA (?), sp.

A single specimen of a small form which may possibly represent *C. browersiana* Cooper was obtained from University of California locality 2142.

Shell equilateral, nearly circular in outline. Umbones low, nearly meeting above the dorsal area. Anterior and posterior ends evenly rounded. Hinge line long. Length, 36 mm.; height, 30 mm.; diameter, 26 mm.

Horizon.—Chico group, Actaeonella oviformis zone.

Trigonarca Conrad

TRIGONARCA CALIFORNICA, n. sp.

Plate 25, figures 2*a* and 2*b*

Type specimen 12313, Coll. Invert. Palae., Univ. Calif., loc. 2141.

Shell trigonal in outline, inequilateral, the posterior end being greatly produced; separated by a wide dorsal area; anterior end short, rather bluntly rounded; posterior end pointed; base line nearly straight, oblique to the hinge line. Umbones small, beaks acutely pointed; umbonal ridge extends from the beak to the posterior extremity. Area between umbonal ridge and posterior margin of shell flattened, and strongly depressed. Dorsal area deeply excavated, marked by at least five deeply incised chevron lines. Surface of shell sculptured by irregular lines of growth. Dentition consists of ten short, straight, posterior teeth, placed obliquely upon the hinge plate, and a less number of short, heavy, anterior teeth. Length, 52 mm.; height, 35 mm.; convexity, 15 mm.

In general form this species recalls *Cucullaea decurtata* Gabb, from which it differs in its less ventricose shape, more elongated posterior end, and its more pronounced umbonal ridge.

Horizon.—Chico group, Actaeonella oviformis zone.

TRIGONARCA EXCAVATA, n. sp.

Plate 25, figures 1*a* and 1*b*

Type specimen 12315, Coll. Invert. Palae., Univ. Calif., loc. 2141.

Shell large, elongate, inequilateral; posterior margin extends nearly straight from the hinge to the pointed posterior extremity. Beaks small, widely separated, situated about one-third the distance from the anterior to the posterior end; anterior margin produced, evenly rounded from the anterior end of the hinge line to the base. A pronounced umbonal ridge extends from beak to the posterior end. Ventral margin nearly straight and not parallel to the hinge line. Posterior dorsal area broad and excavated. Surface of the shell smooth except for a few incremental lines of growth. The hinge of the right valve with three heavy, straight, anterior teeth situated obliquely upon the hinge plate; posterior teeth, four in number, separated from anterior by sixteen small, nodular teeth perpendicular to hinge line. Length of type, 62+ mm.; height, 40 mm.; convexity, 25 mm.

This species resembles *T. brahminica* Forbes from the Arrialoor group of India, but it differs from that species in the absence of radial sculpture. Its more ventricose shape, longer anterior extremity, and its relatively larger teeth distinguish this species from *T. californica.*

Horizon.—Chico group, Actaeonella oviformis zone.

TRIGONARCA SECTILIS, n. sp.

Plate 27, figures 1*a*, 1*b*, and 1*c*

Type specimen 12316, Coll. Invert. Palae., Univ. Calif., loc. 2144.

Shell small, trigonal, inequilateral, ventricose, the diameter being nearly equal to length. Anterior extremity short, evenly rounded. Posterior dorsal side of the shell conspicuously flattened; basal margin nearly straight. Beaks small, widely separated. Posterior umbonal ridge sharply marked, extending to the bluntly pointed posterior extremity. The margins of the shell within this area pout, forming the boundary of a groove which extends from the beaks to the ventral margin. Five oblique anterior teeth, and apparently about the same number of posterior teeth on hinge of cotype. The teeth short, and transverse on the middle portion of the plate. Length of type, 43 mm.; height, 45 mm.; diameter, 40 mm.

This odd-shaped mollusk is represented by a number of specimens from localities within the Actaeonella oviformis zone. It is also found among the collections from northern California belonging to the University of Oregon.

Horizon.—Chico group, Actaeonella oviformis zone.

Family Limopsidae

Genus LIMOPSIS Sasso

LIMOPSIS SILVERADOENSIS, n. sp.

Plate 27, figures 2 and 4

Type specimen 12324, Coll. Invert. Palae., Univ. Calif., loc. 2143.

Shell small, thin, tumid, higher than long; nearly equilateral. Anterior dorsal margin slightly concave beneath the beaks; posterior margin convex, meeting the narrow base with an even curve; margins flattened. Umbones prominent, beaks pointed. Surface of shell apparently smooth; hinge of cotype edentulous, with a V-shaped ligamental pit and 5 to 7 denticulations occurring on both sides of the beak, on a low ridge extending ventrally as two curved lines which meet in a broad curve at a point about two-thirds of the distance from the beak to the base. Length of type, about 15 mm.; height, 17 mm.; convexity, 3 mm.

Horizon.—Chico group, Actaeonella oviformis zone.

Family OSTREIDAE

Genus OSTREA Linnaeus

OSTREA CRESCENTICA, n. sp.

Plate 26, figures 3 and 4

Type specimen 12318, Coll. Invert. Palae., Univ. Calif., loc. 2166.

Shell thick, rugose; upper valve with a pronounced ridge extending from the umbones to the ventral margin. Muscle scars not shown on the type. Length of type, 60 mm.; height, 68 mm.; diameter, 20 mm.

This oyster resembles *O. skidgatensis* Whiteaves and may later be found to fall within the range of variation of that species.

Horizon.—Chico group, all three zones.

OSTREA TAXIDONTA, n. sp.

Plate 26, figure 2

Type specimen 12317, Coll. Invert. Palae., Univ. Calif., loc. 2167.

Shell small, thin, irregular in shape; beaks turned anteriorly. Ligamental pit long and shallow; posterior internal margin of the shell denticulated near the beaks. Length of type, 25 mm.; height, 37 mm.; convexity, 8 mm.

Specimens from the same collecting locality indicate that this oyster has several points in common with the Recent form *O. lurida* Carpenter. The denticulations observed on the Cretaceous species, numbering about twenty, represent a primitive condition of the provinculum that is also retained by the Recent species. *O. acutirostris* Stoliczka also resembles this California species.

Horizon.—Chico group, all three zones.

Genus EXOGYRA Say

EXOGYRA INORNATA, n. sp.

Plate 27, figure 1

Type specimen 12284, Coll. Invert. Palae., Univ. Calif., loc. 2143.

Shell small, rather thin, smooth, very tumid, somewhat elliptical in outline; beaks large, conspicuously twisted; lower valve of the cotype is roughly circular, irregular, margins smooth. The upper valve of the cotype is similar to that of the type. Height of the type, about 35 mm.; length, about 25 mm.

Horizon.—Chico group, Actaeonella oviformis zone.

EXOGYRA CALIFORNICA, n. sp.

Plate 27, figure 5

Type specimen 12320, Coll. Invert. Palae., Univ. Calif., loc. 2143.

Shell small, much higher than long; irregular in outline. Umbones prominent with an umbonal ridge extending to the base. Surface marked by crude radiating ribs.

It is possible that this form is the same species as the specimen from Point Loma, California, that Gabb incorrectly determined as the eastern species *E. costata?*

Horizon.—Chico group, Actaeonella oviformis zone.

Family LIMIDAE

Genus LIMA (Bruguière) Cuvier

LIMA SUBNODOSA, n. sp.

Plate 28

Type specimen 12275, Coll. Invert. Palae., Univ. Calif., loc. 2149.

Shell very large, nearly equivalve; anterior dorsal margin sloping in a straight line from the beaks to a point about midway from the beaks to the base. Anterior end evenly rounded; base arcuate; posterior dorsal margin apparently curves convexly from the small beak toward the posterior extremity, which appears to be broken. Anterior ear long, the dorsal margin sloping slightly; posterior ear broken. Surface of the valve ornamented by numerous fine ribs becoming obscured toward the base by radial rows of nodes on some of the stronger ribs. These nodes extend from 3 to 5 millimeters above the surface from which they rise. Length of type, 140 mm.; height, 150 mm.; convexity, 30 mm.

Horizon.—Chico group, zonal position uncertain.

Family PECTINIDAE

Genus PECTEN Müller

PECTEN ?, sp.

Plate 27, figure 6

Type specimen 12321, Coll. Invert. Palae., Univ. Calif., loc. 2138.

An impression of a peculiarly sculptured form, presumably a pelecypod, was obtained at locality 2138. Its distinctive sculpture has not been recognized as occurring on any known Cretaceous species. The impression consists of about 18 grooves radiating from an apex, separated by flat-topped ridges, every other one of which is slightly more prominent. The grooves are pitted at frequent but irregular intervals, indicating that the radiating ribs bore many blunt spines. The outline of the impression is irregular, due to the state of preservation. It recalls that of a *Pecten,* except for the lack of the ears.

Horizon.—Chico group, Actaeonella oviformis zone.

Family SPONDYLIDAE

Genus SPONDYLUS Linnaeus

SPONDYLUS STRIATUS, n. sp.

Plate 29

Type specimen 12276, Coll. Invert. Palae., Univ. Calif., loc. 2149.

Shell very large, nearly oval in outline; inequivalve; beak of right valve small and pointed, that of the left valve apparently large and irregular. Anterior dorsal margin nearly straight but curving below the ear to meet the even curve of the base; posterior margin slightly concave near the beaks. Anterior ear of the right valve about 36 millimeters long. Shell of right valve about 10 millimeters thick, that of the left valve being somewhat thinner, due in part to a pitted condition of the surface apparently produced by a marine organism. Right valve ornamented by a large number of fine radiating ribs, which are ridged longitudinally and tend to become nodose toward the base of the shell. The lower (left) valve rugose, and apparently not so distinctly ribbed. Hinge and interior of the shell unknown. Length of type, 115 mm.; height, 145 mm.; diameter, 75 mm.

This species resembles a *Lima* in outline and in the characters of the upper (right) valve.

Horizon.—Chico group, Tellina ooides zone.

SPONDYLUS RUGOSUS, n. sp.

Plate 30, figure 3; plate 26, figure 3; and plate 29, figure 3

Type specimen 12277, Coll. Invert. Palae.; specimen 12322, Coll. Invert. Palae., Univ. Calif., loc. 2143.

Shell medium size, very inequilateral, inequivalve; right valve rather flat; left valve ventricose and very rugose. Outline of left valve irregular due to its nodose character. Umbone of left valve very tumid and irregular; umbone of right valve small. Ear long, equaling about one-third the height of the shell. Left valve ornamented by rough growth lines which are in places extended into irregular, lamellar processes, giving a very rough aspect to that valve. Right valve ornamented by numerous fine radiating ribs with imbricated spaces and interspaces. Hinge and pallial line unknown. Ventral margin finely crenulated. Length of type, 72 mm.; height, 95 mm.; diameter, about 40 mm.

The right valve of this species resembles that of the preceding species in general outline and convexity, but it differs from it in having imbricated instead of ridged ribs and in having a more conspicuously crenulated margin. Another specimen from locality 2143 has a more irregular left valve, with a portion of the right valve showing a small part of the surface covered with imbricated ribs. The inner margins of the left valve of that specimen are conspicuously crenulated from a point near the beak to the base of the shell.

The exact locality within Silverado Cañon from which the type specimen (no. 12277) was obtained is unknown.

Horizon.—Chico group, Actaeonella oviformis zone.

Family Pholadomyacidae

Genus HOMOMYA Agassiz

HOMOMYA HARDINGENSIS, n. sp.

Plate 32, figures 1*a* and 1*b*

Type specimen 12291, Coll. Invert. Palae., Univ. Calif., loc. 2134.

Shell large, equivalve; inequilateral; posterior extremity elongated, evenly rounded; anterior extremity broadly rounded. Umbones very tumid, the beaks being distant and markedly curved anteriorly. Shell ornamented on the umbones, at least, by fine, smooth, equidistant concentric ridges. Length of type, 100 mm.; height, about 75 mm.; diameter, 70 mm.

Horizon.—Chico group, Acateonella oviformis zone.

Family Anatinidae

Genus ANATINA Lamarck

ANATINA (?), sp.

Plate 31, figure 5

Type specimen 12286, Coll. Invert. Palae., Univ. Calif., loc. 2162.

Shell small, elongate; anterior dorsal margin slightly excavated; anterior end broadly produced; posterior dorsal margin slopes gently to the bluntly pointed posterior extremity. Umbones inconspicuous; beaks sharply pointed. Surface of shell unknown since the specimen is little more than a cast; anterior adductor scar large and deeply impressed. Length of specimen, 21 mm.; height, 14 mm.; convexity, 3 mm.

Horizon.—Chico group, Turritella pescaderoensis zone.

Family Astartidae

Genus ASTARTE Sowerby

ASTARTE LAPIDIS, n. sp.

Plate 30, figures 4*a* and 4*b*

Type specimen 12285, Coll. Invert. Palae., Univ. Calif., loc. 2135.

Shell small, nearly circular in outline, slightly inequilateral; rather tumid. Anterior dorsal margin concave, set off by an ill-defined lunule; anterior end and base rounded, forming nearly a segment of a circle; posterior dorsal margin convex, meeting the even curve of the base and the posterior end at a point about halfway to the ventral margin. Beaks inconspicuous, pointed. Shell thick, ornamented by rough lines of growth. Hinge plate heavy with a prominent, anterior, cardinal tooth. Length of type, 20 mm.; height, 20 mm.; convexity, 8 mm.

This species is represented by several specimens, all of which are quite uniform as regards general shape.

Horizon.—Chico group, Turritella pescaderoensis zone.

ASTARTE OVOIDES, n. sp.

Plate 30, figure 1

Type specimen 12280, Coll. Invert. Palae., Univ. Calif., loc. 2157.

Shell nearly circular in outline, slightly inequilateral; quite tumid at a point about one-third the distance from the beak to the ventral margin; anterior dorsal slope slightly concave but rapidly becoming convex and changing into an evenly rounded anterior extremity; base regularly rounded, forming with the anterior end an arc of a circle whose diameter is but slightly greater than the height of the shell; posterior extremity curves abruptly from the base toward the beak. Umbones very prominent; beaks sharply pointed, situated anteriorly. Lunule present but imperfectly preserved. An indistinct flexure extends from the posterior end toward the beak, becoming less conspicuous dorsally. Surface sculptured by numerous evenly spaced concentric lines of growth. Hinge and pallial line unknown. Adductor scars subequal, the anterior being the more deeply impressed. Length of type, 28 mm.; height, 28 mm.; convexity, 5.5 mm.

Horizon.—Chico group, zonal position uncertain.

ASTARTE (?) SULCATA, n. sp.

Plate 33, figure 6

Type specimen 12305, Coll. Invert. Palae., Univ. Calif., loc. 2141.

Shell very small, slightly quadrate in outline. Anterior and posterior dorsal margins with similar slopes; posterior end slightly truncated; beaks small, pointed, situated nearly central. Surface covered with a few heavy steplike concentric ridges, which are about half as wide as the interspaces. Length of type, 10 mm.; height, 7 mm.; convexity, about 2 mm.

This small species is very abundant in the Actaeonella oviformis zone. The type represents a rather small individual, some specimens being 15 mm. in length.

Horizon.—Chico group, Actaeonella oviformis and Turritella pescaderoensis zones.

Family CARDIIDAE

Genus CARDIUM Linnaeus

CARDIUM CORONAENSIS, n. sp.

Plate 30, figure 2

Type specimen 12281, Coll. Invert. Palae., Univ. Calif., loc. 2130.

Shell small, nearly equilateral, as broad as high, subquadrate, ventricose; anterior dorsal margin slightly convex, curving gently to the anterior extremity; posterior dorsal margin nearly straight to a point beyond the hinge line, then slopes very abruptly to the base of the shell; base arcuate. Umbones prominent, tumid; beaks sharply pointed, adjacent; anterior dorsal area ill-defined. A ridge extending from the beak to the anterior margin suggests that this species belongs to the subgenus *Protocardia*. Inner margin entire. Surface poorly preserved, but apparently devoid of sculpture. Length of type, 32 mm.; height, 32 mm.; convexity, 24 mm.

Horizon.—Chico group, Actaeonella oviformis zone.

CARDIUM (PROTOCARDIA), sp.

Plate 31, figure 4

Type specimen 12283, Coll. Invert. Palae., Univ. Calif., loc. 2177.

Several imperfectly preserved specimens of *Cardium* were obtained in the fauna that do not appear to have been described. The type is represented by a finely perfect cast, and another on the same piece of rock shows a type of sculpture consisting of many fine grooves bordered by a ridge with wavy lateral margins. These ridges occur on the cast, thus indicating the identity of the two specimens.

The shell is nearly equilateral, very tumid, and somewhat quadrilateral in outline.

This form recalls *C. sagittatus* Gabb in general shape, but it differs from that species in the character of the sculpture. The dimensions of the specimen figured are: height, 18 mm.; length, 18 mm.; convexity, 8 mm.

Horizon.—Chico group.

Family Veneridae

Genus MERETRIX Lamarck

MERETRIX ANGULATA, n. sp.

Plate 33, figure 5

Type specimen 12307, Coll. Invert. Palae., Univ. Calif., loc. 2136.

Shell medium sized; inequilateral; posterior dorsal slope nearly straight; anterior end evenly rounded; posterior extremity truncated; base broadly rounded. Umbones tumid, with blunt beaks. Anterior dorsal margin slightly excavated underneath the beak; lunule ill-defined; a prominent ridge extends from the beak to the posterior ventral margin; inner margin smooth, hinge showing, imperfectly, three cardinals and two laterals. Length of type, 59 mm.; height, about 45 mm.; convexity, 15 mm.

Horizon.—Chico group, Turritella pescaderoensis zone.

MERETRIX NITIDA (Gabb) var. MAJOR, n. var.

Plate 33, figure 2

A large specimen, no. 12279, that has the general form and proportions of the typical species but differs from it in its relatively thicker shell and very much larger size was obtained from University of California locality 2169. None of the several specimens referred to this variety shows the hinge, so that there is some uncertainty as to its true affinities. Length of type, 77 mm.; height, 71 mm.; convexity, 22 mm.

Horizon.—Chico group, Tellina ooides zone.

MERETRIX ?, sp.

Plate 33, figure 2

A large, elongate specimen, no. 12306, that is doubtfully referred to this genus was obtained at locality 2167. The specimen is devoid of shell except on the anterior end, which shows an ill-defined lunule, bounded by an impressed line. Irregular lines of growth are the only evidences of sculpture. The shell is elongate, very tumid, with prominent umbones but inconspicuous beaks. Length, 68 mm.; height, 46 mm.; diameter of cast, 35 mm.

Horizon.—Chico group, Turritella pescaderoensis zone.

Family TELLINIDAE

Genus TELLINA Linnaeus

TELLINA ALISOENSIS, n. sp.

Plate 33, figure 3

Type specimen 12309, Coll. Invert. Palae., Univ. Calif., loc. 2168.

Shell small, elongated, inequilateral; dorsal margin slightly convex, approximately paralleling the nearly straight base line; posterior extremity bluntly pointed; anterior dorsal margin sloping abruptly to the slightly truncated extremity. Beaks inconspicuous, situated at about one-fourth the distance from the anterior to the posterior end; an indistinct ridge extends from the beak to the anterior end. The type is a cast which does not show the muscle scars nor the character of the sculpture. Length of the type, 16.5 mm.; height, 11 mm.

This small species recalls *T. ashburnerii* Gabb, from which it differs principally in being more inequilateral.

Horizon.—Chico group, Tellina ooides zone.

TELLINA SANTANA, n. sp.

Plate 33, figure 4

Type specimen 12310, Coll. Invert. Palae., Univ. Calif., loc. 2169.

Shell small, very thin, elongated, very nearly equilateral; posterior dorsal margin sloping with a straight line to the evenly rounded posterior end; anterior dorsal margin slightly concave near the beaks, then sloping in a broadly rounded curve, base arcuate. Beaks small; surface smooth, with indistinct, incremental lines of growth. Hinge unknown. Anterior adductor scar pear-shaped. Length of type, 35.5 mm.; height, 18 mm.; beak, 16 mm. from the anterior extremity.

This species resembles *T. mathewsonii* Gabb in its dorsal profile, but it is not so high, relatively, as that species.

Horizon.—Chico group, Tellina ooides zone.

TELLINA, sp.

Plate 33, figure 1

Type specimen 12308, Coll. Invert. Palae., Univ. Calif., loc. 2168.

Shell small, very inequilateral; posterior dorsal margin slopes somewhat convexly, curving gently to the elongate posterior extremity; anteror dorsal margin slopes abruptly to the rounded anterior end; base arcuate. Umbones inconspicuous, situated about one-third the distance from the anterior to the posterior end. The specimen is a cast which does not show the muscle impressions nor the exterior of the shell. Length of specimen figured, 15 mm.; height, 7 mm.

Horizon.—Chico group, Tellina ooides zone.

Family Solenidae

Genus SILIQUA Megerle

SILIQUA ALISOENSIS, n. sp.

Plate 34, figure 2

Type specimen 12293, Coll. Invert. Palae., Univ. Calif., loc. 2169.

Shell rather short, wide, slightly inequilateral; anterior and posterior extremities evenly rounded and approximately of the same shape. Beaks small, situated slightly posterior to the middle line of the shell. Exterior of the shell is poorly preserved, so that the sculpture is unknown. A distinct internal ray extends from the beak to the junction of the pallial sinus and the posterior adductor scar. Pallial sinus deep, extending anteriorly about one-third the length of the shell. Length of type, 88 mm.; height, 51 mm.; convexity, 8 mm.

Horizon.—Chico group, Tellina ooides zone.

Family Saxicavidae

Genus PANOPE Ménard

PANOPE CALIFORNICA, n. sp.

Plate 34, figure 1

Type specimen 12292, Coll. Invert. Palae., Univ. Calif., loc. 2142.

Shell short, inequilateral, tumid, gaping widely posteriorly and little if at all anteriorly; anterior extremity evenly rounded, base broadly arcuate; posterior extremity abruptly truncated; anterior dorsal slope short, slightly concave; posterior dorsal slope long, less oblique than the anterior slope, becoming concave upward toward the anterior end. Umbones prominent; beaks acutely pointed, situated at a point about one-third the distance from the anterior to the posterior end. No lunule; escutcheon ill-defined and limited in width by the dorsal edges of the gaping valves. Surface marked by heavy, irregular, incremental lines of growth. Hinge and pallial line unknown. Length of type, 95 mm.; height, 62 mm.; diameter, 45 mm.

This species lacks the radiating sculpture common to the related forms of the Indo-Pacific region.

Horizon.—Chico group, Actaeonella oviformis and Turritella pescaderoensis zones.

Family GASTROCHAENIDAE

Genus GASTROCHAENA Spengler

GASTROCHAENA, sp.

Plate 31, figure 1

Type specimen no. 12282, Coll. Invert. Palae., Univ. Calif., loc. 2179.

Several specimens which appear to be the protective tubes of some member of this genus were obtained at localities 2179 and 2151, Santa Ana Mountains, California. One of these, specimen no. 12282, which is broken at both ends, has a length of 62 mm. and a diameter of 5 mm., at the smaller end and about 9 mm. at the other. The shell is thick and roughened externally by irregular constrictions. The largest specimen shows the bottom of the boring. The lower end is abruptly but evenly rounded with a nearly circular cross-section. This specimen has a diameter of 16 mm. at the bottom and 14 mm. at a point 30 mm. higher.

These specimens resemble the figures by Stolzisky of *G. aspergilloides* Forbes.

Horizon.—Chico group, zonal position uncertain.

Class **GASTROPODA**

Family PYRAMIDELLIDAE

Genus ODOSTOMIA Fleming

ODOSTOMIA SANTANA, n. sp.

Plate 36, figure 2

Type specimen 12299, Coll. Invert. Palae., Univ. Calif., loc. 2169.

Shell very small, imperforate; broadly conical; over twice as long as wide; at least five whorls, only four being completely shown; body whorl large, about twice as high as the three preceding ones; whorls slightly convex with an indistinct appressed suture; aperture ovate, rounded anteriorly but somewhat pointed posteriorly; outer lip thin, simple; inner lip smooth; shell smooth and polished. Length of type, 4.5 mm.; width of body whorl, about 2 mm.

This small shell resembles *O. ? inornata* Whiteaves, from which it differs in its more tumid whorls.

Horizon.—Chico group, Tellina ooides zone.

Family SCALIDAE

Genus EPITONIUM Bolten

EPITONIUM, sp.

A single specimen belonging to this genus was obtained at locality 2142. Only five whorls are preserved, neither the base nor the tip being represented. Each whorl is very tumid; ornamented by fine spiral lines and about ten slightly oblique transverse ribs, which are more pronounced along the middle of the whorl, and which alternate on different whorls.

Horizon.—Chico group, Actaeonella oviformis zone.

Family NATICIDAE

Genus AMAUROPSIS Mörch

AMAUROPSIS PSEUDOALVEATA, n. sp.

Plate 35, figures 1*a*, 1*b*, and 3

Type specimen 12301, Coll. Invert. Palae., Univ. Calif., loc. 2151.

Shell with seven whorls, spire distinctly tabulated, the sides of each spire-whorl flat, except for a shallow groove at the top of the whorl; sutures slightly impressed, the tabulae in some specimens are depressed dorsally and ornamented by several faint revolving ribs; body whorl large, globose, prominently tabulated, below which is a conspicuous shallow groove; aperture semicircular, outer lip apparently thin, inner lip with a callus that completely covers the umbilical region; surface of the type smooth except for very fine growth lines. Height of type, 23 mm.; diameter of body whorl, 20 mm.; length of aperture, 17 mm.

This species is undoubtedly the same as that obtained at Tuscan Springs, California, and figured under the name of the Eocene species *A. alveata* Gabb. It differs from Gabb's Eocene form in being imperforate and having a less expanded aperture.

The type apparently represents an individual of about two-thirds the maximum size of the species. No specimens have been found that equal those described by Gabb as *Euspira tabulata* in size, although this new species resembles it somewhat in form.

Horizon.—Chico group, all three zones.

Genus GYRODES Conrad

GYRODES CALIFORNICA, n. sp.

Plate 35, figures 2*a* and 2*b*

Type specimen 12300, Coll. Invert. Palae., Univ. Calif., loc. 2167.

Shell medium size, nearly as high as broad, spire low, consisting of three whorls, which are depressed, rounded without groove or tabulation; suture appressed; aperture subcircular, broadly rounded below and angulated above; umbilicus very small; surface sculptured by irregular lines of growth. Height of type, about 17 mm.; diameter of body whorl, 19.5 mm.

This species differs from *G. canadensis* Whiteaves in the lack of tabulation of the last two whorls, and from *G. compressus* Waring by the lack of a constriction below the suture.

Horizon.—Chico group, Turritella pescaderoensis zone.

Family Cerithiidae

Genus CERITHIUM Bruguière

CERITHIUM (?) SUCIAENSIS, n. sp.

Plate 35, figure 4

Type specimen 12303, Coll. Invert. Palae., Univ. Calif., loc. 2209.

The specimen herein described includes only portions of three whorls from the lower part of a very large turretted gastropod. The whorls are markedly restricted at the sutures and slightly flattened midway between them; aperture apparently oval; columella smooth, without a sulcus probably imperforate; canal unknown; shell ornamented by about 22 axial ribs, being more prominent near the top and the bottom of the whorl; each rib is deflected backward at the shoulder and joins the suture by a curved line; base of each whorl ornamented by several indistinct revolving ribs. Height of whorl, 24 mm.; diameter, 43 mm.

Horizon.—Chico group, zonal position unknown.

CERITHIUM (?), sp.

Two specimens, each represented by imperfect, partially deccolated whorls, were obtained at locality 2173 and 2135, Santa Ana Mountains. The larger of these has a body whorl having a diameter of 30 mm. It was apparently ornamented by two prominent, spiral rows of nodes, each with at least 18 rather conspicuous nodes. The other specimen (2135) may represent the upper whorls of *C.* (?) *suciaensis,* but the latter is probably distinct. These are unsuitable for figuring.

Family Aporrhaidae

Genus ALARIA Morris and Lycett

ALARIA NODOSA, n. sp.

Plate 36, figures 5*a* and 5*b*

Type specimen 12297, Coll. Invert. Palae., Univ. Calif., loc. 2155.

Shell medium sized, spire high, eight whorls; spire whorls tumid, ornamented by about 14 slightly oblique transverse ribs, which do not reach the suture; region just below the suture on each whorl ornamented by several very fine spiral ridges; body whorl large, canal long; outer lip flat, expanded, lower margin slightly concave; upper margin somewhat concave from the bluntly pointed, upward directed projection of the lip. Height of type, 27+ mm.

This species is apparently represented by a partly deccolated specimen from locality 2142, which shows the same configuration of the lower margin of the lip, but possesses less pronounced transverse ridges.

Horizon.—Chico group, zonal position unknown.

Genus APORRHAIS Da Costa

APORRHAIS VETUS, n. sp.

Plate 36, figure 1

Type specimen 12298, Coll. Invert. Palae., Univ. Calif., loc. 2171.

Shell medium sized, spire high; whorls six or seven; spire whorls convex, regularly curved above and below; suture rather shallow; body whorl large, probably with a short canal; outer lip broadly expanded; margin concave below, terminating in a blunt point at the end of a ridge which originates at the middle of the body whorl. Upper margin of lip extends in an even concave curve nearly to the top of the spire; outer posterior margin of the lip is thickened along the margin of the spire; whorls of the spire ornamented by 8 to 12 transverse ribs and by fine spiral lines; these ribs extend only to the body whorl, which appears to be unornamented except for the angulation that terminates at the apex of the lip. Length of type, 28+ mm.; diameter of body whorl, 15 mm.; length from the middle of the body whorl, 18 mm.

Horizon.—Chico group, zonal position uncertain.

Family BUCCINIDAE

Genus SIPHONALIA A. Adams

SIPHONALIA DUBIUS, n. sp.

Plate 35, figure 5

Type specimen 12304, Coll. Invert. Palae., Univ. Calif., from the Chico of the Santa Ana Mountains, California.

Shell medium size, rather broad; four whorls, those of the spire being ornamented by about ten heavy transverse nodes, which are more prominent on the strongly convex portion of the whorl, becoming obsolete above and below the suture; spire also ornamented by ten rows of nodes that become less conspicuous below, and by about 15 heavy spiral ridges; outer lip thin; aperture ovate; canal probably short. Height of type, 38 mm.; diameter of body whorl, 22 mm.

Horizon.—Chico group, exact locality and zonal position unknown.

Family THAISIIDAE

Genus LYSIS Gabb

LYSIS CALIFORNIENSIS, n. sp.

Plate 37, figures 2 and 3

Type specimen 12287, Coll. Invert. Palae., Univ. Calif., loc. 2167.

Shell with three whorls, each succeeding one increasing rapidly in size; body whorl very tumid, slightly flattened on the upper part, and becoming more so on the broadly expanded lip; spire low, whorls tumid, nearly evenly rounded above and below; suture impressed; aperture large, oval; shell imperforate; surface apparently without ornamentation, but somewhat roughened by irregular lines of growth. The cast of one specimen shows spiral lines suggestive of a spiral sculpture. Height of type, 27 mm.

This species appears to differ from *L. suciensis* Whiteaves in the less oblique character of the whorls and in its general lack of sculpture.

Horizon.—Chico group, Turritella pescaderoensis zone.

Family Volutidae

Genus VOLUTODERMA Gabb

VOLUTODERMA MAGNA, n. sp.

Plate 37, figure 1

Type specimen 12274, Coll. Invert. Palae., Univ. Calif., loc. 2166.

Shell elongate, rather slender; four or more whorls; pillar slightly oblique, without visible plaits; whorls of spire large, decreasing gradually in size; suture appressed; conspicuously shouldered in front of the suture on the last two whorls; body whorl large; outer lip expanded; aperture wide; spire apparently ornamented by spiral ridges which are indistinctly nodose on the penultimate whorl; body whorl ornamented by two equally prominent rows of nodes, numbering from 18 to 20, below which are two rows of less conspicuous nodes; below these in turn are at least seven evenly spaced slightly nodose ridges. Length of type, 95 mm.; maximum diameter of body whorl, 43 mm.

This form resembles *V. gabbi* (White), but it is distinguished from that species by its prominent shoulder. A cast, specimen no. 12278, from the same collecting locality as this new species, appears to have a relatively shorter spire for the penultimate whorl appears to be smaller. The expanded lip of that specimen is shown on plate 39. It is not certain whether this cast should be included with *V. magna;* if not, it probably represents an undescribed form that is more closely related to *V. gabbi.*

Horizon.—Chico group, zonal position uncertain, probably the Turritella pescaderoensis zone.

VOLUTODERMA SANTANA, n. sp.

Plate 36, figure 3

Type specimen 12294, Coll. Invert. Palae., Univ. Calif., loc. 2135.

Shell short, thick, with more than three whorls; pillar oblique, with two strong plaits, probably visible from the aperture of a perfect specimen; sculpture of the early whorls inconspicuously marked by revolving ridges; suture appressed; the slight shoulder below the suture is marked by one or two indistinct revolving ridges; last whorl ornamented by ten equidistant spiral ridges, the first six of which are broken up into about twelve rows of axial nodes; the last four ridges are rather sharp and are continuous, whereas those above become almost obsolete between the strong nodes; outer lip thin, very widely expanded; columella apparently without a callus; canal short. Height of body whorl of the type, 50 mm.; maximum width of body whorl, 37 mm.

Horizon.—Chico group, Turritella pescaderoensis zone.

Family Bullariidae

Genus BULLARIA Rafinesque

BULLARIA TUMIDA, n. sp.

Plate 37, figure 4

Type specimen 12289, Coll. Invert. Palae., Univ. Calif., loc. 2157.

Shell medium sized, rather tumid, whorls involved, the apex depressed; outer lip expanded, rounded posteriorly, forming nearly a right angle with the straight basal margin; aperture rounded anteriorly and but slightly posteriorly; inner lip smooth except for a single umbilical flexure in front. Sculpture consists of conspicuous growth lines that are more prominent on the anterior part of the outer lip. Height of type, 16 mm.; diameter of body whorl, 11 mm.

Horizon.—Chico group, zonal position uncertain.

EXPLANATION OF PLATES

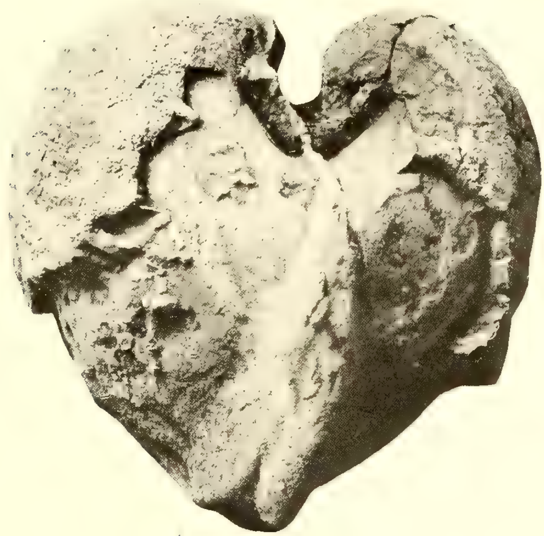
Numbers of specimens refer to specimens in the University of California Collection of Invertebrate Paleontology.

EXPLANATION OF PLATE 24

Fig. 1. Cucullaea (?) cordiformis, n. sp. Type no. 12311, loc. 2158.

Fig. 2. Cucullaea lirata, n. sp. Left valve of cotype, no. 12312, loc. 2149.

All figures approximately natural size.



1

2

EXPLANATION OF PLATE 25

Fig. 1*a*. Trigonarca excavata, n. sp. Exterior of right valve.

Fig. 1*b*. Trigonarca excavata, n. sp. Interior of right valve.

Figs. 1*a*, 1*b*, type no. 12315, loc. 2141.

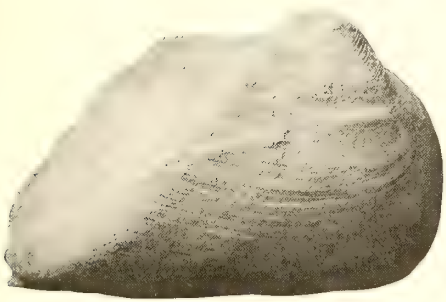
Fig. 2*a*. Trigonarca californica, n. sp. Interior of left valve.

Fig. 2*b*. Trigonarca californica, n. sp. Exterior of left valve.

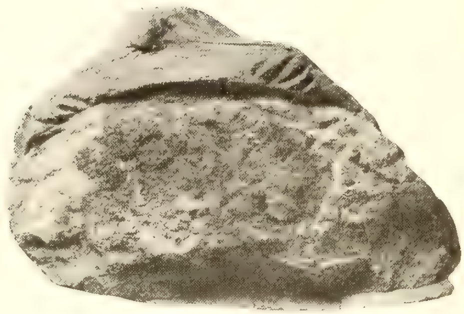
Figs. 2*a*, 2*b*, type no. 12313, loc. 2141.

Fig. 3. Cucullaea lirata, n. sp. Left valve of type no. 12314, loc. 2149.

All figures approximately natural size.



1*a*



1*b*

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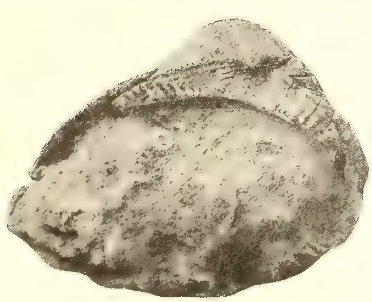
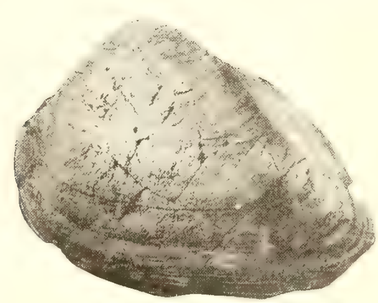


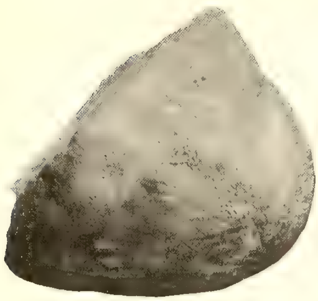
2*a*



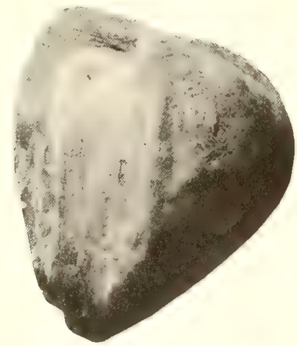
2*b*

EXPLANATION OF PLATE 26

Fig. 1*a*. Trigonarca sectilis, n. sp. Exterior of right valve.
Fig. 1*b*. Trigonarca sectilis, n. sp. Posterior aspect of the type.
Fig. 1*c*. Trigonarca sectilis, n. sp. Anterior dorsal aspect of type.
Figs. 1*a*, 1*b*, 1*c*, type no. 12316, loc. 2144
Fig. 2. Ostrea taxidonta, n. sp. Type no. 12317, loc. 2167.
Fig. 3. Ostrea crescentica, n. sp. Type no. 12318, loc. 2144.
Fig. 4. Ostrea crescentica, n. sp. Specimen no. 12319, loc. 2143.
All figures approximately natural size.

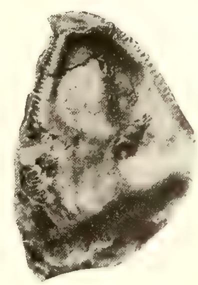


1*a*



1*b*

1*c*



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EXPLANATION OF PLATE 27

Fig. 1. Exogyra inornata, n. sp. × 1. Type no. 12284, loc. 2143.

Fig. 2. Limopsis silveradoensis, n. sp. × 1½. Cotype no. 12323, loc. 2143.

Fig. 3. Spondylus rugosus, n. sp. × 1. Exterior of left valve of cotype no. 12322, loc. 2149.

Fig. 4. Limopsis silveradoensis, n. sp. × 1½. Type no. 12324, loc. 2143.

Fig. 5. Exogyra californica, n. sp. × 1. Type no. 12320, loc. 2143.

Fig. 6. Pecten ?, sp. × 1½. Specimen no. 12321, loc. 2138.

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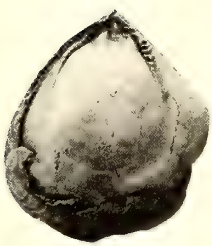

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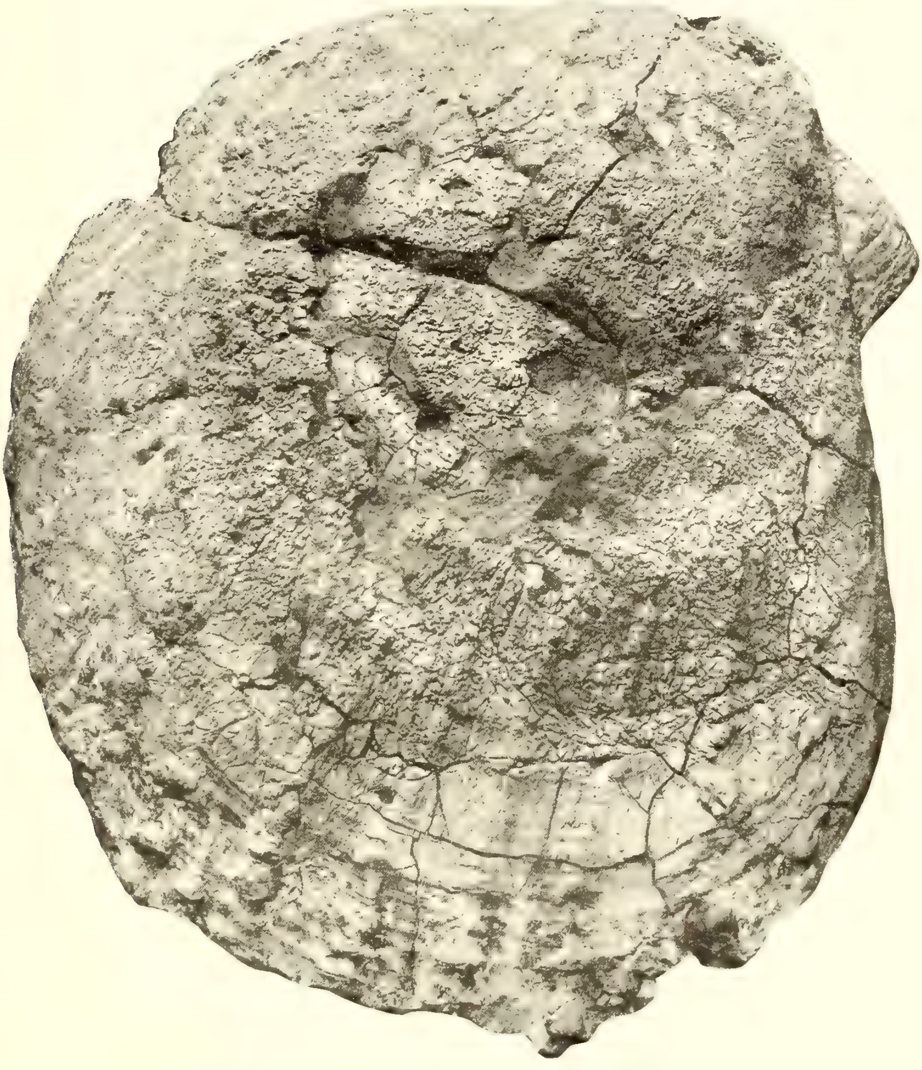
EXPLANATION OF PLATE 28

Lima subnodosa, n. sp. Natural size. Type no. 12275, loc. 2149.



EXPLANATION OF PLATE 29

Spondylus striatus, n. sp. Natural size. Type no. 12276, loc. 2149.

EXPLANATION OF PLATE 30

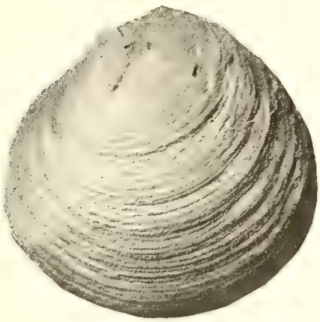
Fig. 1. Astarte ovoides, n. sp. × 1½. Type no. 12280, loc. 2157.

Fig. 2. Cardium coronaensis, n. sp. × 1. Left valve of type no. 12281, loc. 2130.

Fig. 3. Spondylus rugosus, n. sp. × 1. Left valve of type no. 12277, loc. 2143.

Fig. 4*a*. Astarte lapidis, n. sp. × 1½. Exterior of type no. 12285, loc. 2135.

Fig. 4*b*. Astarte lapidis, n. sp. × 1½. Hinge of type no. 12285.



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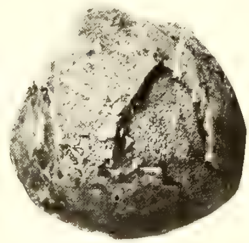

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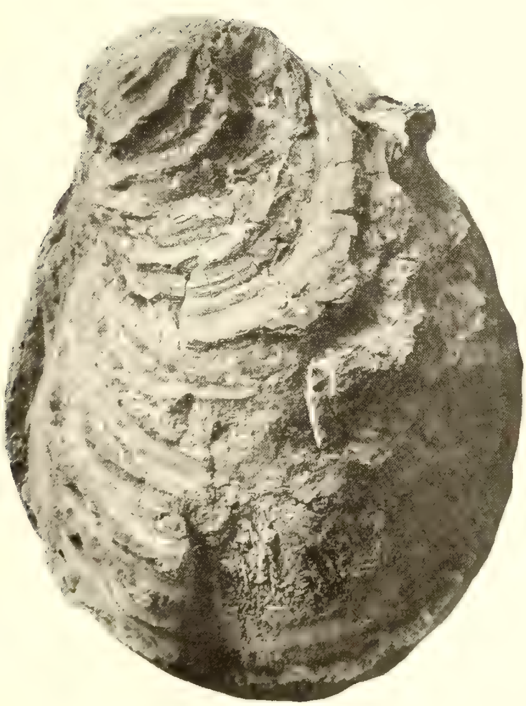

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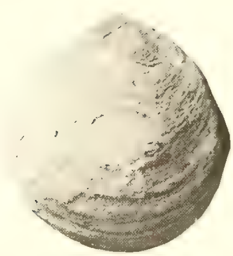
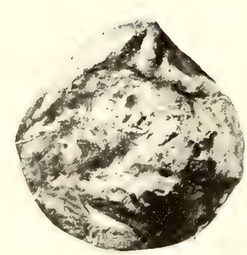


4*a*



4*b*

EXPLANATION OF PLATE 31

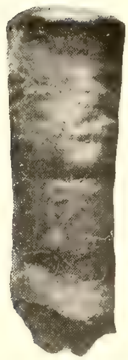
Fig. 1. Gastrochaena, sp. No. 12282, loc. 2179.

Fig. 2. Meretrix nitida (Gabb) var. major, n. var. × 1. Left valve of type no. 12279, loc. 2169.

Fig. 3. Spondylus rugosus, n. sp. × 1. Right valve of type no. 12277, loc. 2143.

Fig. 4. Cardium (Protocardia), sp. × 1½. No. 12283, loc. 2177.

Fig. 5. Anatina (?), sp. × 1½. No. 12286, loc. 2162.



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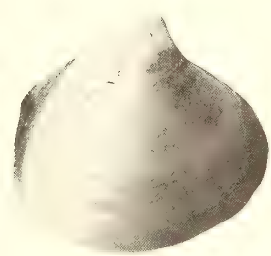

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5

EXPLANATION OF PLATE 32

Fig. 1*a*. Homomya hardingensis, n. sp. Anterior aspect.

Fig. 1*b*. Homomya hardingensis, n. sp. Right valve.

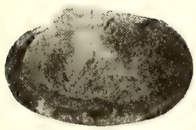
Figs. 1*a*, 1*b*, type no. 12291, loc. 2134. Natural size.

1*a*

1*b*

EXPLANATION OF PLATE 33

Fig. 1. Tellina, sp. × 1½. No. 12308, loc. 2168.
Fig. 2. Meretrix (?), sp. × 1. No. 12306, loc. 2167.
Fig. 3. Tellina alisoensis, n. sp. × 1. Type no. 12309, loc. 2168.
Fig. 4. Tellina santana, n. sp. × 1. Type no. 12310, loc. 2169.
Fig. 5. Meretrix angulata, n. sp. × 1. Type no. 12307, loc. 2136.
Fig. 6. Astarte (?) sulcata. × 1½. Type no. 12305, loc. 2141.



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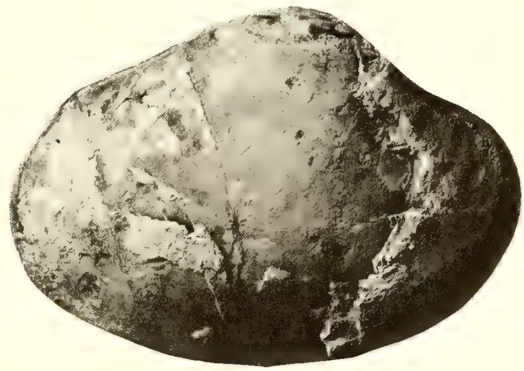

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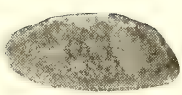

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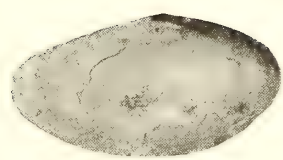

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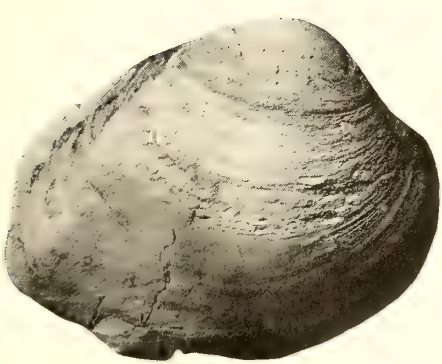

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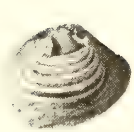

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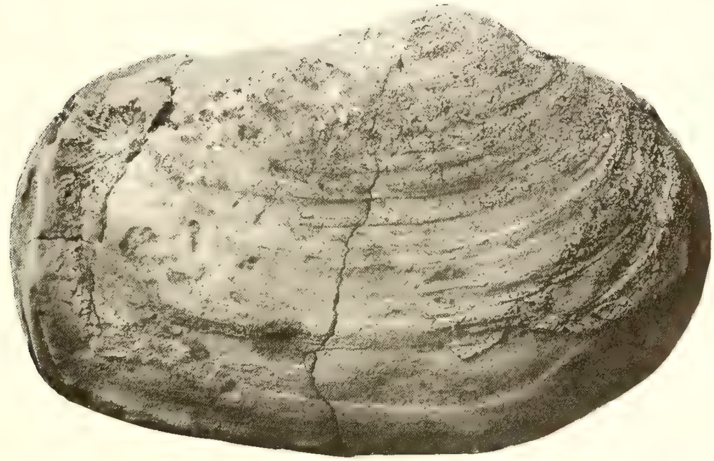
EXPLANATION OF PLATE 34

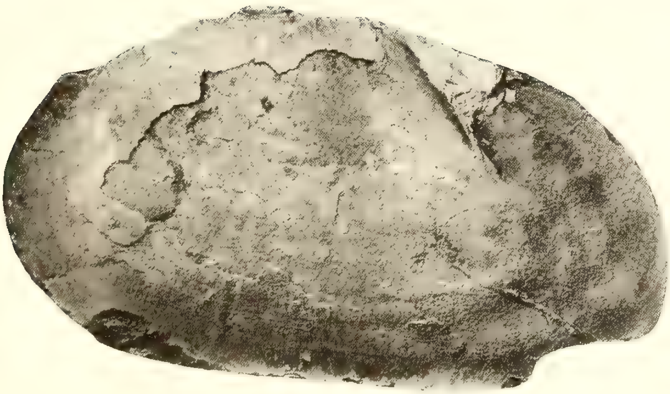
Fig. 1. Panope californica, n. sp. Right valve of type no. 12292, loc. 2142.

Fig. 2. Siliqua alisoensis, n. sp. Type no. 12293, loc. 2169.

All figures natural size.



1



2

EXPLANATION OF PLATE 35

Fig. 1*a*. Amauropsis pseudoalveata, n. sp. × 1½.

Fig. 1*b*. Amauropsis pseudoalveata, n. sp. × 1½.

Figs. 1*a*, 1*b*, type no. 12301, loc. 2151.

Fig. 2*a*. Gyrodes californica, n. sp. × 1½.

Fig. 2*b*. Gyrodes californica, n. sp. × 1½.

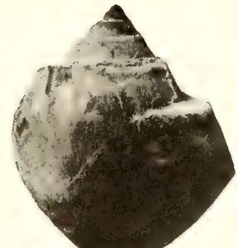
Figs. 2*a*, 2*b*, type no. 12300, loc. 2167.

Fig. 3. Amauropsis pseudoalveata, n. sp. × 1. Cotype no. 12302, loc. 2157.

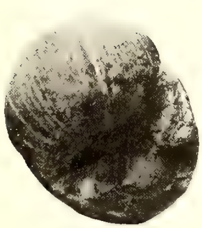
Fig. 4. Cerithium (?) suciaensis, n. sp. × 1. Type no. 12303, loc. 2209.

Fig. 5. Siphonalia dubius, n. sp. × 1. Type no. 12304, from Chico of Santa Ana Mountains, California.

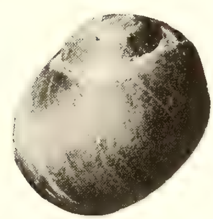
1a



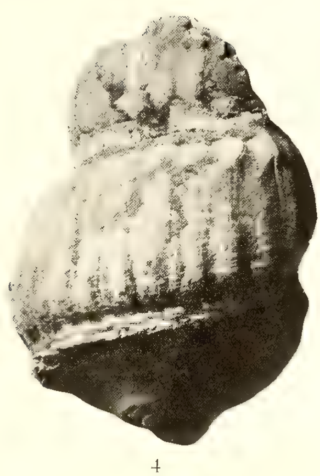
1b



2a



2b



4

3

5

EXPLANATION OF PLATE 36

Fig. 1. Aporrhais vetus, n. sp. × 1. Type no. 12298, loc. 2171.

Fig. 2. Odostomia santana, n. sp. × 4½. Type no. 12299, loc. 2169.

Fig. 3. Volutoderma santana, n. sp. × 1. Type no. 12294, loc. 2135.

Fig. 4. Actaeonella oviformis Gabb. × 1. Specimen no. 12295, loc. 2138.

Fig. 5*a*. Alaria nodosa, n. sp. × 1. Cotype no. 12296, loc. 2142.

Fig. 5*b*. Alaria nodosa, n. sp. × 1. Type no. 12297, loc. 2155.

1

3

2

4

5a

5b

EXPLANATION OF PLATE 37

Fig. 1. Volutoderma magna, n. sp. × 1. Type no. 12274, loc. 2166.

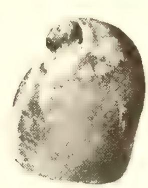
Fig. 2. Lysis californiensis, n. sp. × 1. Type no. 12287, loc. 2167.

Fig. 3. Lysis californiensis, n. sp. × 1. Cotype no. 12288, loc. 2134.

Fig. 4. Bullaria tumida, n. sp. × 1. Type no. 12289, loc. 2157.

1

2



3

4

EXPLANATION OF PLATE 38

Volutoderma magna, n. sp. (?). Natural size. No. 12278, loc. 2166.

INDEX*

* Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 13.

ERRATA

Page 207, footnote 18. *For* A. S. Ellis *read* A. J. Ellis.

Page 214, figure 2. *For* 1 inch = 30 feet *read* 1 inch = 50 feet.

Page 215, line 7 from bottom. *For* 11B *read* 11.

Page 217, line 15. *For* fig. 18 *read* pl. 10, fig. 3.

Page 240, line 29. *For* Plate 4 *read* Plate 12.

Page 241, lines 16 and 17. *For* plate 13, figures 3 and 4 . . . . *read* plate 13, figure 3 and plate 14, figure 1 of the present report, together with two photographs of Sudbury ores (plate 13, figure 2, and plate 14, figure 2) . . . .

Page 366, line 25. *For* Terrace Quartzite *read* Arrastre Quartzite.

Page 387, line 1. *For* plate 24*a* *read* plate 22*a*.

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