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GEOLOGY

ANDREW C. LAWSON

JOHN C. MERRIAM

EDITORS

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THE MINERALS OF TONOPAH, NEVADA

BY

ARTHUR S. EAKLE

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GENESIS OF THE MINERALS

Some of the minerals occurring with the silver deposit at Tonopah were mentioned by Spurr¹ in his paper on the geology of the district and by Burgess² in his discussion of the origin of

¹ Spurr, J. E., Geology of the Tonopah Mining District, Nevada, U. S. Geol. Surv., Prof. paper no. 42, 1903.

² Burgess, J. A., The Halogen Salts of Silver and Associated Minerals at Tonopah, Nevada, Econ. Geol., vol. 6, p. 13, 1911.

the silver haloids. The latter author collected a good suite of the minerals found in the veins and sent them to the writer for further study and report, and it is from a study of this material that the following notes on the minerals have been prepared.

Origin of the deposits.—The silver deposits occur in a trachyte which Spurr first designated as “earlier andesite,” and were formed by ascending solutions carrying the sulphides and the gold and depositing them at a period immediately following the eruption. The typical ore consists of a gangue of massive white quartz and white feldspar containing blotches and bands of finely granular, black silver minerals, small amounts of pyrite, chalcopyrite, galena, and sphalerite, and occasionally free gold. The dark silver bands are mainly argentite, with which are intimately mixed polybasite and perhaps stephanite and tetrahedrite. An analysis of the primary sulphide concentrates of the Montana-Tonopah mine, made by Hillebrand and quoted by Spurr, indicates that the simple sulphide, argentite, predominates, but has probably mixed with it small amounts of silver sulphantimonites and sulpharsenites and some selenide of silver, or of lead and silver. These sulphide minerals are all primary constituents of the veins, yet most if not all of them also occur secondary, and some of the crystals in the cavities of the gangue are doubtless of a later generation.

Oxidation of the veins.—The deposits at Tonopah lie in an arid region and, like most desert deposits of sulphide minerals, have their oxidized zones characterized by a variety of rare secondary minerals not found where simple hydration only is possible. This is due to the fact that surface waters penetrating to the vein matter below and bringing about its alteration become charged with salts leached from the overlying and adjacent strata, and complex oxidation with less usual mineral precipitations result. The descending solutions which brought about the main oxidation of the silver minerals at Tonopah contained the alkali bromide and iodide as well as the much more abundant chloride, and the complexity of the depositing solutions is evidenced by the coatings of haloids, phosphates, arsenates, manganates, and sulphates which line the walls of fissures and cavities in the gangue.

The origin of the silver haloids.—The most important secondary minerals in the zone of oxidation are the three silver salts, cerargeryte, embolite, and iodyrite. They have undoubtedly crystallized out of descending solutions which obtained their chlorides, bromides, and iodides from superficial deposits impregnated with the alkaline salts, and their general arrangement, as stated by Burgess, is in three zones with cerargeryte above, embolite intermediate, and iodyrite below. Since iodyrite is much less soluble in water than cerargeryte, this order of crystallization may appear reversed, but in reality it is the natural order of occurrence when the silver salts have been deposited from mixed solutions such as undoubtedly obtained at Tonopah.

The formation of good crystals of these difficultly soluble salts generally indicates a slow growth by gradual evaporation of very weak solutions, but the degree of solubility and of concentration before crystallization depends upon the solvent, and crystals may not form until the excess of certain salts have first been removed.

In the cerargeryte zone the crystals are quite perfectly formed and have evidently grown from solutions dilute enough to prevent the previous precipitation of manganese and iron hydrates. While the oxides of iron and manganese may be abundant in this zone, their formation from the solutions was independent of, and later than, the formation of the cerargeryte.

In the embolite zone the crystals are in general imperfectly formed and segregated into bunches. They characteristically rest upon coatings of psilomelane and limonite which have been previously deposited from the solutions and therefore indicate a growth from more concentrated solutions.

In the iodyrite zone the imperfectly formed crystals have grown rather rapidly from solutions concentrated sufficiently to precipitate previously psilomelane, flaky hematite and flaky jarosite in abundant coatings and masses. The evidence points strongly to the conclusion that the crystallization of the iodyrite depended upon the prior or simultaneous precipitation of these iron and manganese minerals.

It is manifestly impossible to form more than an approximate idea of the character of the oxidizing solutions. The waters contained essentially chlorides, bromides, iodides, carbonates, and

sulphates of the alkalies, leached from the surface material and, acting on the abundant pyrite and manganese minerals of the rocks, they became charged with iron and manganese salts. Probably more or less free acid and free gas were formed in the mixed solutions, and the decomposing and oxidizing effect of these solutions on the sulphides of the veins and on the gangue must have been comparatively rapid. The solutions which percolated downward through the ore body were essentially sulphated waters of the alkalies, iron, manganese, and silver, with potassium and sodium chlorides, bromides, and iodides.

The alkali chlorides predominated over the bromides and iodides in the upper zone of oxidation and it is safe to say that chlorine was greatly in excess of bromine or iodine in this zone. The dilute solutions moved slowly downward through main channels and narrow fissures, thoroughly saturating portions of the vein, leaching out the potash of the feldspar and converting the silver sulphides to sulphates. With sufficient silver present the evaporation in this zone would have caused the precipitation of the main deposit of the cerargeryte even if the bromide and iodide of silver had also been thrown out previously or with it. These two haloids, however, would not have existed in the alkali chloride solution but would have been completely transposed into cerargeryte, while the bromine and iodine would have been absorbed in the cold solutions and carried down possibly as sodium and potassium salts.

The solutions passing downward became more concentrated in bulk, stronger relatively in bromine, iodine, and alkalies, and at the same time depleted in chlorides, until a stage was reached where the almost constant associate and natural successor of cerargeryte, the double salt embolite, crystallized. Bromine and chlorine are alike and usually accompany and replace each other, so that cerargeryte and embolite are typically associated. As the chlorine diminished in the solutions, bromine replaced it in cerargeryte as shown by tests, and probably a gradation from cerargeryte to embolite occurs in the mines. The embolite zone represents a proportionate increase of bromine to chlorine in the solutions, yet sufficient chlorine was still present to prevent the formation of bromyrite and to form considerable cerargeryte in

this zone and some in the lower zone. The embolite is typically deposited in bunches of imperfect crystals on layers of psilomelane, and the occurrence suggests the possibility that the bromide was soluble in the excess of the alkali-manganese sulphates and could not form readily as embolite until some of the sodium and potash was removed with the manganese by evaporation. No analyses have been made of the manganese oxides, but doubtless they contain considerable potash and sodium, since these two alkalis were abundant in the solutions. It is well known that the silver haloids are soluble in the alkali chlorides, bromides, and iodides, the alkali carbonates, and probably in the alkali sulphates, so that the general tendency of alkaline solutions is to dissolve the silver salts. Cerargerite crystallized in the upper zones because of the predominance of chlorine in dilute solutions of the alkalis, although the solubility of the chloride was raised; but in the embolite zone the solutions had become more concentrated and at the same time considerably stronger in the alkalis, especially potash from the leaching of the orthoclase, and neither the cerargerite, the iodyrite, nor the embolite of this zone crystallized until the hydrate of manganese was thrown down, carrying the restraining alkalis.

The solutions percolating downward carried small amounts of chlorine and bromine and most of the iodine in the form of alkali salts of these elements. They also contained large amounts of potassium, iron, and manganese derived from the veins, and in the final evaporation of the waters, abundant coatings of psilomelane, flaky precipitated hematite and platy crystals of jarosite were formed. The wobbly crystals of iodyrite and smaller bunches of embolite are in general perched upon these coatings or crystallized with them, and the evidence seems conclusive that the iodyrite was soluble in the concentrated solutions and did not crystallize until after the hydrates of iron and of manganese had been precipitated or had begun to form. What kept the iodyrite from forming was probably the strong solutions of potassium and sodium sulphates, and it was not until the alkalis had been removed in the formation of the jarosite and psilomelane that the silver iodide could crystallize. Iodyrite is decomposed by strong solutions of potassium or sodium sul-

phate and also slowly by ferric sulphate and presumably by manganic sulphate, so its solubility may have been due to a combination of these salts.

The three zones probably represent the action of long standing solutions on the silver minerals of each zone and what silver was carried below was in the form of silver sulphate and not as haloids. The bromine and iodine were presumably carried down as alkali salts. The oxidation of the deposit may have been long continuous or at successive intervals, but it seems to the writer that a basin must have formerly existed above the deposit in which the salts accumulated, and that a body of water from this basin penetrated to the ore below carrying these salts.

In the passage of the solutions downward pools were doubtless formed in the ore body, which gave rise to rich pockets of the haloids. The occurrence of some of the iodyrite crystals suggests also that they were formed by fumes of free iodine acting on the silver. Doubtless free iodine was formed by the decomposition of the iodide or iodate in the concentrated hot solutions, and it must have formed if free acid was present.

The hydrous secondary minerals.—The secondary minerals derived by the alteration of the metallic and basic constituents of the deposits are characteristically present in the form of coatings on the walls of cavities and fissures. The coatings are either in very thin, minutely crystalline, drusy layers or they form minute botryoidal groupings. Most of them are brilliantly lustrous but the crystals are generally unmeasurable.

The hydrous manganese oxide is present in soft velvety layers of impure material and in hard mammillary shells of psilomelane. Much of it may have been derived from the alteration of manganese tungstate which appears to be one of the older minerals of the vein. Manganese hydroxides carrying the alkalies undoubtedly played an important part in the formation and crystallization of the silver haloids and in its association with these it was, in general, deposited first and forms the layers upon which the crystals rest.

The soluble phosphate, arsenate, and sulphate occur in the lower or iodyrite zone of oxidation. They have necessarily been crystallized from more concentrated solutions, while at the same time they antedate the formation of much of the iodyrite.

The few carbonates are of probably more recent formation than those minerals derived by the general oxidation of the deposit.

DESCRIPTION OF THE MINERALS

NATIVE ELEMENTS: GOLD AND SILVER

Gold.—Free gold occurs as small flakes and grains in the narrow black bands of argentite, on the borders of small, irregular veins and seams of quartz, mostly in the vicinity of the Valley View vein. Arborescent groupings of deformed octahedrons and rhombic dodecahedrons have occasionally been found in some of the mines. Gold occurs in very limited quantities in rich silver ore, the general ratio of gold to silver being about 1 to 90. The metal appears to have been deposited originally with the silver minerals, either as visible particles or later made visible through the decomposition of the silver minerals containing it. No tellurides have been found in the district and no traces of tellurium in the concentrates, but its near relation selenium is present in over two per cent, as shown by Hillebrand's analysis. It is probably a constituent of polybasite or tetrahedrite, or forms a silver selenide rather than a gold selenide.

Silver.—Wires, films, and spongy masses of metallic silver are frequently found accompanying the various silver minerals, especially in the vugs where these are better crystallized. The wires are generally attached to argentite, polybasite, tetrahedrite, or pyrargyrite, and the metal is evidently a reduction product. Some of the polybasite crystals have their surfaces honeycombed and the small cellular cavities filled with minute capillary silver. Wire silver is prominent in the Belmont mine and one quartz specimen from the 1000-foot level charged with platy tetrahedrite has a fine wire coating.

SULPHIDES: ARGENTITE, GALENA, CINNABAR, PYRITE, CHALCOPYRITE AND SPHALERITE

Argentite.—The chief mineral of the Tonopah veins is argentite, but the sulphide is intermixed with the sulphosalt, polybasite, and possibly stephanite. The mineral is both primary and

secondary and the better crystallized masses in the gangue vugs are probably largely secondary. The common reticulated and arborescent shapes occasionally show the octahedron or cubo-octahedron, very much distorted.

Galena.—Rich sulphide ore containing a high percentage of gold often has galena disseminated through it accompanied by pyrite and chalcopyrite. Galena is found at all depths, and in the lower workings of some of the barren or low-grade veins it is associated with sphalerite and chalcopyrite.

Cinnabar.—Minute patches and thin streaks of the red mercury sulphide are visible in some of the gangue of the West End mine. The mineral is very scarce in the veins and has only been observed in this mine.

Pyrite.—The country rock and wall rock of the deposits contain much pyrite, but its scarcity in the vein-matter has been commented upon by Spurr. It is held to be largely secondary, but some of that is undoubtedly primary which is so intimately associated with the fine granular black silver bands. Many of the crystals of polybasite when broken show small particles of pyrite and chalcopyrite as inclusions.

Chalcopyrite.—Limited amounts of chalcopyrite are seen in all parts of the veins, usually in very fine grains, and it is a common inclusion in the polybasite crystals. It is the source of the few secondary copper salts in the oxide zone.

Sphalerite.—Brown sphalerite is very limited in its occurrence in the veins. It is found with galena, chalcopyrite, and traces of silver, below the 900-foot level of the Mizpah shaft.

SULPHANTIMONITES: POLYBASITE, STEPHANITE?, PYRRARGYRITE,
AND TETRAHEDRITE

Polybasite.—The brittle black sulphantimonite of silver, accompanying the argentite as one of the primary minerals of the veins, is chiefly polybasite. Platy crystals occur in the quartz cavities and seams, some of them with very brilliant faces. When broken they show a characteristic cherry-red color like pyrargyrite. The crystals are thin basal plates with their edge-faces horizontally striated, and they consist mainly of a broad base with narrow faces of the pyramid p (111), the prism m (110),

and the brachypinacoid b (010). A few crystals had in addition the form r (112), and one showed a good face of a new form o (443). The typical habit of the crystals is seen in figure 1, plate 1.

	Measured	Calculated
(110) : ($\bar{1}\bar{1}0$)	60°08'	60°10'
(110) : (010)	30 00	29 55
(001) : (111)	61 15	61 14
(001) : (112)	42 14	42 19
(001) : (443)	67 46	67 38

Stephanite.—Whether stephanite is mixed with the polybasite in the black silver bands is practically impossible to determine. All of the crystals of the brittle black silver occurring in the cavities of the specimens examined are polybasite, so the presence of stephanite was not proved.

Pyrrargyrite.—The dark ruby silver is generally found as a fissure-filling in the quartz, often intergrown with argentite and polybasite, and accompanied by wires of native silver. Most of the mineral appears granular in the quartz, in the characteristic dark gray bands with reddish cast. Small dark-red crystals have been formed in some of the cavities, consisting of the simple combination of second order prism a ($11\bar{2}0$), base c (0001), and rhombohedron r ($10\bar{1}1$).

	Measured	Calculated
($2\bar{1}\bar{1}0$) : ($11\bar{2}0$)	60°02'	60°00'
(0001) : ($10\bar{1}1$)	42 18	42 28

Tetrahedrite.—Thick tabular plates of tetrahedrite in the gangue of quartz and feldspar, with wires of native silver, occur in a specimen from the Belmont mine.

HALOIDS: CERARGERITE, EMBOLITE, AND IODYRITE

Cerargerite.—The chloride of silver is the most abundant member of the haloids in the deposits. It occurs throughout the zone of oxidation, but is principally found in the upper portion of the zone. Waxy coatings of the mineral cover several square feet in area and minute crystals are abundantly disseminated in the soft kaolinized feldspar, and in the small cavities of the quartz. The coatings and crystals have a very brilliant adamantine to waxy luster, and most are of a translucent pale gray color.

Some coatings incline toward a green color and seem to grade into embolite. The crystals are very minute in size and form perfect cubes with generally the octahedron. Some are distorted into prismatic shapes and others are twisted and curved and show evidences of having been formed from dripping solutions.

Spurr³ cites the occurrence of cerargyrite as an inclusion in primary argentite and advances the possibility of the formation of the hornsilver by the solvent action of the same solutions which deposited the original sulphides. It is possible and even probable that some chlorine was present in the original ascending solutions and that some cerargyrite may have been formed, but it appears undoubted that surface waters brought in the bulk of the chloride and accomplished the main oxidation of the deposit.

Embolite.—The chloro-bromide is not so abundant as the simple chloride or iodide, and it is chiefly found intermediate between the two. It occurs in bunches and groups of green, imperfectly formed crystals, often implanted on psilomelane. The crystals are highly deformed cubes and octahedrons, with sometimes the rhombic dodecahedron.

In the crystallization of the cerargyrite considerable bromine was taken up, so the amount of embolite present in the mines does not represent the original quantity of bromine carried in the solutions.

Iodyrite.—Bromine so generally accompanies chlorine that embolite is a characteristic associate of cerargyrite in deposits containing important amounts of the latter. Iodine on the other hand is very rare, and the Tonopah deposit is quite exceptional in having iodyrite in a comparatively large quantity. The iodide is mostly confined to the lower depths of the oxidized zone. It is present as small loose crystals in the cavities and fissures of the veins, and as brilliant crystalline crusts and coatings on the walls of fissures. One of the largest pockets of loose crystals was found in the Valley View vein, a few feet above the 500-foot level. It contained a host of deep yellow crystals mixed with small fragments of stalactitic and conchoidal psilomelane. The crystals also occur characteristically with flaky brown and yellow

³ *Loc. cit.*

jarosite. The later crystallization of the iodyrite is evidenced by its deposition on layers of the iron sulphate and on other secondary minerals lining the fissures.

The crystals are mainly of a bright sulphur-yellow color, but some incline to greenish yellow, and others are tarnished bronze-brown. The brilliant crystals after exposure to light gradually become cloudy and opaque. The best crystals for measurement occur isolated in quartz cavities, generally perched on drusy quartz.

Iodyrite possesses considerable crystallographic importance because it is one of the few known representatives of the dihexagonal-pyramidal, or hemimorphic, class of symmetry, and many of the Tonopah crystals show this hemimorphic character quite prominently. With very few exceptions the crystals are simple combinations of the unit prism ($10\bar{1}0$), base (0001), and steep pyramid ($20\bar{2}1$). The prism is terminated on the upper or positive end, according to the usual orientation, by narrow faces of ($20\bar{2}1$) and a broad base, and on the lower or negative end by ($20\bar{2}\bar{1}$), often without a lower base, as a characteristic habit. The few other forms are very rare and were observed only once or twice in a lot of several hundred crystals examined. Leaving out all doubtful forms, which were many on account of imperfections, the forms determined were:

c (0001)	i ($20\bar{2}1$)	u ($40\bar{4}1$)
m ($10\bar{1}0$)	r ($10\bar{1}1$)	\underline{i} ($20\bar{2}\bar{1}$)
a ($11\bar{2}0$)	f ($30\bar{3}1$)	\underline{c} (000 $\bar{1}$)

One crystal showed narrow faces of the second order prism ($11\bar{2}0$). Several had the unit pyramid ($10\bar{1}1$) as very narrow faces. The steeper pyramids ($30\bar{3}1$) and ($40\bar{4}1$) were each observed on two crystals. The only negative pyramidal termination was ($20\bar{2}\bar{1}$).

The four forms (0001), ($10\bar{1}0$), ($20\bar{2}1$), and ($20\bar{2}\bar{1}$) make up the crystals and the habit or type is governed by the size and predominance of these forms. Few of the crystals are simple because of the alternating growth of prism and pyramid. Successive alternations of these two forms have produced horizontally striated, furrowed, stepped, and tapered crystals which make measurements very poor. A fact also observed was

that the alternations were not rigidly parallel in many cases, and that even the interfacial angles were sometimes distorted. One of the best crystals which gave sharp signals measured $(0001) : (20\bar{2}1) = 58^\circ 43'$ and $(0001) : (\bar{2}021) = 64^\circ 12'$, with angles lying between these for the adjacent readings. Similar variations were noticed on other crystals, and it seems probable that the oscillations in the growth, combined with a slight secularity of the mineral, have caused a deformation of the angles. Some of the prisms have their negative ends terminated by good faces of the steep pyramid and small base, but the lower end is rather characteristically drawn out into a long, wobbly and curved, tapering pyramid. Many of the crystals, especially the larger ones, are mere shells or hollow prisms with irregular cavities.

The imperfect character of most of the crystals renders good measurements impossible, and readings were obtained which correspond to various new and improbable forms. These crystals have been described by Kraus and Cook,⁴ who give several new forms. From the nature of the crystals these new forms would need to be substantiated by further observations of them. As shown above, considerable variation in the angle between the base and pyramid may exist and their forms $(70\bar{7}4)$, $(70\bar{7}3)$, and $(15.0.\bar{1}5.8)$ seem to be striated gradations into, or imperfect readings of, the form $(20\bar{2}1)$. The angle $(0001) : (20\bar{2}1) = 62^\circ 10'$, and their angles for these forms show a variation of $-3^\circ 23'$ to $+3^\circ 23'$, as seen from their measurements:

$$\begin{aligned} (0001) : (70\bar{7}4) &= 58^\circ 47' \\ (0001) : (70\bar{7}3) &= 65\ 33 \\ (00010) : (15.0.\bar{1}5.8) &= 60\ 32 \end{aligned}$$

With good crystals there might be no question about the validity of these new forms, but on the Tonopah crystals their existence is very doubtful. Their new form $(90\bar{9}2)$ may be the known form $(40\bar{4}1)$. The angle $(0001) : (40\bar{4}1)$ is $75^\circ 12'$ and the writer obtained measurements varying from $74^\circ 55'$ to $76^\circ 40'$ for a form which is probably $(40\bar{4}1)$, although the latter angle yields more closely the indices $(90\bar{9}2)$.

⁴ Kraus and Cook, Iodyrite from Tonopah, Nevada, Amer. Journ. Sci., vol. 27, p. 210, 1909.

The best readings obtained for the several forms observed gave as averages:

	Measured	Calculated
(0001) : (10 $\bar{1}$ 1)	43°27'	43°25'
(0001) : (20 $\bar{2}$ 1)	62 13	62 09
(0001) : (30 $\bar{3}$ 1)	70 31	70 36
(0001) : (40 $\bar{4}$ 1)	75 52	75 12
(10 $\bar{1}$ 0) : (11 $\bar{2}$ 0)	30 00	30 00

Twinning is on the usual twinning-plane (30 $\bar{3}$ 4), but not many of the crystals are twinned, comparatively. The twinned crystals are generally flattened parallel to the prism faces in the same zone with the twinning-plane.

Some of the characteristic types of the crystals are illustrated in figures 2 and 3 of plate 1.

OXIDES: QUARTZ, OPAL, CUPRITE, HEMATITE, LIMONITE, MANGANITE, PYROLUSITE, PSILOMELANE, AND WAD

Quartz.—Massive white quartz constitutes the chief part of the gangue. The fine granular silver minerals are always in it, and the best of the crystals occur in its cavities and fissures. Many of the cavities of the veins have been produced by the alteration and leaching out of the feldspathic portion of the gangue, and these pockets are often lined with a secondary deposit of drusy quartz and quartz crystals, which are sometimes corroded and stained yellowish brown. Trigonal development of the quartz terminations are common, but none occur with trapezohedrons.

Opal.—In the Valley View vein a small amount of clear colloidal silica has solidified into colorless hyalite and this has spread as a thin coating over minute crystals of white apatite, giving them a glassy glaze. The opal has taken up crystals of yellow iodyrite and other fragments in its flow and it is one of the latest secondary formations.

Cuprite.—A few small masses of the red copper oxide have been encountered in the oxidized zone, which have their source originally in the chalcopyrite.

Hematite and Limonite.—Naturally the common iron oxides would be plentiful in the weathered zone as impure earthy

masses and stains, from the decomposition of the pyrite and wolframite and former iron-bearing minerals. Dark-red earthy masses with seams of brown jarosite are found in association with the iodyrite. The yellowish stains of limonite color much of the quartz, especially in those cavities and crevices where the fibrous caoxenite occurs.

Manganite, Pyrolusite, Psilomelane, and Wad.—The black oxides of manganese are very abundant in the zone of oxidation, and their close association with the several silver haloids is significant of their influence in the crystallization of the latter. Manganite is present in some of the pockets as long, slender, vertically striated rods. Pyrolusite is finely fibrous and forms coatings along the walls of some of the fissures. A felty variety is seen on some of the specimens. Psilomelane is the common manganese mineral of the mines. It is generally in botryoidal and small mammillary masses, and the embolite and iodyrite are often deposited on them. Some of the pockets of the gangue contain broken fragments of psilomelane mixed with loose crystals of iodyrite. Manganese is present also in soft, velvety coatings, with quite impure mixtures, and may be classed as wad. Brown jarosite crystals are generally implanted on such black coatings.

CARBONATES: CALCITE, MANGANOCALCITE, SIDERITE, RHODOCHRO-
SITE, MALACHITE, AND AZURITE

Calcite.—The carbonates in the mines are all of later secondary origin. Some good calcites line the crevices near the 200-foot level of the Mizpah vein. They rest upon fibrous malachite and some are bright green from inclusions of the copper carbonate and some have a coating of colorless gypsum. The crystals show an unusual habit. They are steep rhombohedral with curved faces, and the rhombohedron is the rare negative form g (05 $\bar{5}$ 2). They are somewhat scalenohedral in habit owing to the curvature of the faces, but without obtuse edges. A few of the crystals have in addition the unit rhombohedron r (10 $\bar{1}$ 1) and the low negative rhombohedron e (01 $\bar{1}$ 2), both in very narrow faces, as seen in figure 4, plate 1.

The measurements were fairly good, notwithstanding the curvature of the main faces.

	Measured	Calculated
(5 $\bar{5}$ 02) : (05 $\bar{5}$ 2)	106°30'	106°44'
(5 $\bar{5}$ 0 $\bar{2}$) : (05 $\bar{5}$ 2)	73 16	73 13
(10 $\bar{1}$ 1) : (01 $\bar{1}$ 1)	74 51	74 55
(10 $\bar{1}$ 1) : (05 $\bar{5}$ 2)	53 39	53 39
(10 $\bar{1}$ 1) : (01 $\bar{1}$ 2)	37 26	37 27
(05 $\bar{5}$ 2) : (0 $\bar{1}$ 11)	112 15	112 33

Manganocalcite.—Specimens of ore taken from the 1000-foot level of the Belmont mine contain crystalline granular patches of a light brown carbonate which turns dark brown when heated and gives a strong reaction for manganese, but no iron. The mineral is chiefly calcium carbonate containing manganese, but the characteristic rose tint is missing. The grains of the mass show some striated and curved faces and only the low rhombohedron (01 $\bar{1}$ 2) can be distinguished.

Sidefite is given by Spurr as one of the minerals of the veins but none of the specimens include this carbonate.

Rhodochrosite.—The manganese carbonate is of very rare occurrence in the deposit. In the crevices of some of the quartz specimens from the Montana-Tonopah mine a few pale rose crystals of minute size occur singly. They are made up of the steep scalenohedron y (32 $\bar{5}$ 1) terminated by the base. The faces of the scalenohedron are striated parallel to their basal edges and the base is invariably dull. The crystals are shown in figure 5, plate 1.

	Measured	Calculated
(32 $\bar{5}$ 1) : (5 $\bar{2}$ 31)	45°37'	45°26'
(32 $\bar{5}$ 1) : (3 $\bar{5}$ 21)	70 50	70 47

Malachite and Azurite.—Small amounts of both copper carbonates occur as stains and crystalline coatings. The malachite associated with the calcite of the Mizpah vein occurs in delicate acicular groups. The azurite is with much of the malachite as light blue earthy material.

SILICATES: FELDSPAR, KAOLINITE, SERICITE, AND RHODONITE

Feldspar and Kaolinite.—The potash feldspar, classed as adularia, is the prominent silicate of the gangue. It is all more

or less altered to pure white, or brownish white, masses and much of it is completely kaolinized to soft white clay. This kaolinization has been brought about by the action of acid or alkali solutions and the soft masses in the upper zone of oxidation are often impregnated with minute crystals of hornsilver.

Sericite.—All of the original silicates of the rock were altered by the original ascending solutions and the scant amount of soft pearly sericitic muscovite now in the gangue is of secondary formation.

Rhodonite.—The rich silver ore of some of the veins shows pinkish bands of rhodonite included in the quartz. Much of the kaolinized feldspar is stained a pale rose color resembling impure rhodonite.

PHOSPHATES AND ARSENATES: APATITE, PSEUDOMALACHITE,
WAVELLITE, TURQUOIS, PHARMACOSIDERITE, AND
CACOXENITE

Apatite.—Minute crystals of apatite line the crevices in the Valley View vein, from the 440-foot to the 640-foot levels. The crystals are snow-white and measure about two millimeters in length. They occur as innumerable crystals forming a coating, and have iodyrite crystals implanted upon them. Some of the crystals have been later coated with a glaze of hyalite. The crystals are combinations of the hexagonal prism with upper base and occasionally very narrow faces of the unit pyramid (fig. 6). This apatite has been formed as a purely secondary mineral and gives no test for chlorine or fluorine. It is probably the simple calcium triphosphate.

Pseudomalachite.—This rare copper phosphate occurs in small globular incrustations on the quartz in association with rhodonite and hübnerite. The globular forms are of a bright emerald-green color and have a finely fibrous structure resembling malachite.

Wavellite.—Little spheres of white wavellite are implanted on specimens of the vein quartz, but they are few in number. Internally they have concentric-radiating, delicately fibrous, structure.

Turquoise.—Small amounts of pale green turquoise, fading into white opaque masses, occur in the crevices of the Mizpah vein at the 600-foot level. The mineral is associated with black manganese oxides and kaolinite, and occurs in the vicinity of much iodyrite.

Pharmacosiderite.—The rare iron arsenate occurs as a coating on quartz at the 370-foot level of the Montana-Tonopah mine. It is light yellowish green and occurs in distinct cubes, with its tetrahedral symmetry indicated by diagonal striations. A few crystals show small faces of the tetrahedron and narrow faces of the rhombic dodecahedron. Deposited on this arsenate are little botryoidal groups of an undetermined dark-red iron phosphate with iridescent surfaces and light brown altered rims.

Cacoxenite.—Radiating tufts of golden yellow and pale yellow cacoxenite occur in the cellular quartz gangue of the Montana-Tonopah mine, about the 500-foot level. The structure of the minerals resembles burrs with short bristles, and the bristles or needles often radiate from a central small circle like spokes from the hub of a wheel. These bunches are typically deposited on drusy quartz which is coated with brownish black velvety layers of manganese oxide, or is colored brown or black by manganese.

SULPHATES: GYPSUM, JAROSITE, AND BARITE

Gypsum.—Very little calcium sulphate is seen in association with the specimens examined, and the mines were quite free of calcium compounds which could form this common secondary mineral. Some of the fissure walls are coated with thin layers of colorless selenite, and it occasionally forms a glaze on argentite and on some of the other secondary minerals. Brilliant crystal faces are seen on the coatings but there are no well-defined crystals.

Jarosite.—The hydrous sulphate, jarosite, is the most prominent of the secondary minerals precipitated from the solutions. It is characteristic of the lower zone of oxidation and is in close association with the larger part of the iodyrite. It generally occurs in flaky masses and flaky coatings, varying from light ochre-yellow to dark reddish brown. These flakes under the microscope are seen to be basal plates with rhombohedral edges.

Small crystals with bright reflecting faces also occur in the crevices of earthy masses and as a deposition on the black manganese coatings. The crystals are rhombohedrons with the basal planes in about equal development, so their resemblance to octahedrons and to cubes with the tetrahedron is quite marked (fig. 7). Some of them have the rhombohedral faces striated while the base is perfect.

The solutions which precipitated the jarosite contained both the sodium and the potassium sulphates, and it is probable that analyses would show the presence of natrojarosite as well as the normal jarosite and gradations of one into the other. A qualitative analysis made of the yellow flakes shows them to be jarosite but with considerable sodium.

Barite.—The sulphate of barium does not occur abundantly in the vein, yet masses of crystals covering several square feet are found on the walls of some of the fissures. The crystals are white and have the common basal-plate habit. Some are half an inch thick and an inch or more wide. The large crystals consist simply of the base c (001) and prism m (110), while the smaller ones have also narrow faces of the pyramid z (111), and brachypinacoid b (010). Thin layers of hematite or limonite coat many of them. Some of the stout plates are later parallel enlargements of smaller plates and the interior crystal had often the brachypinacoid, not present on the outer or enlarged crystal. Figure 8 illustrates the type of crystals.

	Measured	Calculated
(110) : (1 $\bar{1}$ 0)	78°21'	78°22'
(110) : (010)	50 50	50 49
(001) : (111)	64 24	64 19
(110) : (111)	25 42	25 41

TUNGSTATE AND MOLYBDATE: HÜBNERITE OR WOLFRAMITE, AND WULFENITE

Hübnerite or Wolframite.—The manganese tungstate occurs in black platy masses in the compact quartz gangue and in very thin plates in the cavities and seams of the gangue. All of the material contains iron and is to be classed as wolframite rather than as hübnerite. The crystals are tabular parallel to the

orthopinacoid and some of them are exceedingly thin and almost transparent, with a deep red color. They are vertically furrowed and striated and the least touch breaks them into slender rods by the easy clinopinacoidal cleavage. Many of the broad plates have frayed-out ends, while others are terminated by dull bases. The predominating habit shows a broad, striated, front-pinacoid grading into prisms and terminated by a rough base and two small faces of the rear pyramid ($\bar{1}11$), as seen in figure 9. Some of the stouter crystals gave very good readings with the two-circle goniometer, since the striations did not prevent good polar orientation. The prismatic zone was a multiple of narrow striated faces and gave a train of wedges from which only a few could be distinguished as definite forms. Since the crystals are very thin, the pyramidal faces were all small, but mostly very bright. One new pyramid ($\bar{1}22$) occurred on some of the crystals, in good reflecting faces. The forms observed on the crystals and the angles measured and calculated are as follows:

	<i>c</i> (001)		<i>m</i> (110)		<i>d</i> ($\bar{2}11$)
	<i>b</i> (010)		<i>q</i> (830)		<i>o</i> ($\bar{1}11$)
	<i>a</i> (100)		<i>h</i> (310)		<i>e</i> ($\bar{1}12$)
	<i>r</i> (120)		<i>s</i> ($\bar{1}21$)		<i>v</i> ($\bar{1}22$) new

			Measured		Calculated	
			θ	ρ	θ	ρ
<i>m</i>	∞	110	49°48'	90°00'	50°27'	90°00'
<i>q</i>	$\frac{8}{3}\infty$	830	72 54	90 00	72 48	90 00
<i>h</i>	3 ∞	310	74 40	90 00	74 37	90 00
<i>r</i>	$\infty 2$	120	31 00	90 00	31 12	90 00
<i>s</i>	-12	$\bar{1}21$	$\bar{3}0$ 34	63 34	$\bar{3}1$ 00	63 41
<i>d</i>	-21	$\bar{2}11$	$\bar{6}7$ 05	66 21	$\bar{6}7$ 29	66 10
<i>o</i>	-11	$\bar{1}11$	$\bar{5}0$ 00	54 00	$\bar{5}0$ 14	53 42
<i>e</i>	$-\frac{1}{3}1$	$\bar{1}12$	$\bar{5}0$ 00	34 19	$\bar{5}0$ 01	33 59
<i>v</i>	$-\frac{1}{2}1$	$\bar{1}22$	$\bar{3}0$ 50	45 14	$\bar{3}0$ 48	45 15

Wulfenite.—Thin basal plates of wulfenite occur associated with barite and crystals of iodyrite. Twinned crystals of iodyrite have been deposited on the wulfenite plates and are therefore of later generation. The plates are almost colorless and

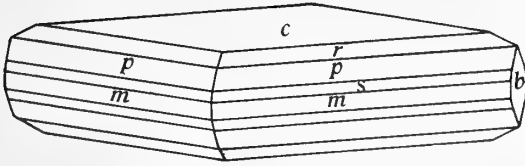
are very thin compared to their lateral dimensions (fig. 10). The forms and angles measured and calculated are as follows:

	<i>c</i> (001)		
	<i>e</i> (101)		
	<i>u</i> (102)		
		Measured	Calculated
(001) :	(101)	57°31'	57°37'
(001) :	(102)	37 56	38 15

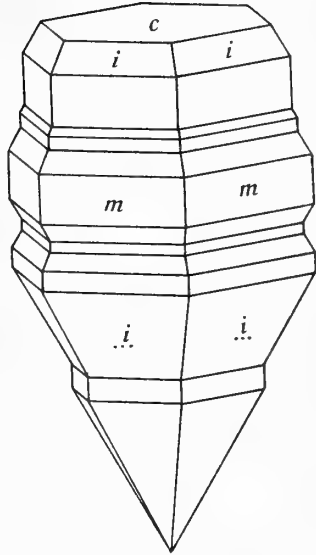
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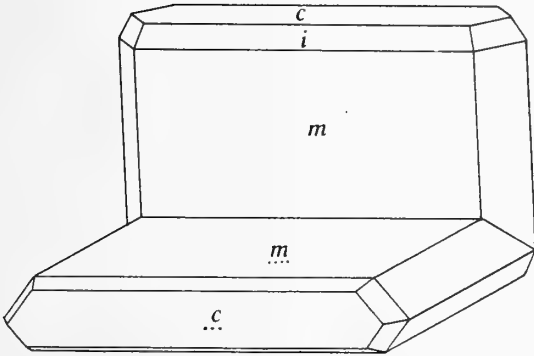
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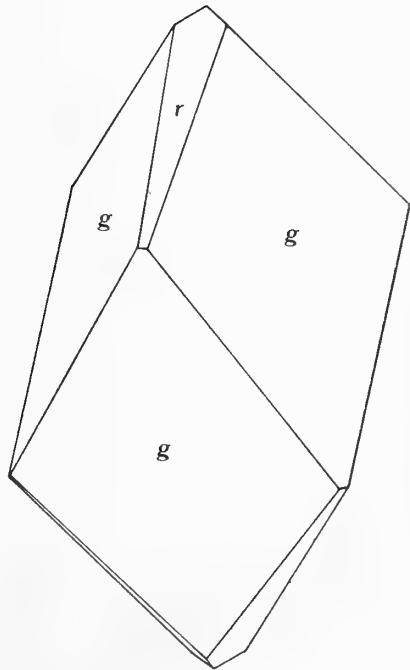
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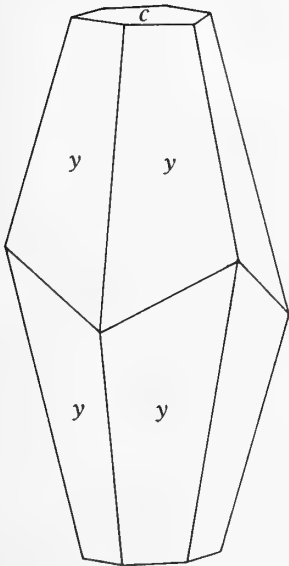
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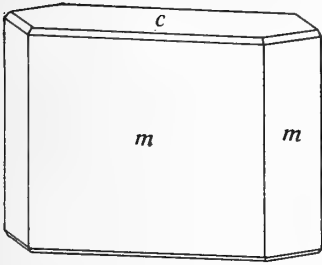
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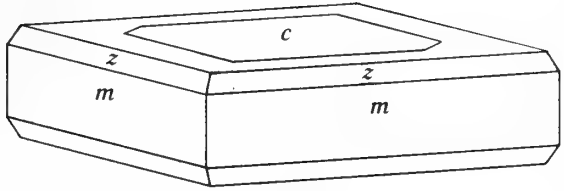
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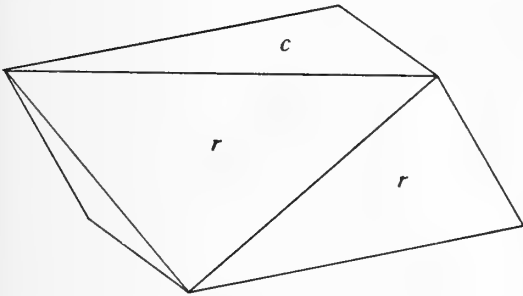
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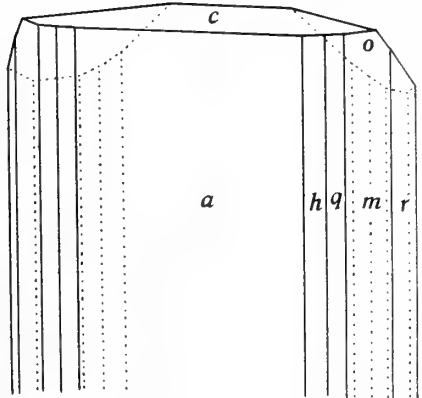
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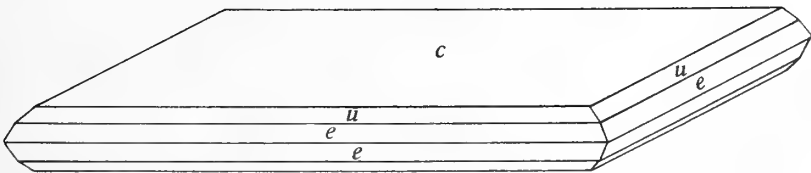
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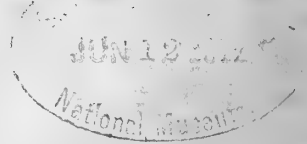
Vol. 7, No. 2, pp. 21-38, plates 3-6

Issued May 25, 1912

PSEUDOSTRATIFICATION IN SANTA
BARBARA COUNTY, CALIFORNIA

BY

GEORGE DAVIS LOUDERBACK



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Stratification, its meaning and origin.—Stratification as applied in structural geology to rock formations may be defined as an arrangement in layers or “beds” as a result of the processes of sedimentation or of the extravasation of sheets of lava.¹

¹ There is some difference of usage here, and many geologists do not include the bedded lavas as stratified formations. Their common occurrence in beds; their formation of series either alone or with their interbedded tuffs, or interstratified in the sedimentary series; the fact that their bedded form is due to the same fundamental conditions as for sedimentary strata (surface conditions, gravity and a pre-existing floor); the possibility of using their attitudes and deformations in exactly the same way as those of sedimentary beds for determining structural relations and earth movements, mark them fundamentally as stratified in the same sense in which the sediments are.

The usage common in geological text-books of making a sharp distinction between stratified or sedimentary and massive or igneous rocks without further qualification or comment ignores some very important relationships. Surface igneous rocks are not only commonly stratified, but often also sedimentary. The volcanic tuffs frequently form stratified sedimentary formations of great thickness and areal extent, as for example in the Mesozoic and Tertiary areas of many of the western states.

The production of geologic bodies by these processes is brought about by the settling, precipitation or spreading out of the component materials on some preëxisting basement or floor and the building up of the mass by the addition of fresh material normally to the upper surface of the deposit. The basement or floor may be the basin of a sea or lake, the bed of a stream, the surface of the ground, more rarely the floor of an underground space or cavern, etc. The appearance of layer-structure is caused by the varying nature or intensity of the agents supplying the material or by the sorting action of the medium or media through which the material passes before coming to rest. The distinction between layers may therefore depend on differences in composition, size of grain, or perhaps only on color change, or on the occurrence of thin bounding layers or separation planes between tabular masses of the same nature. The thicker layers are generally referred to as strata or beds and the thinner as laminae.

Stratification as above defined is geologically a very important condition. It indicates an essentially superficial or epigene origin of the formations exhibiting it, and except for the lava sheets which are set apart by a special group of characteristics, is a distinctive structure common to all of those closely related processes which are grouped under the general name of sedimentation. Furthermore, chiefly as a result of gravity control in these processes, the separation planes between the layers—the stratification planes—are in most types of these deposits formed horizontally or at only a slight inclination to the horizontal. This is a fundamental datum for structural geology, for with it as a basis we may judge of the nature and amount of earth movements that have tilted, folded, and otherwise disturbed the stratified formations.

Pseudostratification.—In this paper the writer will describe occurrences in which there is a layer-structure in elastic sedimentary rocks giving the appearance of beds and often laminae, but not produced by the processes that brought the rock masses into existence. Furthermore, these structures have been formed both with horizontal attitude and with considerable inclination to the horizontal without relation or reference to the amount of tilting that has been suffered by the formation in which they are found.

If the genetic relationship were not to be insisted upon in the definition of the term stratification, but simply the arrangement in layers or beds, such structures might be referred to as secondary bedding or secondary stratification. But in the opinion of the writer, it is desirable to limit the term stratification to the genetic types outlined above and to consider the genetic relationship as an essential element of the concept stratification. On this basis the term pseudostratification is proposed and will be used in the present paper for any structure that closely simulates stratification as defined above, but which is not the expression of an original laying down of the rock-mass layer upon layer on some preëxisting basement or floor. The individual bed-like masses may then be called pseudostrata, any thin subdivisions, pseudolaminae.

Territory studied.—The territory within which these phenomena were particularly studied lies in the central part of Santa Barbara County, California, within the Lompoc quadrangle of the United States Geological Survey, in the hilly country between Los Alamos Valley and Sisquoc Creek (often called “river”), and especially in the vicinity of Cat Cañon (Cañada del Gato), and the country between it and Foxen Cañon.

General nature of formations involved.—The rocks in which these structures are chiefly developed are massive friable Tertiary sandstones—part of the Fernando formation of the Geological Survey—which here usually show only a light development of a cement and which generally crumble down into smooth, rounded slopes showing no surface exposures and rendering the problem of determining the detailed structure of the region rather difficult. The background of plate 5 illustrates the type of topography involved. Uncemented conglomerate or pebbly sandstone may also show like structures.

This territory is in part a petroleum producing district and has therefore been subject to considerable “prospecting” in which the determination of the structural details was an important part of the work, and the common absence of exposures

showing the real attitude of the strata, and the presence of exposures of pseudostrata, have produced considerable confusion.²

Occurrence and appearance of exposures.—The usual occurrence of exposures of pseudostrata is on the sides of stream cuts or small cañons, well up towards the top near where the cañon slope intersects the normal hill slope. We may usually distinguish, below the soil layer, a layer of friable sandstone generally extending from one to five feet below the surface, sometimes to ten or more feet. Then follows a more distinctly indurated layer with parallel or approximately parallel boundaries and varying in thickness from two to four or five feet in different localities. Below this follows a more friable layer, partly or wholly covered with hill wash or talus, which covers the slope from there down to the stream channel. Sometimes these exposures are produced by small landslides or local washouts on some slope. They may vary in length from twenty or thirty feet to a hundred yards or more.

As a rule the attitude of the exposed layers roughly coincides with the surface slope—most commonly the general hill slope, occasionally the cañon slope. In making a section, therefore, across a ridge in areas where no other kinds of exposures are found, it appears as if the ridge were anticlinal in structure. Such an appearance is illustrated on the hills south of Foxen Cañon, and is particularly interesting because the real structure under one of the pseudoanticlinal areas is synclinal.

The appearance of a pseudostratum in exposure is shown in plate 3. Without careful examination with this particular problem in mind, it is not always easy to distinguish such exposures from those of the original stratification of sedimentation.

Determination of original structure.—The real attitude of the formations with reference to their original planes of deposition is frequently very difficult to determine. Bare fossil layers, thin streaks of gravel in the sand, or shaly layers, occasionally

² For the general distribution of formations and for general structures, reference may be made to the geologic map in Bulletin 322 U. S. Geol. Survey, on the Santa Maria Oil District. On this map structure lines are made to stop before reaching the area where pseudostratification is best developed, and the interpretation of the general structure is evidently affected by the occurrence of these exposures and the general lack of distinct stratification exposures.

furnish the proof. In a number of cases where the bed in which the pseudostratification had developed was itself without original visible structure lines, a recent slide or wash, or an excavation made for the purpose, showed distinct structure lines in an under- or overlying layer, especially in shale streaks, or in layers with arranged micaceous materials. A test area of about two square miles, where the only exposures appeared to be those of pseudostratification, was worked over, and it was found that on the careful examination of the deeper slides and washes, and particularly of a series of excavations, a consistent group of observations could be obtained determining the original stratification and the attitude of the original beds. It showed a very open syncline while the more evident exposures of pseudostrata gave consistent indications of an anticline (a pseudoanticline), the axis of the syncline being quite a distance south of the axis of the pseudoanticline.

Subordinate secondary layers.—All of the pseudostrata do not show within themselves distinct minor layers, but in some they are very well developed, and vary from two or three millimeters in thickness up to ten or more centimeters. Layers of this latter thickness down to those of two or three centimeters are more common than the very thin ones, which may be called pseudolaminae. They are often bounded by separation planes and samples may be removed from their exposures as thin plates or approximately parallel bounded blocks. Such a block is shown in plate 6, figure 3. These features are more common in pseudostrata occurring with dips of ten to twenty degrees or more.

Sometimes these minor layers within the pseudostrata are quite parallel and continue for a number of yards—perhaps throughout the whole exposure. Sometimes they may be curved or may cut obliquely across the pseudostratum, or one division plane may cut obliquely across the others. Such oblique and curved arrangements may give rise to appearances that may be called pseudo-current bedding. Typical cases are illustrated in plate 4 and plate 5.

Pseudofolds.—It has already been described how the exposures over an area may consistently give the impression of a folded arrangement of the strata. Plate 5 illustrates a some-

what different case. It shows a structure that a number of men have taken to be an anticline, although the strata on both sides have not the same appearance. On the left can be seen the original stratification, on the right the pseudostratification. The original stratification does not show itself to the eye in the right hand part of the exposure even upon careful examination. The more indurated pseudostratum appears to be cross-bedded. The vertical parallel columnoid appearance of the layer under the pseudo-crossbedded stratum is simply a channeling of the surface of the uncemented sand, in part by dripping water, chiefly by the action of falling sand particles dislodged by various agents or blown by the wind.

Cement of indurated layers.—Some of the indurated layers are grayish white, others yellowish or brownish, and many show in part a color banding, or irregular color blotches suggesting concretionary deposition of cement. Small white or yellowish veinlets of secondary deposition are occasionally found, and the minor layers (and laminae) are often separated by coatings which vary from one-half to three millimeters in thickness, and may be brown or yellow or almost white.

The first material examined was that of the white veinlets, as they were presumably of the purest and most easily separable secondary substance. It is dull opaque white and rather porous and has the appearance often presented by secondary crusts of calcium carbonate or dull sinter.

This material is insoluble in hydrochloric acid, infusible before the blowpipe where it sinters and gives up water, easily soluble in hydrofluoric acid with little or no residue, and fuses with soda to a clear glass. Under the microscope it is chiefly amorphous with a showing here and there of anomalous double refraction. These properties, combined with the refractive index, determine it to be amorphous hydrous silica—opal.

The general cement which has indurated pseudostrata and pseudolaminae is essentially of the same nature in all of the samples examined. The amount of carbonate material is very slight or absent—practically negligible. The ochreous yellow or brown rocks, the predominant types, owe their color to hydrous

oxides of iron, which occasionally act as a cement of minor importance. The chief rôle is played by opaline silica, as the following tests indicate.

Boiling or long standing in contact with concentrated hydrochloric acid turns the rock white and yields a ferruginous solution, accompanied by a slight superficial disintegration, a few of the surface grains becoming disconnected from the mass and settling to the bottom of the liquid. This disintegration action is probably due to physical action, however, more than to the freeing of grains by the solution of the cement.

Boiling with hydrofluoric acid quickly disintegrates this mass; the grains fall apart and we have a clear sand as a residue.

A similar boiling with potassium hydroxide solution completely disintegrates the rock into a ferruginous sand, if a yellow or brown specimen be used, or, if it be one previously leached by hydrochloric acid, a clean white sand results.

A preparation of the sandstone cleared by hydrochloric acid treatment shows distinctly under the microscope the amorphous coating on and between many of the grains, and a crushing of the grains between slide glasses disconnects some of the coating, which shows the characteristics of opaline silica.

The usually ochreous-colored coatings or separation laminae that are often found where distinct separable layers or laminae occur are in like manner determined to consist chiefly of amorphous hydrous silica, colored with ferric hydroxides, and including minute crystal fragments much smaller than the average grain of sandstone, but evidently derived from it mechanically.

Sand pendants.—In a few places where the pseudostrata were undermined by erosion or caving, small sand pendants and mammillations were observed. These vary from slight just noticeable protuberances up to pendants ten or more centimeters in length. They may be roughly cylindrical, with various irregular cross-sections, or, in the shorter ones, conical.

These all have a central core of whitish, dull, opaque, porous opal, similar to that of the white veinlets described above, and usually showing a distinct concentric structure. The axial portion of the concentric structure may be hollow. The outer

portion, representing usually from about the same to double the thickness of the core layers, is of sand cemented by silica, and more or less colored by iron.

These forms probably originated from plant rootlets which, during their decay, became loci for the silica deposition which is rather pure where the rootlets themselves originally were. The outer sandy coatings are bound to the axial portions by silica cement deposited upon and in extension of the siliceous nucleus. They often have the appearance of stalactites. Some small sand pendants are shown in plate 6; their external forms in part broken and not terminated, in figure 2, and longitudinal and transverse sections, showing the silica core and central hole, in figure 1.

Explanation of phenomena.—In seeking for an explanation of these phenomena the position and attitude of the pseudostrata with respect to the surface of the ground is of fundamental importance. As to position, the more indurated layers always have their tops near the surface, rarely over ten or twelve feet below it. In attitude they generally agree with the surface slope, sometimes dipping at a slightly greater angle than the surface. In the cases observed where they dip at a less angle than the surface, and then usually outcrop, the surface slope has been very recently modified by erosion, such as the undermining action of a stream or land sliding and the consequently accelerated hill wash in its vicinity.

The general appearance is often that of three layers or more; when three they are the upper friable below the soil, the indurated, and the lower friable. The appearance of more than three is due to pseudolamination of the indurated layer. There is, however, essentially one layer to account for—the main indurated pseudostratum. This appears to be due to a superficial belt of cementation within the weathering zone, and dependent on the aridity of the climate, the lower limit of cementation being the lower limit of migration of the silica under normal conditions.

The action is, therefore, analogous to the formation of hardpan in soils³ from which it differs chiefly in the fact that it occurs in the midst of a rock formation below the definite soil

³ See Hilgard, E. W., *Soils* (New York, 1910), pp. 162 and 183.

layer, and that it produces a structural appearance closely simulating stratification. It might readily happen that similar phenomena would arise from the deposition of a calcareous or ferruginous instead of a siliceous cement.

Necessary conditions for production of observed phenomena.—

An essential condition for the formation of pseudostratification as exhibited in the localities studied is a porous, moderately even-grained sediment, massive over the areas exposed. That is, it must be without definite segregation of the material into layers of different grain, or alternations of more porous and less porous layers, or other definite marks or conditions resulting from original stratification that might influence the percolation or deposition of cement, and disturb the formation or appearance of the new and independently oriented lines of structure. Furthermore, the climatic conditions would have to be such that while water would be supplied to dissolve, transport and deposit the cement, it would not be humid enough to wash all such solutions into a general ground-water system, and so prevent cementation near the surface.

The rainfall, in other words, should mainly be by short, disconnected showers, giving but a moderate water penetration. This degree of aridity is commonly realized in the western states. The fact that the dip of the pseudostrata is often greater than that of the surface is probably due to the greater penetration of the rain lower down the slope, where the ground may be supplied not only by the direct dropping of water from the atmosphere, but also by the surface movement of the rain sheet from the higher slopes.

The predominance of silica in the cement is probably due to the composition of the sands here involved. Clay substance is very slight in amount, calcium and magnesium unimportant because there is a dearth of decomposable basic feldspar or lime-magnesium-iron minerals, while silica can be derived from the plentiful orthoclase and acid plagioclase, and perhaps from the abundant quartz.

An important auxiliary condition which renders the pseudostratification the more easily mistaken for true stratification is the disintegrable nature of the original formations which yield

a regolith which very effectually hides such indications of stratification as are present, the only exposures showing any structural characters whatever over considerable areas being exposures of pseudostrata.

Origin of subordinate layers.—A more difficult matter to explain is the very distinct layers and lamellae into which some of the pseudostrata are divided, and which are illustrated in plates 4 and 6. These are frequently parallel-sided, sharply defined and physically separable, either by simply lifting the upper from the lower or after a light blow from a hammer, and often with siliceous coatings separating them.

While not visible as such, it seems possible that the cement is deposited with a more or less banded structure due to different penetrations and different levels of depositions in different seasons. In hardpans, where calcareous or ferruginous cement is abundantly developed, a roughly horizontal banding may be distinctly visible. Any agent, then, producing fracture in the rock,—temperature changes, plant action, even the drying out and shrinkage of the siliceous cement,—would tend to break it along the banding surfaces.

In a specimen collected, a distinct silica-coated, roughly parallel-faced layer about three centimeters thick, is a crack running somewhat obliquely to the bounding surfaces, and traceable for about fifteen centimeters on one side and six on the other. It is very distinctly not due to pressure or to faulting or shearing, and it is apparently not a bounding line between two layers of deposition of cement. It may be due to shrinkage or temperature changes. The plane determined by it is partly occupied by a coating of silica. It is shown in plate 6, figure 3.

Some of the silica coatings are peculiarly marked by an irregular network of minute furrows like numerous small worm tracks. These are evidently the impression of fine rootlets, as individuals can be traced and their gradual tapering and branching distinctly made out. Such thin mats of interlocking rootlets are quite competent to extend and complete cracks that may have been started by other agents. They are to be expected only in an exposure or quite near the surface.

The best separation planes were noted in the pseudostrata

with considerable dip. Some of these planes appeared as if they had been formed by a bodily slipping of the wet, poorly cemented sand material, and the consequent development of a plane of more easy water percolation, and therefore silica deposition. Such slipping surfaces may be plane for several meters, or they may be short, irregular, or curved and give the appearance of cross or current-bedding.

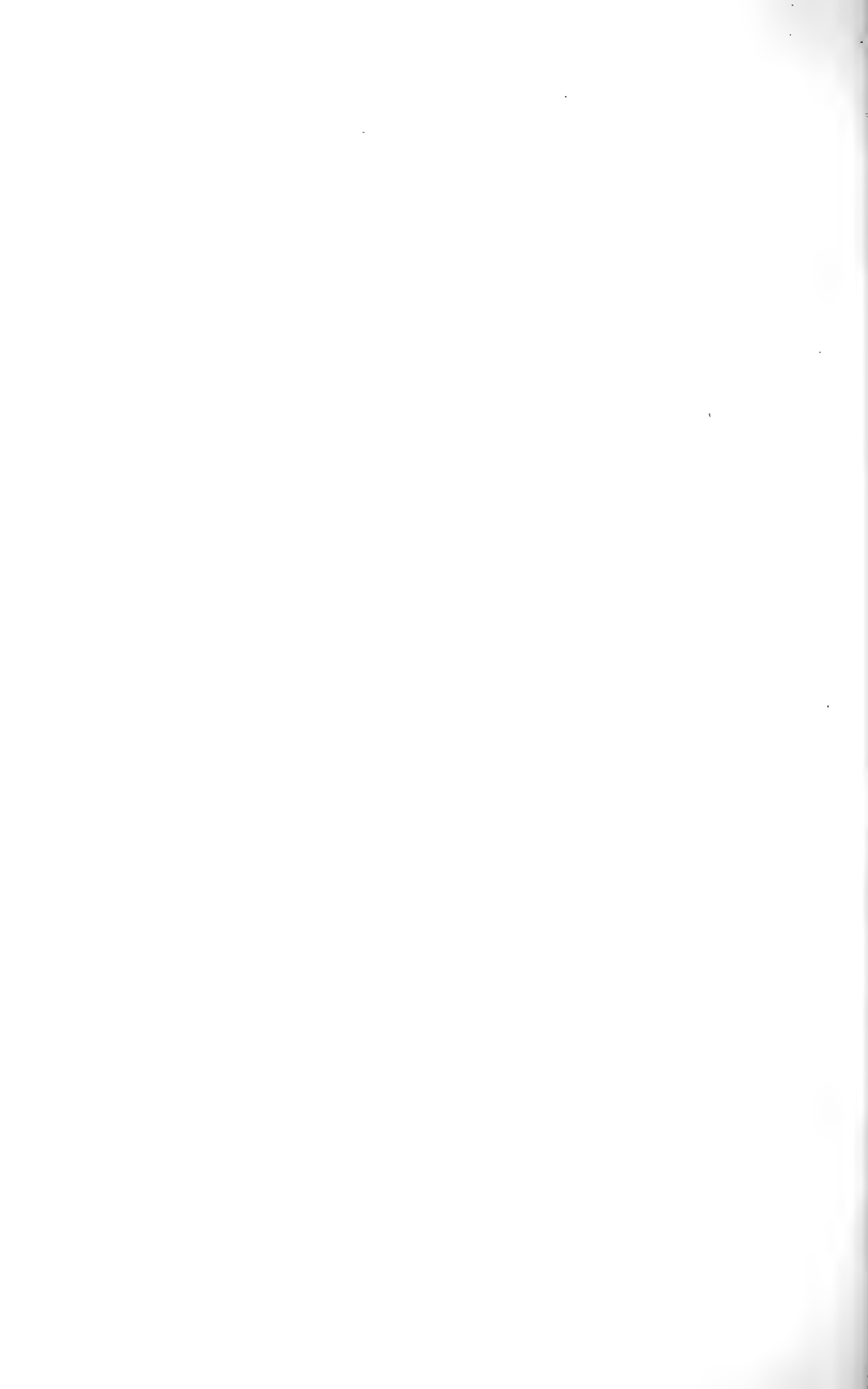
Some of the lamellae show a visible banding of the ferruginous cement parallel to the bounding surfaces. This may in part antedate the formation of the layers, and may have contributed to their production, but in several cases carefully examined, the distribution of ferruginous bands was so peculiarly related to the form of the layer, that it seems necessary to believe that they were later and dependent on it for their form of deposition.

Transmitted March 4, 1912.

EXPLANATION OF PLATE 3

Typical exposure of an approximately horizontal pseudostratum. The real stratification dip (not visible) is down to the right at about 10° . Tinaquaic grant, Santa Barbara County.





EXPLANATION OF PLATE 4

Minor pseudostrata and pseudolaminae. Tinaquaic grant.

Fig. 1.—Lamination approximately parallel to cañon slope. Narrow and more prominently weathering separating layers chiefly of silica. True dip away from observer (north, 8°). Dip of pseudolamination, east 30° .

Fig. 2.—Same locality, showing pseudostratification planes as planes of separation.



Fig. 1



Fig. 2



EXPLANATION OF PLATE 5

Pseudoanticline. Upper Cat Cañon, looking east. True stratification visible on left, dipping north; pseudostratification on right, dipping south. The main pseudostratum has a cross bedded appearance. The columnar layer below is sand fluted by dripping water and falling particles.



EXPLANATION OF PLATE 6

Sand pendants and minor stratum.

Fig. 1.—Sections of sand pendants split longitudinally and broken transversely. The inner light portion is chiefly hydrous silica, the outer dark portion, sand cemented by silica. The central hole is seen in the lower transverse sections and in part in the upper right-hand longitudinal section. Natural size.

Fig. 2.—Portions of sand pendants to show outer surface and general form. None show complete length. Natural size.

Fig. 3.—Separated layer from exposure shown in plate 4, figure 2. The white edges of the secondary silica layers are well shown. The upper surface is coated with such a layer showing ramifying channels as if impressions of plant rootlets. Joint planes transverse to layers are also coated with silica. One newly developing crack is shown on left side, and its walls are also coated with silica. The light colored blotches are due to varying amount of hydrous oxide of iron. It is disposed in bands parallel to the layer surfaces and also in irregular areas determined by the concretionary type of deposition. $\frac{3}{4}$ natural size.



Figs. 1 and 2



Fig. 3



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RECENT DISCOVERIES OF CARNIVORA IN
THE PLEISTOCENE OF RANCHO
LA BREA

BY

JOHN C. MERRIAM

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RECENT DISCOVERIES OF CARNIVORA IN
THE PLEISTOCENE OF RANCHO
LA BREA

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INTRODUCTION

Until recently no remains of true bears and none representing cats of the puma type have been discovered in the collections of carnivore remains obtained at Rancho La Brea. Absence of these two groups has therefore been generally considered as one of the peculiar features of this fauna. Bears of the arctothere group are known from fragmentary remains representing a large species which has been tentatively designated as *Arctotherium californicum*.¹ True cats are represented at Rancho La Brea by the gigantic lion, *Felix atrox bebbi*,² and by wild-cats of the type of *Lynx californicus fischeri*.³

Included in collections from Rancho La Brea which have been prepared for study within the past year there are several fragmentary specimens which evidently represent a bear of the *Ursus* type, and a cat closely related to the existing pumas. These discoveries are of some significance in connection with studies on the distribution of the fauna of Rancho La Brea with reference both to time and to space, and it is therefore deemed desirable to record the information available.

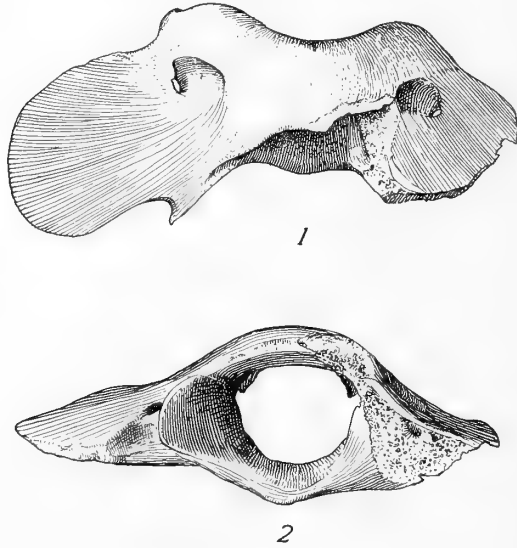
¹ Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol. vol. 6, p. 165, 1911.

² Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol. vol. 5, pp. 291-304, 1909.

³ Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol. vol. 5, p. 394, 1910.

URSUS, sp.

The remains referred to *Ursus* consist of an atlas (no. 12786) and fragments of other vertebrae. The atlas (figs. 1 and 2) is distinctly of the ursid type. It resembles *Ursus*, and differs from



Figs. 1 and 2. *Ursus*, sp. Atlas. No. 12786, $\times \frac{1}{2}$. Fig. 1, superior view; fig. 2, posterior view. Rancho La Brea Beds.

Arctotherium in the character of the posterior opening of the vertebrarterial canal. The general form of the transverse process seems also to resemble *Ursus* more closely than *Arctotherium*, although this cannot be demonstrated as the ends of these processes are broken away.

In such material as is available for comparison the atlas of *Ursus* differs from that of *Arctotherium* in the location of the posterior opening of the vertebrarterial canal. In *Ursus* this opening is on the upper side of the posterior face of the transverse process; in *Arctotherium* (fig. 3) the posterior opening is on the upper side of the transverse process some distance in advance of the posterior margin, much as in the Canidae. In

Ursus the posterior articular faces of the atlas commonly extend backward on angular processes which project some distance behind the proximal region of the posterior border of the trans-



Fig. 3. *Arctotherium simum* Cope. Atlas, superior view. No. 3035, $\times \frac{1}{2}$. Pleistocene of Potter Creek Cave, California.

verse process. In *Arctotherium* the posterior border of the transverse process is slightly notched, but the plates supporting the posterior articular faces are not as prominent as they may be in *Ursus*, and there is a very narrow posterior notch. In both of the characters just mentioned atlas no. 12786 from Rancho La Brea is distinctly ursine rather than arctotherine.

The atlas may be referred to the genus *Ursus*, but specific determination is hardly possible with the material available. In form, size, and position of the posterior opening of the vertebrarterial canal the atlas specimen from Rancho La Brea is nearer to the black bear than it is to the grizzly. The form of the transverse processes differs somewhat from both black and grizzly. Unfortunately in the fossil specimen these processes are incomplete on both sides, and no distinctive characters can be based upon them.

The animal represented by the ursine atlas from Rancho La Brea was about as large as a grizzly of average size, but was very considerably smaller than the gigantic *Arctotherium californicum* known from these beds.

MEASUREMENTS OF ATLAS

Least anteroposterior diameter on dorsal side.....	25.3 mm.
Greatest transverse diameter across anterior articular faces.....	65.5
Greatest height of neural canal.....	26.

FELIS, near HIPPOLESTES Merriam, C. H.

The remains referred to the puma group of felines consist of a portion of a mandible and four perfect metapodials. The jaw and two of the metapodials were found near together and may represent the same individual. They agree approximately in form and dimensions with the corresponding elements of existing cougars included in *Felis hipolestes*, but it is hardly safe on the basis of such fragmentary material to assume that the species can be definitely determined.

The jaw fragment (fig. 4) is almost identical in dimensions

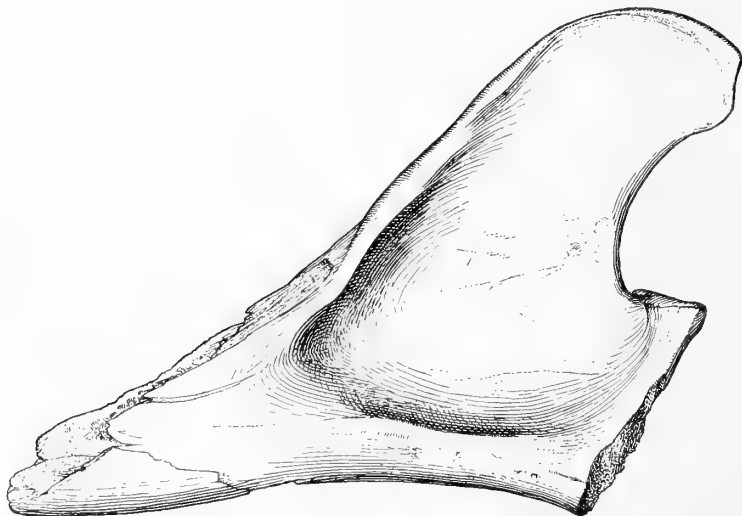
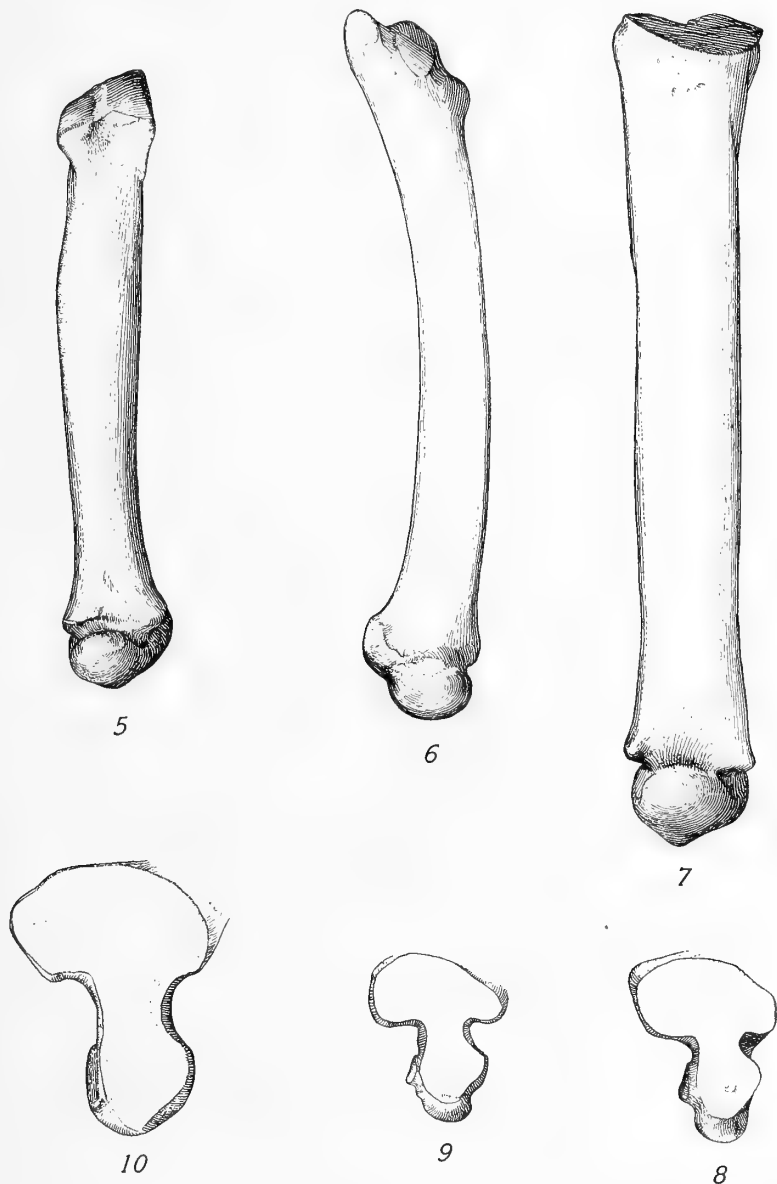


Fig. 4. *Felis*, near *hipolestes* Merriam, C. H. Fragment of mandible. No. 19525, natural size. Rancho La Brea Beds.

with the average of several specimens of *Felis hipolestes*, but differs slightly in the shape of the coronoid process from the normal form in this species. In most specimens of *F. hipolestes* a line drawn between the middle of the posterior side of the condyle and the most posterior part of the upper region of the coronoid process will lean forward. In the specimen from Rancho La Brea such a line is tipped strongly backward. This is generally considered as a characteristic of the tiger, and is a



Figs. 5 to 8. *Felis*, near *hippolestes* Merriam, C. H. Metapodials, natural size, Rancho La Brea Beds: fig. 5, metacarpal IV, anterior view, no. 19526; fig. 6, metatarsal V, anterior view, no. 12245; fig. 7, right metatarsal III, anterior view, no. 19290; fig. 8, left metatarsal III, proximal end, no. 19290. Fig. 9. *Felis hippolestes* Merriam, C. H. Proximal end of left metatarsal III, natural size, Recent, California. Fig. 10. *Felis atrox bebbi* Merriam, J. C. Proximal end of left metatarsal III, natural size, no. 12679, Rancho La Brea Beds.

feature of all specimens of *Felis atrox* thus far examined. In the Rancho La Brea specimen the character just mentioned is coupled with distinctly greater anteroposterior diameter of the upper portion of the coronoid process. This deviation from the form of *F. hippolestes* is, however, so slight that it may have no real taxonomic value.

Of the metapodials representing the small *Felis* form, metacarpal four (fig. 5) is very slightly larger than that of an average specimen of *F. hippolestes*, but is distinguished by the character of the antero-medial region of the shaft. In the specimens of *F. hippolestes* available this area of the shaft is regularly rounded, and almost without tendency to development of an antero-medial angle. In the Rancho La Brea specimen the proximal half of this region is decidedly angular, and is swollen medially so as to produce a noticeable prominence. There is reason to doubt that this difference is due solely to individual variation.

The specimen representing metatarsal five (fig. 6) is a little larger than that of the individuals of *F. hippolestes* available. The Rancho La Brea specimen differs from the Recent ones only in greater width of the postero-medial face for articulation, with metatarsal four, and in the more distinctly angular nature of the proximal portion of the lateral margin.

A right and a left metatarsal three (fig. 7), evidently from the same individual, are a little larger than the corresponding elements of an average specimen of *F. hippolestes*. The dimensional relations between these elements, and the metatarsal five referred to *F. hippolestes* above are almost exactly similar to those between metatarsals three and five in the Recent *F. hippolestes*. The third metatarsals differ distinctly from those of *Felis atrox* and *Felis leo* in certain characters in which these two forms are alike; and in the respects in which they differ from *F. leo* and *F. atrox* they are almost identical with *F. hippolestes*.

The resemblance of metatarsal three in the Rancho La Brea specimens to the pumas, and its separation from the lions, is particularly noticeable in the form of the proximal end, and in the nature of the facets of this region. (See figs. 8 to 10).

In the puma the roughly hammer-shaped proximal articular face shows commonly a very narrow notch on the medial side, and the posterior end of the facet terminates with a clearly-defined margin some distance anterior to the posterior tubercle of the proximal end of this bone. In the *F. atrox* and *F. leo* the medial notch is very wide and the posterior end of the proximal articular facet reaches almost to the end of the posterior proximal tubercle. In the puma the posterior lateral face for articulation with metatarsal four is entirely distinct from the proximal articular face. In the *F. leo* and *F. atrox* this face extends almost if not quite to the latero-proximal angle of the bone. In the third metatarsals (no. 19290), from Rancho La Brea, the proximal facets correspond in form to those of the puma.

The third metatarsals in no. 19290 differ in general form from those of *F. hippolestes* very slightly. They appear a little heavier anteroposteriorly in the proximal region of the shaft, and the antero-lateral side of the proximal end tends to develop a small tubercle between the proximal face and the antero-lateral face for metatarsal four. In the puma the shaft narrows gradually for some distance down from the proximal end, and there is no suggestion of a tubercle in the proximo-lateral region.

The two specimens representing metatarsal three are evidently from a form of the same type as that seen in metatarsal five and metacarpal four described above. This form is not separable from the puma group by any characters thus far known.

Possible relationship of this form to the jaguar, *Felis onca*, has been considered, but the jaw seems to differ distinctly from that species. No material representing the extremities of the jaguar is available for comparison, but the nature of the mandible would seem to suggest that the Rancho La Brea form is a puma rather than a jaguar. Slight differences between the elements available and the corresponding parts of pumas at hand for comparison suggest that the Rancho La Brea specimens may represent a species or a subspecies different from *F. hippolestes*, and possibly a form as yet undescribed.

MEASUREMENTS

Mandible	
Height from inferior margin below masseteric fossa to summit of coronoid process	64. mm.
Height of summit of coronoid process above condyle	37.
Transverse diameter of condyle	30.8
Metacarpal IV	
Greatest length	82.6
Least transverse diameter of shaft	9.2
Metatarsal III	
Greatest length along middle of shaft	108.5
Least transverse diameter of shaft	13.
Least anteroposterior diameter of shaft	10.9
Greatest transverse diameter of proximal end	19.2
Greatest anteroposterior diameter of proximal end	24.3
Metatarsal V	
Greatest length	95.6
Least transverse diameter of shaft	9.1

CONCLUSIONS

The apparent absence of arctotheres, of true bears, and of cats of the puma group from the Rancho La Brea fauna, has appeared to give this assemblage a distinctly ancient aspect compared with other Pleistocene faunas in the Pacific Coast region. There are still many peculiar features in the life of Rancho La Brea which make it seem quite different from that of the Pleistocene known from other localities of this province. Some of these peculiarities will be interpreted as due to difference in time, and some to difference in habitat. The known presence of true bears, arctotheres, and cats of the puma group brings the Rancho La Brea fauna into closer relation with the other Pleistocene faunas of this region than had previously seemed possible.

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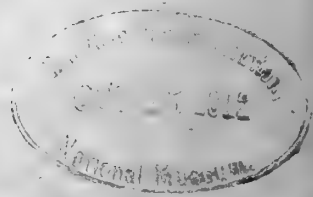
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Issued October 10, 1912

THE NEOCENE SECTION AT KIRKER PASS
ON THE NORTH SIDE OF MOUNT
DIABLO

BY

BRUCE L. CLARK



UNIVERSITY OF CALIFORNIA PRESS
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INTRODUCTION

Mt. Diablo may be described as the core of an anticline which is overturned and overthrust. The Franciscan series forms the core of the mountain mass. Stratigraphically above this and surrounding the mountain is a series of sedimentary formations, ranging in order through the Knoxville (Jurassic ? to Cretaceous), Chico (Cretaceous), Martinez (Lower Eocene), Tejon (Upper Eocene), Monterey (Lower Neocene), San Pablo (Middle Neocene), and Pinole Tuff and Orindan (fresh-water formations belonging to the Upper Neocene).

The beds described in this paper lie to the north of Mount Diablo. The lowest of the Neocene beds are between six and seven miles north of the main peak. The width of the section described is about two miles, the outcrop, mapped, is about six miles long. The general strike of the beds is about N 70° W; the dip varies from 40° to 20° N E.

HISTORICAL REVIEW

The formations of the Mt. Diablo region were first described by Whitney in 1865.¹ In 1891 and again in 1898 Turner² described the section more in detail, listing thirty-eight species of marine invertebrates from the San Pablo on the north side of the mountain, determined by J. C. Merriam.

In 1898 J. C. Merriam,³ in his paper "The Neocene Sea Urchins of Middle California," described the San Pablo formation on San Pablo Bay, and correlated with it marine beds from the vicinity of Mt. Diablo, described as Pliocene by Whitney and Turner.

In 1909 C. E. Weaver, in his paper on the "Stratigraphy and Palaeontology of the San Pablo formation in Middle California,"⁴ gave a brief description of the San Pablo in the region

¹ Geological Survey of California, vol. 1, pp. 31, 1865.

² Bull. Geol. Soc. Amer., vol. 2, p. 383, 1898; Jour. Geol., vol. 6, pp. 443-449, 1898.

³ Univ. Calif. Publ., Bull. Dept. Geol. vol. 2, no. 4, pp. 109-118, 1898.

⁴ Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, no. 16, pp. 243-269, 1909.

of Mount Diablo, listing forty-six species of marine invertebrates from the beds on the north side of the mountain.

Both Whitney and Turner stated that there was apparently a conformable sequence of formations from the top of the mountain down, including Cretaceous, Eocene, Miocene, and Pliocene. Since these papers were published, unconformities have been reported between the Franciscan and the Knoxville, the Chico and the Martinez, and the Martinez and the Tejon.⁵

MONTEREY

Relation to Tejon.—The Monterey series forms the basal member of the Neocene on the north side of Mount Diablo. Between unquestionable Monterey and Tejon it has not as yet been possible to draw a sharp line in this section.

A series of light brown to gray, micaceous, medium-coarse, massive sandstones about 2000 feet in thickness which underlie the clearly recognized Monterey is possibly the upward continuation of the Tejon, but so far no invertebrate fossils have been found in them. Carbonaceous material, including leaves and wood, is abundant in the upper part of this formation, and it may be possible in the future to get good leaf collections that will throw some light on the question of the age of these beds. This zone is doubtfully referred to the Tejon but intensive collecting will be necessary before its age can be certainly determined.

Shale Member.—Above the micaceous sandstones just described, and having the same dip and strike, appears a series of shales, 150 to 200 feet in thickness, which quite certainly represents the Monterey. The lowest member of this series is a layer of white to light buff, diatomaceous shale, which in some localities contains considerable lenses of limestone. Just what relation these shales have to the micaceous sandstones below is not clear.

The Monterey shale of this section is in some localities thin-bedded and slightly cherty. In other places it appears as a

⁵ Dickerson, R. E., Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, no. 8. pp. 174-176, 1911.

typical soft, light diatomaceous earth, such as is characteristic of the Monterey in the many parts of the state. The lower part of this shale band is very diatomaceous, the most common diatom present is of the genus *Coscinodiscus*. The upper portion of this member is more argillaceous and darker in color; diatoms are absent and leaf impressions are quite common. Fish scales and vertebrae are very common through the shale. Thus far, only two species of invertebrates have been found in the shale; these are *Leda cahillensis* Arnold, and an ophiuroid. The latter appears to be a species found commonly in the Monterey near Pinole Station on San Pablo Bay. These two species, taken with the lithologic character of the shales, indicate that the beds are Monterey.

Carbonaceous Shales and Sandstones.—The shale just described in the Kirker Creek section grades up into a series of massive sandstones alternating with thin layers of shale and clay. The sandstones are, for the most part, soft, of a medium-coarse texture, massive, and vary from a gray to a yellow-brown color. The shales and clays interbedded with the sandstones show considerable variation. Some of the layers of the shale are black, others are nearly pure white. Carbonaceous material, and impressions of leaves and wood are abundant in many parts of this zone, and it appears that the beds were deposited under estuarine or fresh-water conditions. The combined thickness of this part of the section and the shale below is roughly estimated as 1000 to 1200 feet.

Tuffaceous Shales and Sandstones.—Above the shales and massive sandstones just described is a series of white ash-beds, tuffaceous shales, and fine tuffaceous sandstones. These beds in the vicinity of Kirker Creek have a thickness of about 400 feet. They were included by Turner and by Weaver in the San Pablo formation. The results of the writer's work show that they belong to the Monterey, and lie unconformably below the San Pablo.

The following is a section seen in these tuffaceous sandstones and shales about one mile to the west of Kirker Creek (SW $\frac{1}{4}$, Sec. 3, R. 1 E, T. 2 S). At the base of these beds, immediately above the massive sandstones and shales already de-

scribed, is a thin layer of conglomerate. The conglomerate grades up into a fine gray sandstone, and a few feet above the base is a thin layer of hard, dark-brown, conglomeratic sandstone, in which the following species of marine invertebrates were found: *Dosinia whitneyi*, *Maetra*, n.sp., *Nucula (Acila) dalli*, *Marcia*, cf. *oregonensis*, *Solen rosaceus* ?, *Yoldia cooperi*, and *Lunatia lewisi*. Above this fossiliferous layer the sandstones grade up into a shaly and sometimes sandy tuff. These beds are light gray to white in color. They are quite argillaceous and crumble easily in the hand. Turner determined the tuff beds of this horizon to be rhyolitic in composition, giving an analysis of a specimen. The upper part of the series grades into a fine sandstone which is quite fossiliferous. At several horizons impressions of shells were found, and leaf impressions are common, especially toward the top. Lying unconformably on these upper sandstones is the conglomerate of the basal San Pablo.

About one mile to the east of the section described above, just to the east of the Kirker Creek, the sandstones at the top of the Monterey are lacking, the upper part of the Monterey being a white, fairly hard, shaly tuff, which is interbedded with thin layers of fine to medium coarse, sometimes cross-bedded, tuffaceous sandstones. As these tuffaceous beds are followed to the east, they gradually thin out. About two and one-half miles to the east of Kirker Creek, on the west side of Markley Cañon, only ten to fifteen feet of these shaly tuffs are seen just below the San Pablo. On the east side of Markley Cañon the tuffs are absent, and here the San Pablo rests on a lower member of the Monterey.

Fauna of Upper Monterey.—The beds described above contain the following fauna:

<i>Cryptomya</i> , cf. <i>ovalis</i> Conrad.	<i>Yoldia cooperi</i> Gabb.
<i>Dosinia whitneyi</i> Gabb.	<i>Amphiura</i> , sp. (?)
<i>Modiolus multiradiatus</i> Gabb.	<i>Calyptrea inornata</i> Gabb.
<i>Macoma nasuta</i> Conrad.	<i>Cancellaria</i> , sp. (?)
<i>Maetra</i> , n.sp.	<i>Cerithium</i> , sp. (?)
<i>Marcia</i> , cf. <i>oregonensis</i> Conrad.	<i>Clavella</i> , n.sp.
<i>Nucula (Acila) dalli</i> Arnold.	<i>Dentalium conradi</i> (?) Dall.
<i>Panopea generosa</i> Gould.	<i>Dentalium petricola</i> Dall.
<i>Siliqua patula</i> var. <i>nuttalli</i> Dixon.	<i>Lunatia lewisii</i> Gould.
<i>Solen rosaceus</i> ? Carpenter.	

Of the species listed above, *Dosinia whitneyi* does not go higher than the Monterey. *Marcia*, cf. *oregonensis* is one of the most common forms in the Upper Monterey. *Nucula* (*Acila*) *dalli* was first described from the San Lorenzo formation (Oligocene). It occurs in the Miocene of Oregon and Washington. *Mactra*, n.sp., is a form found in the Monterey near the town of Pinole. *Dentalium conradi*? has been found only in the Lower Miocene of this region. *Dentalium petricola* and *Calyptraea inornata* are both common forms in the Monterey, and are not found in the San Pablo. All of the others, excluding the new species, are common forms in the Monterey.

SAN PABLO

General Discussion.—Lying unconformably above the Monterey is the San Pablo. Previous writers have referred to these beds as a formation; further study shows that they may well be classed as a series. This is true, not only for the section to be described in this paper, but apparently also for the type section on San Pablo Bay, and for that on the south side of Mount Diablo. Lithologically there are great variations in the beds, which can be mapped as distinct units. On the south side of Mount Diablo two distinct brackish water zones are found intercalated with marine beds, and at one locality, in Sycamore Cañon to the northeast of the town of Danville, an unconformity is to be seen near the middle of the series. More work needs to be done before it can be determined whether this unconformity may be correlated with an unconformity on the north side of the mountain, described in this paper. Whether either of these unconformities is of more than local significance is not yet determined. In the type section at San Pablo Bay a brackish water zone also appears.

In the description of the San Pablo to the north of Mount Diablo the writer has used the name "series" for these beds, dividing them into two divisions, an Upper Division and a Lower Division. The correlation of these divisions with the upper and lower parts of the section on San Pablo Bay seems justified on palaeontological evidence.

Lower Division.—That part of the San Pablo series which is here designated as the Lower Division has a thickness, as measured to the west of Kirker Creek, of about 350 feet. The basal beds of the Lower Division in this vicinity are composed of a layer of coarse conglomerate which is in places ten to fifteen feet thick. The conglomerate consists of well-rounded pebbles, some of which are three to four inches in diameter. They are mostly made up of quartzites and volcanics, together with some boulders of sandstone and shale. In the vicinity of Markley Cañon the basal beds consist of a layer of massive to very much cross-bedded, coarse to conglomeratic sandstone, that stands out distinctly from the gray sandstones above, because of its reddish-yellow color.

That the San Pablo series in this region rests unconformably on the Monterey is shown by the following facts: (1) There is a difference in strike and dip, and a slight irregularity in contact between the two. (2) The basal beds of the series appear to rest upon different members of the Monterey as one follows the line of the strike. (3) Borers of the pholadid type were found along this contact for a distance of over three miles. (4) Well-rounded boulders lithologically identical with the tuffaceous sandstones and the shales of the Monterey below, are found in the basal conglomerate. These facts, together with the sharp lithological break, leave no doubt as to the unconformable relationship of the San Pablo and the Monterey.

In the vicinity of Kirker Creek the strike and dip of the Monterey and the lower beds of the San Pablo are practically the same, but to the east of Markley Cañon there is a difference in strike of from 10° to 15° and at least 5° difference in dip. As pointed out above, the tuffaceous beds of the Upper Monterey gradually wedge out in going east from Kirker Creek and disappear at Markley Cañon, the basal beds of the San Pablo resting on successively lower horizons of the Monterey.

The Lower Division of the San Pablo in general may be characterized as made up of coarse, massive sandstones, conglomerates, and a very minor amount of finer material. Cross-bedding is very evident at different horizons, and in some localities, especially to the west of Kirker Creek, considerable tuff

is found mixed in with a very much cross-bedded sandstone. The sandstones, especially toward the top, are vivianitic, but are not so blue as those seen in the division above. The Lower Division may be considered a shallow water or strand deposit.

In the section to the west of Kirker Creek, about two hundred and fifty feet above the base of the Lower Division and above a medium fine to shaly, fossiliferous sandstone, is about a hundred feet of coarse, angular-grained, tuffaceous, massive sandstone, which is quite conglomeratic at the base, and very much cross-bedded toward the top. There is a strong suggestion that these cross-bedded sandstones are terrestrial in origin, and are possibly sand-dune material.

Fauna of Lower Division.—The following species of invertebrates were obtained from the Lower Division of the San Pablo series:

Astrodapsis tumidus Rémond.	Olivella pedroana Conrad.
Scutella gabbi Rémond.	Ostrea lurida Carpenter.
Astyris richthofeni Gabb.	Ostrea titan Conrad.
Balanus, sp.	Ostrea vespertina var. sequens ?
Calliostoma splendens Carpenter.	Arnold.
Calyptrea costellata Conrad.	Panopea estrellana Conrad.
Calyptrea filosa Gabb.	Panopea generosa Gould.
Cardium corbis Martyn?	Paphia staminea Conrad.
Cerithium, sp. ?	Peeten pabloensis Conrad.
Chama pellucida Broderip.	Peeten crassicardo Conrad.
Chionella newcombiana Gabb.	Peeten discus Conrad.
Chione, sp. indet.	Phacoides tenuisculpta Carpenter.
Corbicula, n.sp.	Pholas, sp. ?
Crepidula rugosa Nuttalli.	Platydon cancellatus Conrad.
Cryptomya ovalis Conrad.	Pleurotoma, n.sp.?
Dosinea, n. s.	Saxidomus nuttalli Conrad.
Littorina remondi Gabb.	Schizodesma abseissa Gabb.
Littorina, sp. a.	Siliqua patula var. nuttalli
Lunatia lewisii Gould.	Conrad.
Macoma, n.sp.. Conrad.	Solen, n. sp.
Metis alta Conrad.	Spisula albaria Conrad.
Modiolus multiradiatus Gabb.	Spisula catilliformis Conrad.
Mytilus coalingensis Arnold, n. var.	Thais canaleulata Duclou.
Nassa mendica Gould.	Tresus nuttalli Conrad.
Ocenebra lurida var. aspera Baird.	

The most common species in the Lower Division of the San Pablo series are: *Metis alta*, *Mytilus coalingensis*, n. var., *Modiolus*

multiradiatus, *Ostrea titan*, *Saxidomus nuttalli*, *Tresus nuttalli*, and *Crepidula rugosa*. No evidence of faunal zones was found within the Lower Division of the San Pablo.

Upper Division.—Above the massive cross-bedded sandstones in the Kirker Pass section there are several thin layers of hard, dark-gray sandstones, which weather a rusty brown. These hard layers cap one of the larger hills about one mile to the west of Kirker Creek. These layers are lenticular and along the strike in places grade into concretionary sandstones. This zone is very persistent and served as a basis for separation of the lower division of the series from the upper. Impressions of leaves and pieces of silicified wood are found in abundance, both above and below these hard layers. Turner,⁶ in his paper on "The Geology of Mount Diablo," reports the occurrence in this zone, of fossil leaves of the following species, determined by Lesquereux:

<i>Diospyros virginiana</i> , var. <i>turneri</i> ,	<i>Laurus</i> , cf. <i>canariensis</i> Heer (?)
Lx.	<i>Viburnum</i> , cf. <i>rugosus</i> Pers. (?)
<i>Magnolia californica</i> Lx.	<i>Vitis</i> , sp. und.

Just below the hard layers of sandstone mentioned above is a very marked irregular contact. This irregularity is seen between coarse sandstones above and fine shaly sandstones below. This contact was first called to the attention of the writer by Mr. Graham Moody. The irregularity was traced for a distance of nearly a mile. In some places there is as much as three to four feet of relief. As far as could be determined, there was no difference in dip and strike between the beds above and below. That the irregularity is due to erosion, there can be no doubt. The great abundance of leaves and silicified wood along this zone has already been mentioned. Also along this horizon there is a series of silicified trees that stand perpendicular to the dip of the beds. In some cases indications of roots were observed. One can hardly doubt that these stumps are in place.

To sum up, it may be said that an unconformity at this horizon in the San Pablo series is shown: (1) by an irregular contact; (2) by the great abundance of fossil wood and leaves

⁶ Bull. Geol. Soc. Amer., vol. 2, p. 497, 1891. Description of Leaves, U. S. National Museum, vol. I, II, p. 35, 1889.

together with tree trunks standing at right angles to the dip; (3) by the character of the deposits found along this zone; i.e., a very tuffaceous, angular-grained, cross-bedded sandstone.

In the section just referred to, immediately above the hard layers of sandstone, there is a layer of medium-coarse, tuffaceous, angular-grained, concretionary sandstone between ten and fifteen feet thick. This layer is very much cross-bedded, and, like the cross-bedded sandstones below the hard layers, suggests that they are sand-dune deposits. The tufts in these sandstones and the conglomerates above the basal beds of the Lower Division were determined by Turner as andesitic in origin.⁷

The Upper Division of the San Pablo series has a thickness of about 250 feet, and consist mainly of coarse to medium-fine, bright-blue vivianitic sandstones, alternating with irregular bands of light-buff clays. At a number of horizons these clays have a thickness of several feet, and are thin-bedded and may be classed as a shale. The sandstones are the predominating phase of this division.

One of the noticeable features of this part of the series is that the contacts between some of the clay layers and the sandstones are slightly irregular, and the change from a sandstone to a clay is often very sharp. Another thing that is to be noted is that leaf impressions and silicified wood are very common at different horizons in both the sandstones and the clays. It was in the upper part of this division that Turner's leaf collection of 1897 was obtained.⁸

The following flora obtained by Turner from this horizon was determined by Professor F. H. Knowlton:

Fern, probably Pteris, but very fragmentary.	Castanea, sp. leaf.
Populus, female catkin.	Vaccinum, sp. single small leaf.
Alnus, fruits and leaves.	Arbutus, numerous well-preserved leaves.

Fauna of Upper Division.—Good fossil localities in the Upper Division of the San Pablo are very rare. Shells are found at several horizons, but in nearly all cases they are very poorly

⁷ Jour. Geol., vol. 6, p. 497, 1898.

⁸ *Idem.*, vol. 6, p. 498.

preserved. The following species have been collected from the upper beds:

✓ <i>Astrodapsis whitneyi</i> Rémond.	<i>Mya japonica</i> Gray.
<i>Calliostoma splendens</i> Carpenter,	<i>Pecten</i> , n.sp.
n. var?	<i>Pecten discus</i> Conrad.
<i>Cardium quadrigenarium</i> Conrad.	<i>Pecten pabloensis</i> Conrad.
<i>Corbicula californica</i> Gabb.	<i>Platoydon cancellatus</i> Conrad.
<i>Cryptomya californica</i> ? Conrad.	<i>Pseudocardium gabbi</i> Rémond.
<i>Cryptomya ovalis</i> Conrad.	<i>Saxidomus nuttalli</i> Conrad.
<i>Littorina</i> , n.sp., <i>b.</i>	<i>Solen sicarius</i> Gould, n. var.
<i>Littorina</i> , n.sp., <i>c.</i>	<i>Calyptraea filosa</i> Gabb.
<i>Macoma</i> , n.sp. Conrad.	<i>Trophon ponderosum</i> Gabb.
<i>Macoma secta</i> Conrad.	<i>Zirphaea dentata</i> Gabb.
<i>Modiolus multiradiatus</i> Gabb.	

Faunal Zones.—Because of the meagerness of the fauna in the Upper Division it may possibly seem premature to assume the presence of two faunal zones in the San Pablo series corresponding to the two divisions as described. It would seem reasonable to suppose that the absence of certain species from the upper beds that are found in the lower could be accounted for by the larger representation of individuals in the latter, but the absence of certain species in the lower beds that are found in the upper would not indicate that this is the correct explanation of the difference. Some indication of zonal difference between the faunas of the upper and lower divisions is found in the presence in the Upper Division of the following species not known in the Lower Division: *Astrodapsis whitneyi*, *Pseudocardium gabbi*, *Littorina*, sp. *b.*, *Littorina*, sp. *c.*, *Corbicula californica*, and *Trophon ponderosum*. In the Upper Division two new species of *Littorina* are found which are not found in the Lower Division, while *Littorina rémondi* and *Littorina*, sp. *a* are not found in the Upper Division. In the Lower Division a new species of *Corbicula* is found which is not found in the Upper, while *Corbicula californica*, so common in the upper beds, has not been found in the Lower Division.

Practically the entire fauna of the San Pablo at Kirker Pass belongs to shallow water. Quite a number of species, such as *Corbicula*, *Ostrea*, and *Littorina*, are either fresh-water or brackish-water forms.

PINOLE TUFF

Lying unconformably above the Upper Division of the San Pablo is a series of tuff beds. This unconformity is shown by a marked, irregular contact with as much as ten to fifteen feet relief, and a slight difference in dip and strike.

The thickness of these tuffs is about one hundred and fifty feet. The basal bed of this series, as seen west of Kirker Creek, is a layer of a white, massive tuff, three to four feet thick. The beds immediately above the basal white layer are made up of large angular fragments of light-gray to bluish pumice, which are included in a matrix of rather ashy, reddish-brown material. This ashy matrix gives a noticeably red color to the beds. Scattered through these tuffs are angular fragments of volcanic rock, which are undoubtedly volcanic ejections thrown out with the ash. These beds are massive and stand out as prominent layers several feet in thickness.

In the vicinity of Markley Cañon, at the base of the Pinole Tuff, is a layer of conglomerate, which contains subangular water-worn boulders of basalt, two to three feet in diameter. These coarse boulder-beds are overlain by coarse, thick layers of reddish tuff, which weathers out in prominent wall-like outcrops.

One mile and a quarter to the west of Kirker Creek a basalt flow about four feet in thickness was found in these basal beds. This is situated only a few feet above the contact, with the tuff above and below. The rock shows a distinct flow structure, and the upper surface is quite vesicular.

The upper members of the tuff beds lack the reddish color. In some places they are nearly pure white, and have lenses of cross-bedded gravels and sands mixed irregularly with them. Turner determined these tuff beds to be rhyolitic in composition.

The tuff beds above the San Pablo at Kirker Pass have been correlated provisionally with the Pinole Tuff seen on San Pablo Bay, that to the north of Carquinez Straits, and that in the vicinity of the town of Walnut Creek, first, because of their stratigraphic position; second, because of their lithologic and

petrographic similarity. No fossils have been found in these tuffs at Kirker Pass, and it is a question whether they are land or water deposits.

ORINDAN

Above the Pinole Tuff is a series of light-yellow to gray, medium-fine sandstones, and clays. In this region it is difficult to get good outcrops in these beds, and the writer has given very little attention to them. They are provisionally called Orindan, chiefly because of their stratigraphic position. These beds have been folded with all the other formations, and dip gently to the northeast. They extend out into the valley, where they are covered with terrace material.

GENERAL SECTION

GENERAL STATEMENT OF SECTION AS SEEN ABOUT ONE MILE TO THE WEST OF KIRKER CREEK

Orindan		Yellow sandstones and clays.
Pinole Tuff	150 ft.	{ Tuff with gravel and sand. Basalt flow. Massive tuff beds.
San Pablo Upper Division	250 ft.	{ Bright blue vivianitic sandstones alternating with layers of clay. Estuarine deposits, 200 ft. Fossil wood zone, coarse, massive cross- bedded sandstones 50 ft.
San Pablo Lower Division	350 ft.	{ Coarse, massive, very much cross-bedded sandstones. Eolian (?) deposits, 100 ft. Medium to coarse grained fossiliferous sand- stones, thin layers of fine and coarse con- glomerate, tuffaceous cross-bedded sand- stones, coarse gray conglomeratic fossil- iferous sandstones and basal conglomerate, 250 ft.
Monterey	1600 ft.	{ Tuffaceous sandstones, shaly ash beds with leaves and thin layers of cross-bedded sandstones, 400 ft. Carbonaceous sandstones alternating with shales and clays, 1000 ft. Diatomaceous shale, 200 ft.

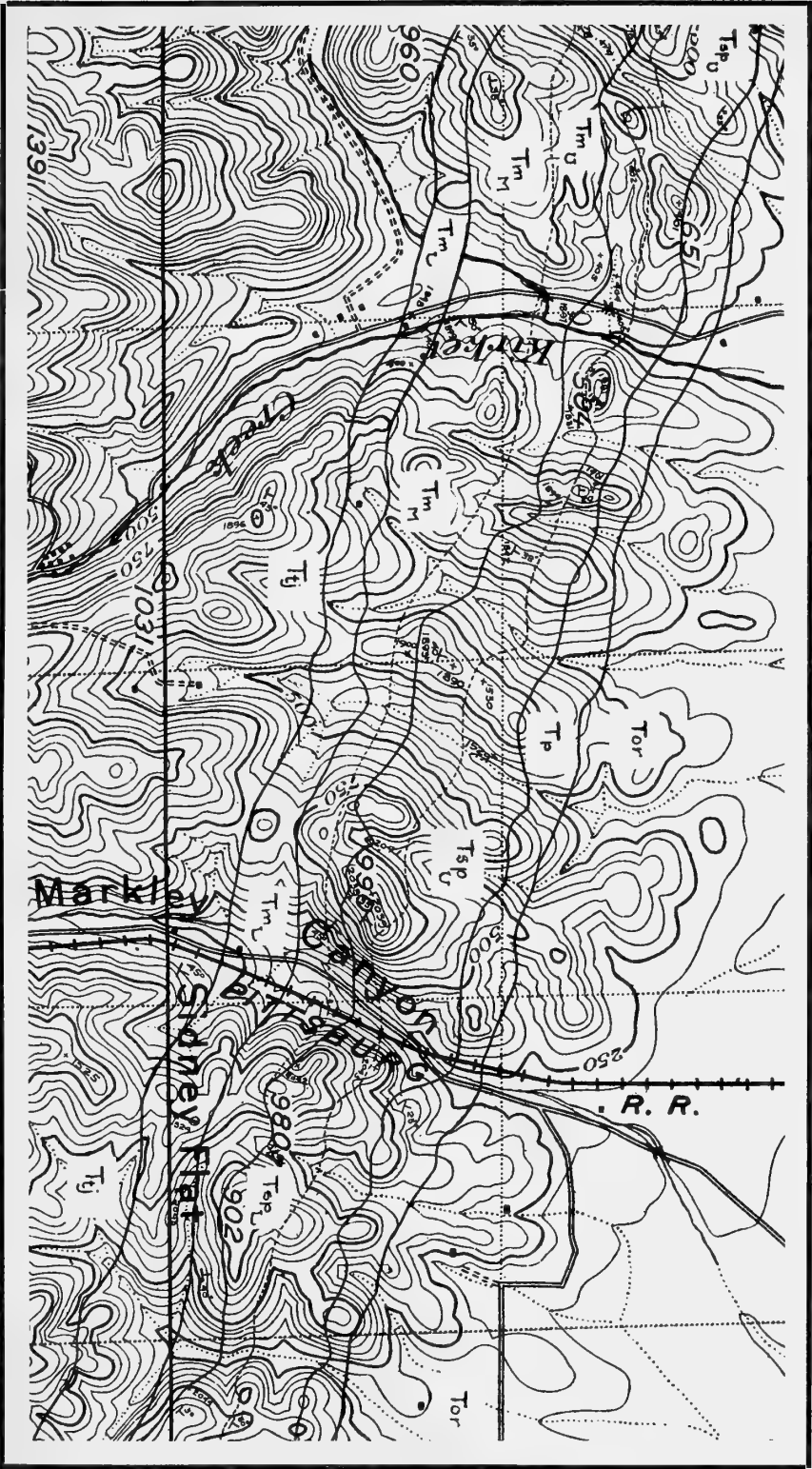
COMPARISON WITH SECTION ON SOUTH SIDE OF MT. DIABLO

The comparison of the Neocene beds on the north side of the mountain with those on the south side is very interesting, especially as regards the San Pablo series. The San Pablo on the south side of the mountain has a thickness of about 2500 feet as against 600 feet on the north side. The lower beds on the south side are more homogeneous than those on the north side of the mountain. The Monterey on the south side lacks the carbonaceous shales and sandstones seen near the middle of the series on the north side.

As a whole, it may be said that the Neocene on the north side of the mountain is characterized in a greater degree by strand conditions than are the deposits on the south side of the mountain.

SUMMARY

Some of the more important results obtained in a study of the Kirker Pass section are as follows: (1) The deposits of a large part of the middle and upper Monterey had either a fresh-water or an estuarine origin; (2) the fauna above and below the estuarine beds of the Monterey series is Lower Neocene in age; (3) a well-marked unconformity exists between the Monterey and the San Pablo; (4) the San Pablo is to be classed as a series rather than as a formation; (5) the deposits of the San Pablo at Kirker Pass are distinctly littoral, grading from marine to brackish-water conditions; (6) in the middle of the San Pablo series there are evidences of land conditions as shown by an irregular contact, fossil wood, leaf impressions, and the character of the deposits; (7) the Pinole Tuff lies unconformably on the San Pablo.



Outline map of Formations at Kirker Pass. Tor, Orindan; Tp, Pinole Tuff; Tsp, San Pablo (U, upper; L, lower); Tm, Monterey (U, tuffaceous beds; M, carbonaceous shale; L, diatomaceous shale); Tj, Tefon.
Adapted from U. S. Geol. Surv. topographic sheet



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CONTRIBUTIONS TO AVIAN PALAEO-
TOLOGY FROM THE PACIFIC COAST
OF NORTH AMERICA

BY

LOYE HOLMÈS MILLER

UNIVERSITY OF CALIFORNIA PRESS
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INTRODUCTION

When the vertebrate palaeontologist turns his attention to the group Aves as represented in North America, especially if he be confronted with the problems represented by a considerable mass of unassorted material, he cannot but feel that he pushes out into almost uncharted waters, a wide sea where the few islands recorded by previous explorers— islands too often shrouded in mist—may perhaps never appear upon his horizon. The scarcity of previous record, the wide separation in place of the bird-bearing deposits, coupled with the inadequacy of descriptions and the poverty of museums in collections of Recent avian osteology—all these are factors which conspire to give the student entering upon such an undertaking the feeling that he stands or falls unto himself. In full cognizance of these conditions the present paper is undertaken. Its dual purpose is the recording of certain facts but recently made known in this interesting field, and the correlating, insofar as this is possible, of the results thus far attained.

ACKNOWLEDGMENTS

Study of the University of California collections was taken up at the invitation of Professor John C. Merriam, head of the Department of Palaeontology of that institution, and to his unstinted aid, encouragement, and advice much of what value this study may possess is here freely ascribed. Grateful acknowledgement is also made to Messrs. Joseph Grinnell and H. S. Swarth of the California Museum of Vertebrate Zoology for information cheerfully furnished on many Recent species and for the loan of osteological material. Specimens of great interest and value were loaned or donated by Dr. F. A. Lucas, Dr. A. Smith-Woodward, Dr. F. C. Clark, Dr. C. O. Esterly, Mr. E. J. Fischer, and Mr. J. Z. Gilbert. The very generous attitude taken by Madam Ida Hancock-Ross and the associated owners of Rancho La Brea in issuing permits to excavate the asphalt deposits made possible the assembling of much valuable material essential to the work. Through the personal efforts of Dr. J. C. Hawver, of Auburn, California, as well as by the very cordial

assistance extended by him to the author, our knowledge of the Hawver Cave deposits has been greatly advanced. To each of these persons the author's sincere thanks are extended.

SIGNIFICANCE OF OSTEOLOGICAL CHARACTERS IN ORNITHOLOGY

In a zoological group of such narrow delineation and of such great homogeneity as the class Aves, where separation into the various systematic divisions is based upon relatively small variations and where these variations affect structures not preserved for study, a considerable degree of care must be exercised when interpreting discoveries of the palaeontologist in terms of modern systematic zoology. The difference noticeable to a worker in the former field should in many cases be multiplied by a very large factor upon their transposal to the latter. Degrees of divergence which to the palaeontologist seem of no more than specific rank might, by the worker in systematic ornithology, having also various intricate details of color-pattern or feather structure at his disposal, be found correlated with differences of more than generic importance. The distinction upon osteological characters of many well-defined species of Recent birds is a matter requiring complete skeletons of individuals of known sex; even then conclusions are often in question. It is here conceded as possible under these conditions, and considering the fact that most of the fossil specimens are not capable of articulation, that many of the fossil specimens ascribed to living species might, if all characters were determinable, be separated as distinct forms. It must be remembered also that within certain groups the osteological differences between species is greater than in others. The feather of the bird is an epidermal structure which reflects with sensitiveness the activities of the animal and is plastic as a specific character under the influences of environmental changes. It is a proper basis of specific distinction, yet it is almost never preserved in the fossil state. The tooth of the mammal, likewise an epidermal structure and highly representative of the animal's activities, is a character used in common by the palaeontologist and the modern systematist. Zoology and palaeontology are then much more nearly upon the same

basis in the determination of mammals than is the case with birds. Recognizing this principle, the author of this paper has proceeded with perhaps more than necessary caution in the announcement of new species, preferring to err on the part of conservatism rather than to confuse the literature of the subject by making assertions which must later be modified; and there are in the collections studied many specimens regarding which further knowledge is considered necessary before problems upon which they may throw light can be attacked in more than a speculative way.

REVIEW OF THE LITERATURE

Since the epoch-making discoveries by Marsh which added so materially to our conception of the ancestry of birds, contributions to knowledge in the field of avian palaeontology have been few as compared with the rapid enlargement of our understanding of the other vertebrate groups. Bird remains on the Pacific Coast are mainly from Pleistocene strata; thus there is eliminated the probability of shedding much new light upon the ancestry of certain groups in which our interest is so acutely focused, for example the *Stereornithes*. Discoveries recently made have contributed to science chiefly in two ways, first in giving us an appreciation of the relative antiquity of the main groups into which birds are divided; and, second, in adding to our knowledge of the geographical distribution of these groups. The consideration of geographical distribution is but begun when we record the range of the Recent species. Determination of the factors which have led to such distribution, if we aspire to something better than mere speculation, must look to the record of previous conditions as brought to light through palaeontological inquiry.

The fossil-bearing rocks of the Pacific Coast of North America, while rich in the remains of mammals and reptiles, have until recently yielded but little information concerning the avian group.

In 1878, Cope¹ described three new species of birds from the *Equus Beds* of Oregon. All three species belong to genera

¹ Cope, E. D., *Bull. U. S. G. S., Terr.*, iv, No. 2, May 3, 1878.

still inhabiting the region; thus their importance is limited to the evidence they furnish of the division of a genus into several coördinate species.

In 1892, Shufeldt² published the results of an extended study of the Cope and the Condon collections of birds from this same region. In this very thorough discussion there are fifty species enumerated, fourteen of which are described as new. The entire number, with the exception of the gallinaceous *Paleotetrix gilli*, are assigned to existing genera. *Phoenicopterus* is the only existing genus recorded which is foreign to the region at present.

In 1894, Cope³ described a single species, *Cyphornis magnus*, from a formation in Vancouver, British Columbia, which he placed with some reservation in the Eocene, but which was later considered by others to be Oligocene. The species is considered as pelecanid in its affinities but generically distinct from any form now living.

Lucas, in 1901,⁴ described a new genus and species of diver, *Mancalla californiensis*, from a formation at Los Angeles, California. From the associated invertebrate fauna, this species is considered by Dall to be of upper Miocene or lower Pliocene age.

As a result of the preliminary study put upon the University of California collections by the present writer, there have appeared a series of short papers dealing with a number of species from Fossil Lake, Oregon, and from the caverns and the asphalt beds of California. While these papers record one unique form, *Teratornis*, of unusual interest, the main value of the contributions, like that of Shufeldt's, lies in the light shed upon the former distribution of families of birds still living.⁵

² Shufeldt, R. W., Journ. Acad. Nat. Sci. Phila., Ser. 2, No. 9, p. 389, 1892.

³ Cope, E. D., Journ. Acad. Nat. Sci. Phila., Ser. 2, No. 9, p. 449, 1894.

⁴ Lucas, F. A., Proc., U. S. Nat. Mus., vol. 24, p. 133, 1901.

⁵ Miller, L. H., Univ. Calif. Publ., Bull. Dept. Geol., vols. 5-6 *passim*, 1909-11.

MATERIAL AVAILABLE

The material upon which studies of the west coast fossil birds have been based has been collected from nine different horizons, summarized as follows:

OLIGOCENE

Vancouver, B.C. One species (a single specimen).

MIOCENE

Virgin Valley Beds, Virgin Valley, Nevada. One species.

Los Angeles, California. One species (a single specimen).

PLEISTOCENE

Potter Creek Cave, California. Sixteen species.

Samwel Cave, California. Nineteen species.

Hawver Cave, California. Twelve species.

Rodeo Pleistocene, California. One species (a single specimen).

Rancho La Brea, California. Forty-nine species.

Fossil Lake, Oregon. Fifty-three species.

The avian collections assembled at the University of California represent seven of these localities. One of the seven is identical with that studied by Cope and Shufeldt, namely, the Fossil Lake region of Oregon. The remaining six collections, so far as known to the writer, have not been studied previous to the assumption of the task here in part recorded. Three or four hundred specimens represent the bird remains from the caves, and three or four thousand have been taken from the asphalt at Rancho La Brea.

So far as can be learned, the Oligocene horizon yielding *Cyphornis* to Cope, and the Miocene, from which Lucas described *Mancalla*, have yielded no other avian fossils.

OLIGOCENE FAUNA

Cyphornis magnus Cope is the only species known to the coast from strata of possibly so great age. The form was described by Cope⁶ from a single specimen, the proximal end of a tarsometatarsus, the property of the Geological Survey of Canada. The osteological characters displayed by the specimen are such as to have led Cope to assign the species with some reserve to the family Pelecanidae. Interest centers to some extent in a combination of the two characters,

⁶ Cope, E. D., Journ. Acad. Nat. Sci., Phila., Ser. 2, No. 9, p. 449, 1894.

large size and high degree of pneumaticity. The latter character was considered by the author of the species as indicating the bird's ability to fly. If such conclusion be true, the species, since the tarsometatarsus equaled in size that of the rhea, must be considered as the largest known flying bird.

It may not be out of place here to consider the propriety of Cope's position regarding the relation of pneumaticity to the power of flight. Let it be conceded that *Cyphornis* belonged to the Pelecanidae, birds of large size which are possessed of a high degree of pneumaticity. We may then ask if the character pneumaticity necessarily became vestigial or disappeared with the loss of ability to fly resulting from increased size. The development of such a character as gigantism might be a matter of comparatively short time, while the persistence of the character pneumaticity might be very tenacious. An instructive case in point is that of *Geococcyx*, a cuckoo of terrestrial habit whose powers of flight have been almost entirely sacrificed. The pectoral arch in this bird is an absurdly weak structure, while there is an accompanying accentuated development of the posterior limb region. Despite this inversion of the appendicular parts, the skeleton remains highly pneumatic. It seems well within the range of possibility that *Cyphornis* should have gained its large size by a rapid specialization—a tendency run riot under certain conditions not adverse to it—and yet this specialization cost the bird its power of flight without blotting out the character of pneumaticity.

MIocene FAUNA

Mancalla californiensis Lucas, from the upper Miocene of Los Angeles, California, is described by Lucas⁷ as being much like the Recent species of murre (*Uria troille*) of that region, but more highly specialized in that it was probably without the power of flight. The single specimen known consists of the major part of the left humerus of a bird about the size of the recently extinct great auk (*Plaurus impennis*). Interest in this discovery lies largely in the strong similarity of the bird to Recent

⁷ Lucas, F. A., Proc. U. S. Nat. Mus., vol. 24, p. 133, 1901.

forms, in its flightless character suggesting to the author of the species an insular breeding-ground free from enemies, and finally in the fact that the accompanying molluscan fauna indicates a climate cooler than that which characterizes the region at present. It is regrettable that a larger number of species was not discovered in the same horizon.

PLEISTOCENE FAUNA

Potter Creek Cave.—Potter Creek Cave⁸ takes its name from its location on Potter Creek, about one mile east of Baird, a station of the U. S. Bureau of Fisheries on the McCloud River in Shasta County, California. The locality lies at present in the lower Transition zone at an elevation of 1500 feet above the sea. The surrounding country is well timbered with conifers, oaks, and maples in the main, and with lower scrub forming thickets in less favorable exposure. Topographically the region is rendered rather rough by numerous small tributaries of the McCloud River cutting through the Baird Shales, and the McCloud Limestones, to form cañons with abrupt slopes and much dissected ridges. The cave occupies at present a position 800 feet above the McCloud River, only slightly over a mile away.

According to the observations of Sinclair, the river flowed during the formation of the cavern deposits at approximately the level of the cave floor. The lowering of the river bed and the backward cutting of tributary streams brought about more rapid drainage of the country to either side of the cave, less water entered the fissure, and cave-cutting ceased. Openings were formed later in the roof of the cave by surface erosion, thus permitting the entrance of clay, rock fragments, broken bones and possibly of live animals. Subsequent uplift increased the cutting by streams in the region, and Potter Creek cut down through one of the galleries, thus forming the present cave entrance.

There were two or three of these periods of uplift as determined by Sinclair which changed the character of the country from one of moderate relief to one of mountainous aspect dis-

⁸ See Sinclair, W. J., Univ. Calif. Publ. Am. Arch. Ethn., vol. 2, pp. 1-27, 1904.

sected by river cañons. The indications are that the actual elevation at present is considerably greater than that during the deposition of the bone-bearing material. Certainly the relation of the cave to the river level has changed in the neighborhood of eight hundred feet. There is no evidence of a later subsidence noted, so we may assume that the conditions during the period of deposition were more like those at Rancho La Brea than they are at present, i.e., less abrupt elevation and a smoother topography. The presence of *Dendragapus* in the cave deposits is an indication, however, that conditions were not identical in the two localities.

A very interesting description of the various chambers and galleries of the cavern is given in Sinclair's paper. The fossil-bearing matrix represents the accumulation on the floors of the chambers and pockets in the form of fans of detritus, admitted doubtless through old chimney-like chutes now entirely blocked by limestone accretions and washed debris. These fans of accumulated material were encrusted, and in some instances cemented, by stalagmitic deposits so that blasting had to be resorted to in places.

The remains are in most cases entirely dissociated. Sinclair notes the finding of a few skeletons in their proper anatomical relations, such as those of a squirrel, a woodrat, a snake, and a bat. These are all animals which would go into caves of their own accord and after death fall upon the floors of the caverns. No case of bird skeletons in any degree associated is to be found. The bones have entirely lost their organic matter and appear almost as though calcined. Perfect bones of the smaller vertebrates are rare. In most cases fracture has occurred and in many the articular surfaces have been injured, either on account of the delicacy of the cancellated bone in that region, or because the presence of articular cartilages tempted the appetites of gnawing forms. Weathering and cracking due to exposure on the surface is the only reasonable explanation of the imperfections of some specimens.

Sinclair suggests three methods of possible introduction of animal remains into the cave. Washing by rills which carried bones from the surface down by way of the nearly vertical chim-

neys seems a very probable method. These open chimneys may have acted as pitfalls into which animals blundered in passing over the surface. Again, predatory forms may have carried their prey into the mouths of the caverns whence the accumulated bones were washed, or carried by woodrats, into the more remote recesses. This last method seems to the present author the most probable means of introduction of such forms as the anserines among birds. *Falco peregrinus*, whose remains also occur in the deposits, is a large and powerful hawk which habitually resorted to such places to nest. About the entrances to their nesting crevices today one commonly finds the accumulated bones of a great variety of vertebrates brought as prey. Their predilection for the anserines has given these birds their common name of duck hawk.

Sinclair records the following list of vertebrates from the Potter Creek Cave deposits, marking extinct species with an asterisk:

SINCLAIR'S LIST OF SPECIES FROM POTTER CREEK CAVE

* <i>Arethotherium simum</i> Cope.	<i>Callospermophilus chrysodeirus</i>
* <i>Ursus</i> , n. sp.	Merriam, C. H.
* <i>Felis</i> , n. sp.	<i>Lepus californicus</i> Gray.
<i>Felis</i> , near <i>hippolestes</i> Merriam,	<i>Lepus klamathensis</i> Merriam, C.
C. H.	H.
<i>Lynx fasciatus</i> Rafinesque.	<i>Lepus</i> , near <i>auduboni</i> Baird.
<i>Lynx fasciatus</i> , n. subsp. (?)	<i>Lepus</i> , sp.
<i>Urocyon townsendi</i> Merriam, C. H.	* <i>Teonoma</i> , n. sp.
<i>Vulpes cascadenis</i> Merriam, C. H.	<i>Neotoma fuscipes</i> Baird.
* <i>Canis indianensis</i> Leidy.	<i>Microtus californicus</i> Peale.
* <i>Taxidea</i> , n. sp.	* <i>Thomomys</i> , n. sp.
<i>Bassariscus raptor</i> Baird.	<i>Thomomys leucodon</i> Merriam, C.
<i>Mephitis occidentalis</i> Baird.	H.
* <i>Spilogale</i> , n. sp.	<i>Thomomys monticola</i> Allen
<i>Putorius arizonensis</i> Mearns.	* <i>Aplodontia major</i> , n. subsp.
<i>Arctomys</i> , sp.	<i>Scapanus californicus</i> (?) Ayres.
<i>Sciurus hudsonicus albolimbatus</i>	<i>Antrozous pallidus</i> Merriam, C. H.
Allen.	* <i>Platygonus</i> (?) sp.
<i>Sciuropterus klamathensis</i> Mer-	<i>Odocoileus</i> , sp. a.
riam, C. H.	<i>Odocoileus</i> , sp. b.
<i>Spermophilus douglasi</i> Richard-	<i>Haplocerus montanus</i> Ord.
son.	* <i>Euceratherium collinum</i> Sinclair
<i>Eutamias senex</i> (?) Allen.	and Furlong.

* Species marked with the asterisk (*) are either extinct or are no longer represented in the region.

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|------------------------------------|---|
| *Bison, sp. | *Equus occidentalis Leidy. |
| *Camelid. | *Equus pacificus Leidy. |
| *Megalonyx wheatleyi (?) Cope. | Crotalus, sp. |
| *Megalonyx jeffersonii (?) Harlan. | Mylopharadon conocephalus Baird and Gerard. |
| *Megalonyx, n. sp. | Ptychocheilus (?) grandis (?) (Ayres). |
| *Megalonyx, sp. | Acipenser medirostris (?) Ayres. |
| *Mastodon americanus Kerr. | |
| *Elephas primigenius Blumb. | |

To this list of species published by Sinclair, the studies of the present author⁹ would add the following birds:

SPECIES OF BIRDS FROM POTTER CREEK CAVE

- | | |
|-------------------------------|--------------------------------|
| Branta canadensis (Linnaeus). | *Catharista shastensis Miller. |
| Oreortyx pieta (Douglas). | Buteo borealis (Gmelin). |
| Dendragapus obscurus (Say). | Falco peregrinus Tunstall. |
| *Bonasa umbellus (Linnaeus). | Falco sparverius Linnaeus |
| Indeterminate odontophorid. | Otus asio (Linnaeus). |
| *Meleagris, sp. | *Bubo sinclairi Miller. |
| *Gymnogyps amplus Miller. | Colaptes cafer (Gmelin). |
| Cathartes aura (Linnaeus). | Corvus brachyrhynchos Brehm. |

* Species marked with the asterisk (*) are either extinct or are no longer represented in the region.

Samwel Cave.—Samwel Cave was explored by E. L. Furlong, then of the University of California, who published an account of his work two years after the appearance of Sinclair's paper on the Potter Creek Cave. Furlong's account¹⁰ pictures a cavern not essentially different from that described by Sinclair. The conditions of interment seem to have been somewhat different, however, since there occurred a number of entire skeletons of large and small carnivores and one form of ungulate, *Preptoceras*, which were preserved without fracture of the bones and in the proper anatomical relation. Furlong reaches the conclusion that the cavern was used as a lair by such forms as the bear and the cougar. To this lair the bodies of larger ungulates like *Euceratherium* and *Preptoceras* were dragged as prey. Some of the carcasses were left almost entire while others were torn to pieces and the bones more or less broken by the

⁹ Miller, L. H., Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, p. 385, 1911.

¹⁰ Furlong, E. L., Am. Journ. Sci., vol. 22, pp. 235-247, Sept., 1906.

teeth of the captor. The suggestion is also made that the cavern may have been used as a den for hibernation by various ursines, even as other caverns in the region are known to be used by bears of today.

No specimen of bird skeleton was found with bones in proper place, so the probability is that the remains representing this class were introduced largely as in the case of the Potter Creek Cave specimens. Some essential difference must have existed, however, since the relation in numbers of the different species is so different in the two localities. The Cathartiformes appear in Potter Creek Cave represented by forty-five specimens distributed over three species. In Samwel Cave there appear but six specimens possibly assignable to the group. *Falco peregrinus*, represented in the former cave by four specimens, is wanting in the latter. The owls are represented by five specimens in the former and eleven in the latter, the grouse by thirty-four in the former as against one hundred and twenty-four in the latter.

This difference of faunal proportions is perhaps most readily explained by the probable difference between the original openings of the caves. Let it be conceded that, as suggested by the respective authors, Potter Creek Cave opened by a relatively small chimney or two on the surface of the Pleistocene hillside and that Samwel Cave opened by a large chamber, the first part of which ran more nearly horizontally. Vultures, ravens, and the peregrine falcon nest in small cavities in rocky cliffs out of the way of small predatory mammals like the raccoons and the weasels. Their bones and those of their prey would accumulate in these pockets and eventually find their way into deeper recesses through fissures or chutes as described by Sinclair. The owls, however, resort to large open-mouthed caves to roost during much of the year, which fact would account for their greater abundance in Samwel Cave. Raccoons were found in abundance by Furlong as entire skeletons on the floor of Samwel Cave, thus suggesting that these animals frequented the place as a lair. The ground-dwelling birds, their natural prey, thus come to form a large proportion of the avian remains in these deposits. Procyonid forms are not listed by Sinclair from Potter Creek

Cave. They were either absent from the region or did not frequent the vicinity of the cave mouth. It seems not improbable that these small carnivores had a distinct relation to the number of gallinaceous bird remains to become entombed in the various cave deposits.

The following list of mammals is recorded by Furlong from the Samwel Cave:

FURLONG'S LIST OF SPECIES FROM SAMWEL CAVE

Ursus americanus Pallas.	Lepus, sp.
Ursus, n. sp.	Thomomys monticola Allen.
Ursus, sp.	Thomomys, sp.
Vulpes, sp.	Microtus, sp.
Urocyon townsendi Merriam, C. H.	Neotoma fuscipes, Baird.
Procyon, near lotor Linn.	Neotoma, sp.
Putorius arizonensis Mearns.	Citellus douglasi Richardson.
Mephitis occidentalis Baird.	Sciurus, sp.
Mustela, sp.	Euceratherium collinum Sinclair and Furlong.
Felis, near hippolestes Merriam, C. H.	Preptoceras sinclairi Furlong.
Aplodontia, near major Merriam, C. H.	Haplocerus, sp.
Aplodontia rufa Rafinesque.	Odocoileus, sp. a.
Erethizon epixanthus Brandt.	Odocoileus, sp. b.
Aretomys, sp.	Equus occidentalis Leidy.
Lepus auduboni Baird.	Elephas, sp.
	Megalonyx, sp.

SPECIES OF BIRDS FROM SAMWEL CAVE.

Indeterminate anserine a.	Falco sparverius Linnacus.
Indeterminate anserine b.	Asio wilsonianus (Lesson).
Indeterminate anserine c.	Bubo virginianus (Gmelin).
Oreortyx picta (Douglas).	*Bubo sinclairi Miller.
Indeterminate odontophorid.	Glaucidium gnoma Wagler.
*Gymnogyps amplus Miller.	*Mieropallas whitneyi (J. G. Cooper).
Cathartes aura (Linnaeus).	Colaptes cafer (Gmelin).
*Catharista shastensis Miller.	Cyanocitta stelleri (Gmelin).
Accipiter velox (Wilson).	
Buteo swainsoni Bonaparte?	

* Species of birds marked with the asterisk (*) are extinct or else foreign to the locality.

Hawver Cave.—Hawver Cave is now located in the same faunal zone as the caves previously discussed and at about the same elevation, though some two degrees to the southward. The

formation of the cave is essentially the same except that the work of solution is still probably going on to some extent. The method of entombment of the organic remains appeared to Furlong to be the same as that acting in the case of Potter Creek Cave, i.e., the washing in of surface material by the action of streamlets.

The presence of *Megalonyx* and *Equus* indicate the Pleistocene age of the bone-bearing deposits in the fissure. There appear no remains of the large ungulates *Euceratherium* and *Preptoceras* to correspond with the deposits of the Shasta caves, but this condition may be more apparent than real, since but a limited amount of work was done in the cave before the level of the water in some of the passages rose to a point so high that access to the main bone-bearing chambers was prevented.

But twelve species of birds are represented in the collections from this cave. Four of these are no longer represented in the region. The fact that the cave is still open and that changes due to the action of water are still going on lends a feeling of uncertainty as to the exact age of any specimen. The association in loose material of remains which are unquestionably Pleistocene in origin with others representing still existing species is no guaranty of the age of the latter. There is continually going on a measure of differential motion in some of the debris accumulated, which would possibly mingle fragments deposited at quite different times. Solution, shifting and re-cementing may have recurred several times although the excellent state of preservation of most of the bones would militate against the idea that a great deal of such movement had taken place.

The few mammals thus far identified from Hawver Cave are listed as follows:

Equus occidentalis (?) Leidy.
Apلودontia, sp.

Megalonyx, sp.
Felis hippolestes Merriam, C. H.

LIST OF BIRDS FROM HAWVER CAVE.

* <i>Nettion carolinense</i> (Gmelin).	** <i>Geranoaëtus melanoleucus</i> Auct.?
* <i>Oreortyx picta</i> (Douglas).	* <i>Colaptes cafer</i> (Gmelin).
* <i>Lophortyx californica</i> (Shaw).	* <i>Cyanocitta stelleri</i> (Gmelin).
* <i>Meleagris</i> , sp.	* <i>Corvus corax</i> Linnaeus.
* <i>Cathartes aura</i> (Linnaeus).	* <i>Euphagus cyanocephalus</i> (Wag-
* <i>Catharista shastensis</i> Miller.	ler).
* <i>Archibuteo ferrugineus</i> (Lichten-	
stein).	

* An asterisk indicates that the species is extinct or no longer found in this region.

Rancho La Brea.—The Rancho La Brea beds constitute one of the most unique and at the same time one of the richest of Pleistocene deposits in the west; unique because in the entombment of remains the factor of chance has been reduced to a minimum by the presence of an attractively baited and automatic trap; rich because the trap was insatiable in its demands, because the material was promptly immersed and preserved in semi-fluid asphalt, and because of the fact that the trap was almost continually operative, it would seem, for a considerable period of time.

According to Merriam,¹¹ who bases his conclusions on personal observation and upon the opinions of Arnold, Orcutt, and other geologists, crude asphaltic oil from the underlying Fernando shales, here gently upfolded, has been forced to the surface through cracks or chimneys in these folded strata to accumulate upon the surface as more or less extensive oil pools. This heavy oil, under the influence of sun and wind, underwent a process of natural distillation, becoming more and more viscid until in the larger accumulations it was sufficiently tenacious to entrap and hold the largest mammals of the region, *Elephas*, *Mastodon*, and *Paramylodon*. As pointed out by the same author, additions to these lenses of asphalt took place at the center as fresh oil rose through the chimneys from below; at the same time dust and sand drifted over and obscured the firmer asphalt of the margins. These two factors combined to bring about a most deceptive condition in the mass by leaving the periphery fairly firm and yet permitting a gradually increas-

¹¹ Merriam, J. C., Mem. Univ. Calif., vol. 1, No. 2, pp. 199-213, 1911.

ing degree of plasticity toward the center without a positive demarcation of the danger zone. Upon this treacherous surface a mammal would be unaware of danger until the dust-covered surface yielded under his weight. His sudden start or his leap for safety would make all the more complete his entanglement.

While these exposed traps must have been in many cases passive, concealed in an open or perhaps but slightly wooded locality where animals would blunder into them, they must often also have been actively attractive to animals through the two important factors of water and food. During a considerable period of time spent in working these fascinating deposits, the author has had frequent recourse to the water accumulated in depressions of the asphalt. This water has proven quite acceptable for drinking and for bathing. As algae accumulate, frogs, toads, dragonflies, mosquitoes, and other insect forms invade it; rushes and marsh-grass border the pools, their roots actually in contact with asphalt of the highest degree of tenacity. In a number of cases the asphalt accumulations represent depressions in the general surface of the country where not only the direct rainfall would be temporarily held empounded but more lasting pools representing surface drainage or even seepage would accumulate. The presence of bedded leaf-masses and of water-worn fragments of wood intermingled with the animal remains would support the view that there were at times ponds of a more or less permanent nature. The animals of poorly watered regions in the southwest are perforce far from fastidious in the matter of drinking water; hence the herbivorous mammal must certainly have found the vicinity of these water pools one offering very positive attraction as to water and perhaps grass as well.

The entanglement of one ungulate would suffice to attract a multitude of carnivores. The creature probably acted not infrequently as live bait for a considerable time, so that its struggles and outcries served to whet the appetites and overcome the instincts of caution in the hungry carnivore. It appears from Merriam's studies that young animals or else old or diseased individuals have very frequently been thus tempted, though there appear animals of all ages.

The prevailing conditions also led to a greatly distorted relation between predaceous and non-predaceous species in point of numbers. While removing a single femur of *Paramylodon* there were found touching it three complete skulls of *Canis indianensis*, and even this proportion of three to one is much too small to represent the facts truthfully. In a collection of bird remains made by the writer the number of specimens of *Aquila* exceeds the number representing all the non-raptorial species combined, while fifty-six per cent of the species recorded are predatory.

The cessation of struggling on the part of the entrapped animal did not end its services as trap bait. Some forms which normally seek an active prey, e.g., *Canis* and *Aquila*, may on occasion resort to carrion. A decrepit wolf or a hungry eagle may not infrequently thus supply the demands of necessity. The odors emanating from these pits where freshly excavated are, to human nostrils, strongly suggestive of carrion. Gases exhaled by animal bodies submerged in the plastic mass would accentuate this olfactory effect to such a degree as probably to attract carrion feeders. Was this influence also felt by birds? Darwin's well-known experiments on Andean condors kept in captivity have long been accepted as proving that the vultures do not employ the olfactory sense in the perception of food. However, the experiences of later naturalists with *Cathartes*, which is often caught in wolf-traps with concealed bait, leads us to emphasize the fact that Darwin was experimenting with birds in captivity which had been fed perhaps from early youth in more or less regular fashion. We must at least concede it possible that the abundant vulture remains in the asphalt are the result in part of this factor of odor in attracting them to the locality.

PARTIAL LIST OF MAMMALS FROM RANCHO LA BREA.

* <i>Canis indianensis</i> Leidy.	<i>Putorius</i> , sp.
* <i>Canis oreutti</i> Merriam, J. C.	* <i>Areotherium californicum</i> Merriam, J. C.
* <i>Canis andersoni</i> Merriam, J. C.	* <i>Elephas</i> , sp.
* <i>Canis occidentalis furlongi</i> Merriam, J. C.	* <i>Mastodon</i> , sp.
* <i>Lynx occidentalis fischeri</i> Merriam, J. C.	* <i>Equus</i> , sp.
* <i>Felis atrox bebbi</i> Merriam, J. C.	* <i>Bison antiquus</i> Leidy.
* <i>Smilodon californicus</i> Bovard.	* <i>Capromeryx minor</i> Taylor.
<i>Mephitis</i> , sp.	* <i>Camelops</i> (?), sp.
	* <i>Paramylodon</i> , sp.

SPECIES OF BIRDS KNOWN FROM RANCHO LA BREA.

<i>Chaulelasmus streperus</i> (Linnaeus).	<i>Haliaeetus leucocephalus</i> (Linnaeus).
<i>Anser albifrons</i> (Scopoli) ?	* <i>Morphnus woodwardi</i> Miller.
<i>Branta canadensis</i> (Linnaeus).	* <i>Geranoaëtus grinnelli</i> Miller.
* <i>Ciconia maltha</i> Miller.	* <i>Geranoaëtus fragilis</i> Miller.
<i>Jabiru mycteria</i> (Lichtenstein).	<i>Falco peregrinus</i> Tunstall.
<i>Mycteria americana</i> Linnaeus.	<i>Falco</i> , sp.
<i>Ardea herodias</i> Linnaeus.	<i>Falco sparverius</i> Linnaeus.
* <i>Grus minor</i> Miller.	* <i>Polyborus tharus</i> Auct.
<i>Grus canadensis</i> (Linnaeus).	<i>Aluco pratineola</i> (Bonaparte).
<i>Lophortyx</i> sp.	<i>Asio flammeus</i> (Pontoppidan).
* <i>Meleagris</i> ?	<i>Otus asio</i> (Linnaeus).
* <i>Pavo californicus</i> Miller.	<i>Bubo virginianus</i> (Gmelin).
<i>Gymnogyps californianus</i> (Shaw).	<i>Speotyto cunicularia hypogaea</i> (Bonaparte).
* <i>Sarcorhamphus clarki</i> Miller.	* <i>Neomorpha</i> , ? sp.
* <i>Pleistogyps rex</i> Miller.	<i>Colaptes cafer</i> (Gmelin).
* <i>Cathartornis gracilis</i> Miller.	<i>Otocoris alpestris</i> (Linnaeus).
<i>Cathartes aura</i> (Linnaeus).	<i>Corvus corax</i> Linnaeus.
* <i>Catharista occidentalis</i> Miller.	<i>Corvus brachyrhynchos</i> Brehm.
* <i>Teratornis merriami</i> Miller.	* <i>Corvus</i> , sp.
<i>Elanus leucurus</i> (Vieillot).	<i>Xanthocephalus xanthocephalus</i> (Bonaparte).
<i>Circus hudsonius</i> (Linnaeus).	<i>Agelaius gubernator</i> (Wagler).
* <i>Circus</i> , sp.	<i>Sturnella neglecta</i> Audubon.
<i>Buteo</i> , sp.	<i>Pipilo</i> , sp.
<i>Buteo borealis</i> (Gmelin).	<i>Lanius ludovicianus</i> Linnaeus.
<i>Aquila chrysaëtus</i> (Linnaeus).	

* Species marked with an asterisk (*) are extinct or foreign to the locality.

Fossil Lake.—The horizon designated by Cope as Silver Lake and classed collectively with several other horizons as the Equus Beds, was thought for many years to be of Pliocene age and as such was considered by Cope and by Shufeldt in their studies

of the birds from that region. Our knowledge of the various western horizons has, however, been extended by later investigators in stratigraphy and in the correlation of faunas, with the result that these beds are now proven unquestionably to be of Pleistocene age. Such change of interpretation alters materially the significance of discoveries announced by Cope and by Shufeldt in that it reduces appreciably the extent to which several existing genera are known to run back in time.

The various descriptions of this region are summarized in a concise and very lucid paragraph or two by Osborn¹² from which the following may well be quoted:

“One hundred and fifty miles northwest of the old Lahontan shore lines in the heart of the Oregon Desert of the great basin, and twenty miles northeast of Silver Lake, there is a slight depression in the desert perhaps twenty acres in extent marked Christmas Lake on the maps, to which Cope gave the name ‘Fossil Lake.’ This ‘Silver,’ ‘Christmas,’ or ‘Fossil’ lake region was successively explored by Condon, Cope, Sternberg (who made the chief collections), and Russel (1882). . . . Though actually twenty miles distant from Silver Lake, the rich fauna of mammals and birds found has been described by Cope¹³ and Shufeldt, and referred to by Gilbert, as the fauna of the Silver Lake Equus beds. . . .

“Proof that the country was partly fluviatile and partly wooded is afforded by the presence of the muskrat (*Fiber*), the otter (*Lutra*), the beaver (*Castor fiber*), and the giant beaver (*Castoroides*).

“ The bird life was very abundant and not very dissimilar from what we might observe at any of the alkaline lakes of the West, resorted to at the present day by wild fowl during their migrations. Great flocks of swans (*Cygnus paloregonus*), geese (*Anser condoni*), and ducks were there; a cormorant (*Phalacrocorax*) was among the rarities; among the species of grebe (*Podiceps occidentalis*) is one still inhabiting this region. There were also coots (*Fulica minor*) and herons (*Ardea paloccidentalis*). Other forms of birds include two species of grouse, crows, and eagles. The strangest figure upon the scenes among the birds was a true flamingo (*Phoenicopterus copei*). The northernmost distribution of flamingoes at the present is southern Florida and the Bahama Islands (lat. 27° N). Shufeldt concludes that the climate might well be compared with that of Florida or the lower part of Louisiana, that the vegetation was fully as luxuriant as it now is in those parts, and that the palms were abundantly represented. This conclusion as to a Floridan climate and the existence of palms is, however, very questionable. Brown¹⁴ observes that the South American flamingoes (*Phoenicopterus chilensis*) migrate as far south as

¹² Osborn, H. F., The Age of Mammals, p. 458.

¹³ Cope, E. D., The Silver Lake of Oregon and its Region, Am. Nat., vol. 23, pp. 970-982, 1889.

¹⁴ Mr. Barnum Brown in a note to the author [Osborn].

the lakes in central eastern Tierra del Fuego, lat. 53° S, where they are said to breed, and certainly spend a part of the season. This region corresponds in temperature to the climate of central Alberta, Canada, 400 miles north of Silver Lake. Thus it appears that the presence of *Phoenicopterus copei* at Silver Lake has very little weight in the determination of climate. It is more probable that the northern lakes of that period contained mollusks on which the flamingoes fed.”

Aside from an extinct genus of grouse, *Phoenicopterus* is the only genus recorded fossil that might not reasonably be expected to occur in the region at the present time.

Shufeldt's original paper¹⁵ gives a detailed description of most of the species of birds found in the Fossil Lake beds and a synoptical list of the known species was published in a paper by the writer¹⁶ as follows:

Æchmophorus occidentalis (Lawrence).

Pygopodes:	<i>Æchmophorus occidentalis</i> (Lawrence). <i>Colymbus holboelli</i> (Reinhardt). <i>Colymbus auritus</i> Linneus. <i>Colymbus nigricollis californicus</i> (Heermann). <i>Podilymbus podiceps</i> (Linneus).
Lougipennes:	<i>Larus argentatus</i> Pontoppidan. <i>Larus robustus</i> Shufeldt. <i>Larus californicus</i> Lawrence. <i>Larus oregonus</i> Shufeldt. <i>Larus philadelphia</i> (Ord). <i>Xema sabini</i> (J. Sabine). <i>Sterna elegans</i> Gambel. <i>Sterna forsteri</i> Nuttall. <i>Hydrochelidon nigra surinamensis</i> (Gmelin).
Steganopodes:	<i>Phalacrocorax maeropus</i> (Cope). <i>Pelecanus erythrorhynchos</i> Gmelin.
Anseres:	<i>Lophodytes cucullatus</i> (Linnaeus). <i>Anas platyrhynchos</i> Linnaeus. <i>Mareca americana</i> (Gmelin). <i>Nettion carolinense</i> (Gmelin). <i>Querquedula discors</i> (Linnaeus). <i>Querquedula cyanoptera</i> (Vieillot). <i>Spatula clypeata</i> (Linnaeus). <i>Dafila acuta</i> (Linnaeus). <i>Aix sponsa</i> (Linnaeus).

¹⁵ Shufeldt, R. W., Journ. Acad. Nat. Sci. Phila., ser. 2, no. 9, pp. 389-45, 1892.

¹⁶ Miller, L. H., Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, pp. 79-87, 1911.

	<i>Marila valisineria</i> (Wilson).
	<i>Clangula islandica</i> (Gmelin).
	<i>Harelda hyemalis</i> (Linnaeus).
	<i>Anser condoni</i> Shufeldt.
	<i>Anser albifrons gambeli</i> Hartlaub.
	<i>Branta hypsibata</i> Cope.
	<i>Branta canadensis</i> (Linnaeus).
	<i>Branta propinqua</i> Shufeldt.
	<i>Chen hyperboreus</i> (Pallas).
	<i>Olor paloregonus</i> (Cope).
Odontoglossae:	<i>Phoenicopterus copei</i> Shufeldt.
Herodiones:	<i>Ardea paloccidentalis</i> Shufeldt.
Paludicolae:	<i>Fulica americana</i> Gmelin.
	<i>Fulica minor</i> Shufeldt.
Limicolae:	<i>Lobipes lobatus</i> (Linnaeus).
Gallinae:	<i>Tympanuchus pallidicinctus</i> (Ridgway).
	<i>Pedioecetes phasianellus columbianus</i> (Ord).
	<i>Pedioecetes lucasi</i> Shufeldt.
	<i>Pedioecetes nanus</i> Shufeldt.
	<i>Palaeotetrix gilli</i> Shufeldt.
Accipitres:	<i>Aquila pliogryps</i> Shufeldt.
	<i>Aquila sodalis</i> Shufeldt.
Striges:	<i>Bubo virginianus</i> (Gmelin).
Passeres:	<i>Euphagus affinis</i> Shufeldt.
	<i>Corvus annectens</i> Shufeldt.

ADDITIONAL SPECIES OF BIRDS IN THE CALIFORNIA COLLECTIONS

Pygopodes:	<i>Aechmophorus lucasi</i> Miller.
Anseres:	<i>Erismatura jamaicensis</i> (Gmelin).
Accipitres:	<i>Circus hudsonius</i> (Linnaeus).

PARTIAL LIST OF MAMMALS FROM FOSSIL LAKE.¹⁷

<i>Ursus</i> , sp.	<i>Lepus</i> , sp.
<i>Felis</i> , sp.	<i>Mylodon sodalis</i> Cope.
<i>Canis latrans</i> Say.	<i>Equus pacificus</i> Leidy.
<i>Canis</i> , cf. <i>occidentalis</i> Richardson.	<i>Equus</i> , n. sp.
<i>Vulpes</i> , cf. <i>pennsylvanicus</i> Bodd.	<i>Elephas</i> , sp.
<i>Lutra canadensis</i> Schreber.	<i>Platygonus</i> , cf. <i>vetus</i> Leidy.
<i>Fiber zibethicus</i> Linnaeus.	<i>Platygonus</i> , sp.
<i>Arvicola</i> , sp.	<i>Eschatus conidens</i> Cope.
<i>Thomomys</i> , sp.	<i>Camelops kansanus</i> Leidy.
<i>Geomys</i> , sp.	<i>Camelops vitakerianus</i> Cope.
<i>Castor</i> , sp.	<i>Camelops</i> , sp.
<i>Castoroides</i> , sp.	<i>Antilocapra</i> , sp.

¹⁷ Sinclair, W. J., Univ. Calif. Publ. Am. Arch. Ethn., vol. 2, p. 1, 1904.

Rodeo Pleistocene.—Almost nothing has been recorded concerning this formation. The region has been repeatedly visited by parties from the University of California and the Pleistocene age of the beds definitely established.

The single specimen of bird remains from the locality was picked up at the base of the exposure by Professor J. C. Merriam with parts of the matrix of the Pleistocene beds still adhering to it. The bone is a perfect tarsometatarsus of average size.

SINGLE SPECIES FROM RODEO PLEISTOCENE.

Æhmophorus occidentalis (Lawrence).

PRESENT PHYSIOGRAPHIC AND GEOGRAPHIC RELATIONS OF THE
WEST AMERICAN REGIONS IN WHICH FOSSIL AVIAN
REMAINS ARE KNOWN

The nine localities referred to above have yielded several thousand specimens in all. Only five of these specimens, representing three species, are from deposits older than the Pleistocene; hence we may consider our knowledge as practically limited to that age. Since also the systematic groups larger than the species display in the case of birds such remarkable longevity, time relations between the several Pleistocene horizons become of minor importance except as we learn of variations in climate during that period.

There is on the other hand an advantage to be derived from the approximate contemporaneity of the deposits. The entombment of many specimens at about the same time under a variety of conditions and in a number of different localities gives us an unusually accurate conception of the avifauna of that time. The Fossil Lake deposits yield mainly those species to be found about open, shallow lakes; the caverns are so located as to have entombed those species which inhabit lower mountainous country; the Rodeo Pleistocene consists of seashore accumulation; the Rancho La Brea beds are the result of a peculiarly diverse combination of circumstances which led to the trapping of open-plains birds with a preponderance of raptorial species.

The asphalt beds lie in latitude 34° N, on the coastal side of the Santa Monica Mountains within a few miles of the sea and

less than two hundred feet above its level. The locality is today a typical open valley country, protected on the north by the east-and-west Santa Monica Range, yet tempered by the cool and moisture-laden breeze from the sea. Faunally, the locality lies in the Upper Sonoran zone of the San Diego region.

The Shasta caves occupy a position further inland and seven degrees to the northward of Rancho La Brea. Their elevations vary between 1300 and 1500 feet above sea-level. The isothermic zone represented is slightly above that of Rancho La Brea, it being Upper Sonoran and lower Transition. The isohumic area is that of the Sacramento-San Joaquin, which is an area of slightly greater precipitation than is the San Diegan.

The two localities are at present distinguishable in their avifauna by the presence or the absence of several species which are of interest in the light of palaeontological records. The entire group of grouse, represented in the Shasta region by *Dendragapus*, is wanting at Rancho La Brea. *Oreortyx* and *Cyanocitta*, present in the cave region, are wanting in the immediate vicinity of the asphalt beds. *Geococcyx*, present in the latter locality, is wanting in the former.

These, however, are birds of slight volant power. The species of less restricted activity, such as the Raptores and the water-birds, are common to the two localities at present.

The Fossil Lake region of Oregon lies in latitude 43° N, full nine degrees north of Rancho La Brea, and is on the eastern side of the Cascade Range. This separation from the coastal slope would influence the smaller species of birds more than the larger. Winter temperatures would be more severe, with summer temperatures fully equal to those of southern California. The rainfall at the present time is such as to give the region the name of "Oregon Desert."

There appears, then, as distinguishing the five more important localities today, a difference of nine degrees of latitude, a range of elevation from 100 to 1500 feet above the sea, and a faunal difference limited to the Upper Sonoran and lower Transition zones. There is no evidence of marked change in elevation since Pleistocene times; hence it seems probable that a somewhat similar relationship between the localities prevailed

during the Pleistocene period and that the specimens obtained from the various horizons represent in the aggregate, with a considerable degree of accuracy, the avifauna of the Pacific coast at that time.

RELATION OF PLEISTOCENE FAUNAS TO THOSE OF THE PRESENT DAY

A partial list of the Recent birds of the Transition zone in the Shasta region is given in the report of a biological survey of the region by C. H. Merriam.¹⁸ The list is appended here and the more striking differences displayed by the other localities are noted. This comparison may prove of interest in considering the fossil avifauna.

RECENT AVIFAUNA OF THE SHASTA REGION

(Partial list from Upper Sonoran and Transition zones)

<i>Oreortyx picta</i> (Douglas).	<i>Speotyto cunicularia</i> (Molina).
<i>Lophortyx californica</i> (Shaw).	<i>Glaucidium gnoma</i> Wagler.
<i>Dendragapus obscurus</i> (Say).	<i>Colaptes cafer</i> (Gmelin).
<i>Zenaidura macroura</i> (Linnaeus).	<i>Aphelocoma californica</i> (Vigors).
<i>Cathartes aura</i> (Linnaeus).	<i>Cyanocitta stelleri</i> (Gmelin).
<i>Circus hudsonius</i> (Linnaeus).	<i>Sturnella neglecta</i> Audubon.
<i>Buteo borealis</i> (Gmelin).	<i>Euphagus cyanocephalus</i> (Wagler).
<i>Aquila chrysaetos</i> (Linnaeus).	<i>Lanius ludovicianus</i> Linnaeus.
<i>Falco mexicanus</i> Schlegel.	<i>Planesticus migratorius</i> (Linnaeus).
<i>Falco sparverius</i> Linnaeus.	
<i>Bubo virginianus</i> (Gmelin).	

To this list may be added the following species which possibly occur in the locality, though not recorded by the collectors of the survey party:

<i>Accipiter velox</i> (Wilson).	<i>Falco peregrinus</i> Tunstall.
<i>Accipiter cooperi</i> (Bonaparte).	<i>Aluco pratineola</i> (Bonaparte).
<i>Astur atricapillus</i> (Wilson).	<i>Asio wilsonianus</i> (Lesson).
<i>Buteo swainsoni</i> Bonaparte.	<i>Otus asio</i> (Linnaeus).
<i>Archibuteo ferrugineus</i> (Lichtenstein).	<i>Geococcyx californianus</i> (Lesson).
<i>Haliaeetus leucocephalus</i> (Linnaeus).	<i>Corvus corax</i> Linnaeus.
<i>Gymnogyps californianus</i> (Shaw).	<i>Corvus brachyrhynchos</i> Brehm.
	Cosmopolitan water birds

¹⁸ Merriam, C. H., Results of a Biological Survey of Mt. Shasta, California, N. Am. Fauna, No. 16, 1899.

SOME RECENT BIRDS NOTED IN THE SILVER LAKE REGION.¹⁹

Geese, Swans, Pelicans, Cormorants	<i>Oreoscoptes montanus</i> (Townsend,
<i>Æchmophorus occidentalis</i> (Law- rence).	J. K.)
<i>Myadestes townsendi</i> (Audubon).	<i>Asyndesmus lewisi</i> Riley.
<i>Ixoreus naevius</i> (Gmelin).	<i>Recurvirostra americana</i> Gmelin.
	<i>Himantopus mexicanus</i> (Müller).

If, as is suggested by the configuration of the country, the former elevation of the caves was slightly less than at present and the country less broken, conditions were then more favorable than at present for such species as *Geococcyx californianus* and *Archibuteo ferrugineus*. The probability that slow-moving streams and small lakelets served to attract waders, anserines, and *Haliaëtus* would be greater in such a condition of the country.

In the vicinity of Fossil Lake, Oregon, the present avifauna would show probably several points of divergence from the cave region and from Rancho La Brea. *Oreortyx*, *Cyanocitta*, *Aphe-locoma*, and *Geococcyx* would probably be lacking, while one would doubtless meet with *Pedioecetes*, *Centrocerus* and *Cyanocephalus*.

At Rancho La Brea, *Elanus* and *Geococcyx* would prove more abundant, *Agelaius*, *Xanthocephalus*, and *Otocoris* would be plentiful, while *Dendragapus*, *Oreortyx*, and *Cyanocitta* would not be likely to occur. *Elanus* and *Geococcyx* at Rancho La Brea, *Dendragapus* in the Shasta region and *Centrocerus* and *Pedioecetes* in the Fossil Lake region are the chief differences dependent upon latitude to be noticed among the three faunas. The other discrepancies are such as would be due to slight difference in altitude, the proximity of water or the topography of the region.

The long list of smaller passerines, piciforms and macrocheirs is here purposely omitted, since they, though very important in the determination of faunal zones, seem not to have been preserved in the fossil state to any great extent.

Distribution of the Cathartidae.—One of the groups of chief interest in discussing the subject of distribution in the light

¹⁹ Cope, E. D., The Silver Lake of Oregon and its Region, Am. Nat., vol. 23, p. 970, 1889.

of palaeontological study is the raptorial subdivision embracing the New World vultures. The exclusive possession by the Americas of so marked a group of large and strong-flying birds as the Cathartidae and the total absence there of any form of the true Vulturidae, which occupy the same bionomic position in the Old World, is one of the striking phenomena in animal distribution. Aside from the fact that the group is so well defined, there being no Recent forms showing transition between it and the other raptorine subdivisions, we find it not poor in species and it is widely distributed in the western hemisphere.

There are endemic to the New World no less than five distinct cathartine genera—a goodly number for a group, the smallest member of which approaches in size the largest eagles. All are birds capable of long-sustained flights and they are unsurpassed in their ability to meet the emergencies of changed elevation and shifting air currents that would prove disturbing to less perfect fliers. This very factor may, by insuring them against being driven astray by storms, bring about a distribution more in accord with their own needs or inclinations.

As an instructive comparison in the matter of distribution one might consider the short-eared owl (*Asio flammeus*). This bird is almost cosmopolitan, occurring unmodified over both hemispheres and even in such isolated islands as the Hawaiian group, though no more maritime and no more capable a flier than the cathartid vultures. It might be suggested as a distinction between these two cases that the vultures are non-migratory and are confined to the tropics, and would, therefore, have no tendency to wander, would not be exposed to the danger of scattering by storms and would always be separated from the other continents by the widest parts of the ocean basins. An examination of the ranges and the habits of the existing species will, however, prove the fallacy of such views. *Cathartes aura* is migratory or not as occasion demands. It is resident to 40° N latitude and thence northward it becomes migratory, being starved out in winter. Its habitual range extends from 55° N latitude to Tierra del Fuego and the Falkland Islands on the south.²⁰

²⁰ Coues, E., Key to N. Am. Birds (ed. 5; 1903), vol. 2.

Other members of the group range as follows: The Andean condor (*Sarcorhamphus*) occurs along the Cordillera from equatorial Peru to the extremity of Patagonia and from sea-level to the highest summits of the Andes; *Catharista urubu* inhabits the whole of tropical America, southward to Argentina and northward as a straggler to the Canadian border; the two remaining genera, *Gyparchus* and *Gymnogyps*, occupy successively more circumscribed areas. Not, however, till the latter was so nearly exterminated by human agency, was either form of restricted range. *Gymnogyps* is confined entirely to the Nearctic realm, *Sarcorhamphus* is entirely Neogaëic, but the three remaining forms are distributed without regard to realm and all are independent of the generally recognized life-zones. That a group thus distributed, many of whose members are so independent of climatic and of minor geographic barriers, should be limited to the western hemisphere seems indeed strange.

The influence of a virile and aggressive species is not infrequently effective as a barrier to the distribution of a less active one and it may be urged that the slightly more rapacious vulturines of the Old World have served as a check upon any tendency of the cathartids to diffuse into Eurasia. Such a view is controverted by the fact that the latter birds prove themselves perfectly able to maintain their existence in competition with the polyborine scavengers which, in a way, represent the Old World vultures in their habits.

With the geographical limitations of the group before us, the question of ancestry and the geological record assume a very important aspect.

Concerning the antiquity of the group there is unfortunately but little known. Previous to the opening up of the Rancho La Brea deposits in California, fossil cathartids of unquestionable identity were unknown to North America. Cope's *Palaeoborus umbrosus*²¹ from the Pliocene of New Mexico, which he originally placed in the genus *Cathartes*, he later transfers to the genus *Vultur*. The new genus *Palaeoborus* was established by Coues for its reception since “. . . . the description and figures

²¹ Cope, E. D., U. S. G. Surv. W. of 100th Merid., vol. 4, pt. 2, p. 287, 1876.

clearly indicate a bird generically distinct from *Cathartes* and the improbability of the occurrence of a true *Vultur* in North America is extreme."²² With the former point at least there can be no possible disagreement after a consideration of Cope's figures of *Palaeoborus*. Whether the form may be considered cathartine at all is open to very serious question. Lucas²³ considers it as more probably of polyborine affinities.

In South America fossil cathartids are less rare. *Cathartes* and *Gyparchus* are reported from the Pleistocene caves of Brazil.²⁴ Moreno and Mercerat²⁵ describe two species from the Pampean Pleistocene and three from the Pliocene of the Santa Cruz. The Pleistocene species, *Cathartes fossilis* and *Sarcorhamphus fossilis*, represent genera still existing in that region. The three species from the Santa Cruz, *Psilopterus communis*, *P. australis* and *P. intermedius*, belong to an extinct genus which is placed by the authors adjacent to *Cathartes* and is considered by them to be intermediate or transitional between that genus and *Sarcorhamphus*. The three species of *Psilopterus* are based on the most fragmentary material. The figures are such as to indicate specimens in rather poor state of preservation as to surface markings. Trochleae are corroded away and intermuscular lines are entirely wanting. *P. intermedius* is based on a single specimen consisting of two tarsal trochleae. The other two species are based upon fragmentary tarsi poorly preserved. While there may be no question in the minds of these authors as to the relationships of the genus *Psilopterus*, there appears nothing in the lithographed figures or in the very meager descriptions that is at all convincing.

Beyond the above instances, the only record of fossil cathartids previous to the excavations at Rancho La Brea is the remarkable specimen made known by Gaillard²⁶ from the phosphorites of Quercy, an Oligocene horizon in France. This species,

²² Coues, E., Key to N. Am. Birds (ed. 2; 2884), p. 822.

²³ Lucas, F. A., in Zittel's Text-Book of Palaeontology, Eng. trans., vol. 2, p. 277, 1902.

²⁴ Winge, O., Fugle fra Knoglehaler i Brasilien, Museo Lundii, 1887.

²⁵ Palae. Argentina, An. Mus. La Plata, pt. 1, p. 67, 1891.

²⁶ Gaillard, C., Ann. de l'Univ. de Lyon, n. ser. 1, Sc. & Med., fasc. 23, 1908.

Plesiocarthartes europeus Gaillard, thus becomes at once the most ancient cathartid, and the only instance known to the author of the occurrence, fossil or Recent, of the family outside the American continents. The species, as far as can be learned, is represented by a single bone, a fragmentary tarsometatarsus preserved in the Museum of Lyons. The specimen is, however, sufficient to establish beyond question the cathartine relationships of the species. Its author considers the case to be one of an individual's having straggled from its normal range. In view of the extensive examination of most of the European horizons which has failed thus far to furnish evidence of its further occurrence there, the conclusions reached by Dr. Gaillard may be considered as probably correct.

With the progress of work at the University of California our knowledge of the group under discussion is considerably advanced. In the collections from Fossil Lake the abundant avian remains are almost entirely of aquatic forms, although there appear in the University collections, as well as in the much larger Cope and the Condon collections, a number of raptorial species. There are, however, no specimens referable to the Cathartidae, a rather conspicuous absence.

There appears no reason deducible from the habits of the turkey vulture of today why, if vultures were present during the formation of these beds, their remains should not have been preserved there. In fact, there is every reason for considering the vulture a more favorable subject for preservation in such deposits than are the other raptors. The turkey vulture is one of the commonest of beach-combers along the shores of both fresh and salt-water bodies and it comes habitually in great flocks to spend the warmer parts of the day wading in the shallower waters or sitting about the sand bars of quiet streams. The negative evidence very strongly suggests the absence of cathartids from the region during the deposition of the Fossil Lake beds.

Potter Creek and Samwel caves both furnish remains of these vultures, while the Rancho La Brea asphalt is especially rich in raptorial species, about equally divided between the cathartids and the falconids.

At Rancho La Brea there occur six truly cathartine species as follows: *Gymnogyps californianus*, *Sarcorhamphus clarki*, *Cathartornis gracilis*, *Pleistogyps rex*, *Cathartes aura*, and *Catharista occidentalis*. Besides these forms, the aberrant *Teratornis* is nearer to the Cathartidae than to any other family at present recognized. In the cave deposits there appear the two forms, *Catharista shastensis* and *Gymnogyps amplus*, belonging to existing genera.

The condors and *Teratornis* represent the extreme of specialization in point of size, the greatest degree of diversity, and possibly also the least specific longevity. *Gymnogyps californianus* alone of the six larger forms has persisted unchanged from the time of formation of the asphalt beds, where it is the most abundant of the condors, until the present time, when it seems on the verge of extinction. Probably its associates of that time had passed the prime of their specific existence while the present form, less specialized toward gigantism, constituted a younger development reaching its maximum of virility later than its congeners but becoming decadent by the present time.

As a result of the excavations at Rancho La Brea the genus *Catharista* became known to the Pleistocene of North America, its first discovery in the fossil state. Its range was at the same time extended from its previous limits—the tropical and lower Austral zones of both continents—to include the Pacific Coast region of California, an area at present occupied by an Upper Sonoran fauna. The fossil species *C. occidentalis* is found in great abundance in the asphalt. Its relative abundance as compared with the other vultures there is shown by a census of an unassorted collection of the bird remains, which gave the following results:

<i>Gymnogyps californianus</i>	11 individuals
<i>Cathartes aura</i>	20 individuals
<i>Catharista occidentalis</i>	21 individuals

As indicated in the note descriptive of *Catharista occidentalis*, the difference between the fossil and the Recent forms lies in the greater body size of the fossil form accompanied by a difference in proportion of the segments of the posterior limb. The tarsus *Polyborus* there appear the following fossil forms whose nearest

shows a greater degree of robustness, both absolute and relative. The humerus is slightly longer and stouter, but whether the wing expanse is increased to a degree commensurate with the increased body weight is questionable. We seem, then, to be dealing with a vulture that was of a heavier body and shorter limb than the persistent *Catharista urubu*. The difference becomes more significant when it is noted that the character separating the extinct from the persistent species of *Catharista* is identical with one of those separating the more restricted *Catharista urubu* from the wider ranging *Cathartes aura*. It should also be noted that the extinct form *Catharista shastensis* from the caves is separable from the Rancho La Brea species, *C. occidentalis*, by a greater robustness of the tarsometatarsus and by a greater body size as indicated by its stouter coracoid. The cave form, the asphalt form, and the Recent form of *Catharista* thus fall with the Recent *Cathartes* into a series of progressively lighter-bodied and possibly more strongly flying vultures, which display, in the cases of the last three at least, a progressively greater ability to cope with their environment.

That the cavern and the asphalt deposits are not of the same age is evidenced by the occurrence therein of distinct but closely related species of cathartids belonging to two genera, i.e. *Gymnogyps* and *Catharista*. The localities are separated by approximately seven degrees of latitude and a difference in elevation of fourteen hundred feet. Both lie at present in approximately the same faunal zone. Species possessed of the excellent volant powers shown by the large vultures when present in the considerable numbers indicated by their remains in the two deposits would scarcely feel the restrictions of such slight barriers as could have existed at that time.

The existing species of *Gymnogyps*, before its numbers were depleted by the influence of man, ranged from Lower California to British Columbia and from sea-level to the summits of the Coast Range, while the existing *Cathartes* is almost ubiquitous. Furthermore our knowledge of the Recent vultures as a group would lead us to discard as incongruous the conception of a vulture so strictly boreal as to come southward in considerable numbers as far as the Shasta region and not reach the more

favorable environment of Southern California. We must, then, almost of necessity conclude that the separation of the two faunas is due to difference in time rather than to any other factor.

The two horizons have in common with the Recent North American fauna three cathartine genera, viz., *Cathartes*, *Catharista*, and *Gymnogyps*. *Catharista*, at present foreign to the immediate vicinity, is represented in the two deposits by distinct species. *Gymnogyps californianus* is abundant in the asphalt beds and in the Recent fauna of a region including and extending far beyond both localities, yet the genus is represented in the cave deposits only by a distinct species, *G. amplus*. It is hard to explain how the cavern deposits could have been interpolated between the Rancho La Brea horizon and the Recent and still possess two distinctive cathartine forms and only one, *Cathartes aura*, in common with either of them.

Distribution of Falconidae.—Palaeontology has added materially to our knowledge of this group in at least two respects, namely in our concepts of the former distribution of its members and of the degree of adaptive radiation that has taken place within its limits. The three genera *Geranoaëtus*, *Morphnus*, and *Polyborus*, limited in Recent time to tropical or to south temperate America, are now known to have ranged in the previous period well up into California. *Geranoaëtus* went as far north as Hawver Cave and the other two as far as Los Angeles. The larger phase of *Haliaëtus*, which is limited at present to the northern parts of North America, had not at the time of deposition of the asphalt beds withdrawn to the northward as a distinct geographical race. The remains of *Haliaëtus leucocephalus* from these beds embrace in their range of variation extremes of size surpassing at either end of the scale the two existing races, *H. l. alascanus* and *H. l. leucocephalus* now geographically distinct.

As illustrative of the number of adaptive radiations of the eagle group we may point to the six fossil eagles of Marsh, Shufeldt, and Miller. These are as follows: *Aquila sodalis*, *A. pliogryps*, *A. dananus*, *Morphnus woodwardi*, *Geranoaëtus grinelli*, and *G. fragilis*. Besides these extinct forms there were found fossil the three persisting species *Aquila chrysaëtos*,

Haliaëtus leucocephalus, and *Geranoaëtus melanoleucus*. *Aquila pliogryps* Shufeldt is described from a single bone, the basal phalanx of the right hallux. The species is considered to be slightly larger but more slender-limbed than *Aquila chrysaëtos*. The material representing the species is so limited that no clear impression of its closer relationships can be formed. *Morphnus woodwardi* from Rancho La Brea may well have been such a bird, though there is no way of obtaining more than the suggestion of similarity from the fact that they were both eagles of slender build. The statement made by Shufeldt is that *Aquila pliogryps* was slender of foot, as indicated by the slightly longer digits. *Morphnus* is a genus of long-shanked eagles with relatively weak feet, as indicated by the size of the trochleae. The digits certainly must have been much smaller in *Morphnus woodwardi* than in *Aquila chrysaëtos* or in *A. pliogryps*.

Shufeldt's species, *A. sodalis*, is founded on the proximal part of a tarsometatarsus. The specimen is figured from the anterior aspect drawn to natural scale. Compared with the Rancho La Brea eagles, *A. sodalis* corresponds quite closely in size with *Geranoaëtus fragilis*, the smallest of the group there represented. *A. sodalis* seems, however, to be of an entirely different nature if the position of the papilla of the tibialis anticus may be taken as indicative. In a discussion of the splendid series of eagle tarsi from the asphalt, it has been pointed out by the author²⁷ that the position of this tubercle seemed to bear a very definite relation to the slenderness of the tarsus, i.e., the long-shanked forms have the tubercle placed high up on the shaft of the bone. Applying this principle to Shufeldt's figure of *A. sodalis*, it would seem that the Fossil Lake species was not of the same group of eagles as the more southern genera *Morphnus* and *Geranoaëtus* assembled by Ridgway under the caption Morphni. In *A. sodalis* the papilla of the tibialis anticus is placed farther down the shaft and the proximal foramina are separated by a much wider space. Unfortunately the character of the hypotarsus is not shown in Shufeldt's figure of *Aquila sodalis* nor is an accurate impression of the region obtainable from the description. It seems proper to consider the two species

²⁷ Miller, L. H., Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, p. 305, 1911.

described by Shufeldt as distinct from any of the Rancho La Brea forms.

Aquila dananus Marsh²⁸ is described as being slightly smaller than the existing *A. chrysaëtos*. A single specimen of the species was taken in the Loup Fork of Nebraska. It consists of the distal part of the tibia only and is not figured by Marsh in the original description. The assignment of the specimen to the genus *Aquila* is proper in the absence of any feature to distinguish it from that genus. The suggestion of the possible identity of one of the Fossil Lake forms, *A. sodalis*, with Marsh's *A. dananus* is made in Shufeldt's paper but that author considers the case improbable on the score of smaller dimensions in the former species. *Geranoaëtus gracilis* Miller from the asphalt is the smallest of the fossil eagles from California and, as indicated above, this species is about the same size as *A. sodalis* Shufeldt. Marsh himself considered the Loup Fork specimen to be "nearly as large as the Golden Eagle," in which case *A. dananus* may be considered as probably intermediate in size between *Aquila chrysaëtos* (Linnaeus) and *Morphnus woodwardi* Miller.

The only other fossil falconids from American localities outside of California are Cope's *Palaeoborus umbrosus*,²⁹ which Lucas³⁰ very properly ascribes to the Polyborinae, and two species from South America recorded by the Argentine palaeontologists, Moreno and Mercerat.³¹ *Lagopterus minutus* Mor. and Mer. is the smaller of these two South American species. It is represented by an almost perfect humerus which, according to the authors describing it, is intermediate between *Buteo* and *Polyborus*, with the preponderance of characters relating it with *Polyborus*. The other species, *Foetopterus ambiguus*, Mor. and Mer., is considered to be intermediate between *Buteo* and *Cathartes*, but is assigned by the authors to the Falconidae. The

²⁸ Marsh, O. C., *Am. Journ. Sci.*, vol. 2, p. 125, Aug. 1871.

²⁹ Cope, E. D., *U. S. Geol. Surv. W. of 100th Merid.*, vol. 4, pt. 2, p. 287, 1876.

³⁰ Zittel, *Textbook of Palaeontology*, trans. by Eastman, vol. 2, p. 277, 1902.

³¹ Moreno and Mercerat, *Palae. Argentina, An. Mus. La Plata*, vol. 1, 1891.

more intimate relationships of the forms are not discussed by the authors.

LIST OF SPECIES ASSIGNED TO THE SUBORDER FALCONES THAT ARE KNOWN TO OCCUR AS FOSSILS IN NORTH AMERICA

Species marked with the asterisk are extinct or are no longer represented in the region. Species marked with the double asterisk are considered to show their closest relationship to forms at present more southern in their distribution.

- Elanus leucurus (Vieillot), Rancho La Brea.
- Circus hudsonius (Linnaeus), Rancho La Brea, Fossil Lake.
- **Circus sp. (smaller than hudsonius), Rancho La Brea.
- Aquila chrysaetos (Linnaeus), Rancho La Brea.
- *Aquila sodalis Shufeldt, Fossil Lake.
- *Aquila pliogryps Shufeldt, Fossil Lake.
- *Aquila dananus Marsh, Loup Fork.
- Haliaetus leucocephalus (Linnaeus), Rancho La Brea.
- **Morphnus woodwardi Miller, Rancho La Brea.
- **Geranoaetus grinnelli Miller, Rancho La Brea.
- **Geranoaetus melanoleucus Auct. (?), Hawver Cave.
- **Geranoaetus fragilis Miller, Rancho La Brea.
- Buteo borealis (Gmelin), Rancho La Brea, Potter Creek Cave.
- Buteo swainsoni (?) Bonaparte, Samwel Cave.
- *Buteo, sp. (larger than Archibuteo), Rancho La Brea.
- Archibuteo ferrugineus (Lichtenstein), Hawver Cave.
- Falco peregrinus Tunstall, Rancho La Brea, Potter Creek Cave.
- *Falco, sp. (smaller than peregrinus), Rancho La Brea.
- Falco sparverius Linnaeus, Rancho La Brea, Samwel Cave and Potter Creek Cave.
- **Polyborus tharus Auct., Rancho La Brea.
- *Palaeoborus umbrosus (Cope), Loup Fork of New Mexico.
- Accipiter velox (Wilson), Samwel Cave.

The species of *Circus* remaining undetermined is a form smaller than the North American *C. hudsonius*. It is not named in this paper since no opportunity has been presented to compare it with the South American species *Circus cinereus* and *C. maculosa*. The last two species, it seems, are smaller than *C. hudsonius* and possibly the asphalt specimens referred to the indeterminate species are of a form identical with the one or the other.

The material from Rancho La Brea representing *Polyborus* is abundant and embraces most parts of the appendicular skeleton and the beak, including the characteristic nareal region. All this material was compared very carefully with the Recent

phase of *Polyborus tharus* as represented by a single specimen from Argentina. As no appreciable difference could be noted, the fossil form is referred to the existing species, *P. tharus*.

Anomalies in Distribution.—According to Ridgway³² the present distribution of *Polyborus tharus* is from Amazonia southward through South America. The bird thus reaches in the Argentine and the Patagonian climates a set of conditions as rigorous as any that it would be liable to experience in the northern hemisphere in the latitude of Los Angeles. The extremes of climate due to the presence of the ice sheet is thought by Allen to have given rise to the periodical movements of birds which finally merged into the present seasonal migration.³³ Would not a plausible explanation be that the polyborine under discussion was driven southward by the cold of the glacial epoch but failed to respond to the later amelioration of climate because of a nature less susceptible to the development of a migratory instinct and therefore remained in the lower latitudes or below the tropics? No record of the true Polyborinae is yet found in the deposits of the southern hemisphere to correspond with the Pliocene form, *Palacoborus umbrosus* (Cope), from New Mexico or to extend the occurrence of the group even back to the Pleistocene, as the Rancho La Brea material does so abundantly for the northern hemisphere. If, on this slender thread of negative evidence, we assume that the group arose in the North Temperate zone, the explanation suggested above seems a plausible one.

Geranoaëtus and *Circus* present cases similar to that of *Polyborus*, while *Morphnus* differs in that the genus is at present limited to the tropics and probably never reaches a southward distribution which would correspond climatically with the region of Hawver Cave or of Los Angeles.

These two cases of *Polyborus* and *Morphnus* mentioned above are typical of as many classes of change in distribution since the formation of the various Pleistocene deposits. Parallel with *Polyborus* there appear the following fossil forms whose nearest

³² Ridgway, R., U. S. Geol. & Geog. Surv. Terr., vol. 1, No. 6, p. 451, 1876.

³³ Allen, J. A., The geography and distribution of birds, Auk, vol. 10, No. 2, April, 1893.

relatives occur in the southern hemisphere at a latitude corresponding with the region of deposit in the northern hemisphere.

Fossil Species	Nearest Living Relative
Phoenicopterus copei Shufeldt.....	Phoenicopterus ruber ? Linnaeus
Ciconia maltha Miller.....	Euxenura maguari (Temm.)
Mycteria americana Linnaeus	Mycteria americana Linnaeus
Jabiru mycteria (Lichtenstein).....	Jabiru mycteria author
Catharista occidentalis Miller.....	Catharista urubu (Vieillot)
Sarcorhamphus clarki Miller.....	Sarcorhamphus gryphus Auct.
Circus, sp.	Circus cinereus or C. maculosus
Geranoaëtus melanoleucus Auct.....	Geranoaëtus melanoleucus Auct.
Geranoaëtus fragilis Miller	
Polyborus tharus Auct.....	Polyborus tharus Auct.

Cases parallel with *Morphnus* in having their nearest related Recent phase limited to more tropical zones are as follows:

Fossil Species	Nearest Living Relative
Pavo californicus Miller.....	Pavo cristatus or Meleagris ocellatus
Morphnus woodwardi Miller.....	Morphnus guianensis Auct.
Geranoaëtus grinnelli Miller.....	Morphnus guianensis Auct.
Micropallas whitneyi (Cooper).....	Micropallas whitneyi (Cooper)
Geocoeyx (?), sp.	Neomorpha geoffroyi (Temm.)

One of the striking features in the study of so representative a series of deposits, all of so nearly the same age as are the bird-bearing deposits of the Pacific Coast, is the total absence of certain forms which one would expect to find therein. While it is conceded that negative evidence in palaeontology is a frail peg upon which to hang an opinion, yet the negation may be so pronounced and so uniformly persistent that, in some cases at least, the only conclusion possible is that species did not occur in the region during the time of deposition.

The particularly favorable conditions offered at Rancho La Brea for the trapping of vultures and eagles has been commented upon in a previous paper on the condors. There was exposed at that place during an indefinite period a more or less constantly baited trap which was unusually attractive to both vulture and eagle. It was automatic in its operation, effective in its hold upon the victim, and almost ideal in the preservation of its catch, the remains of which were sealed from the air in liquid asphalt while still in the flesh. The entire collection of raptorial remains includes, however, no specimen of the royal vulture (*Gyparchus papa*) or of the harpy eagle (*Thrasaëtus harpya*),

both of which occur at present along the Mexican border within fifteen degrees of the latitude of Los Angeles.

The collection of wading birds from the coast, while not rich in point of numbers, embraces a goodly variety. *Jabiru*, *Mycateria*, *Ciconia*, *Grus*, *Ardea*, and *Phoenicopterus* are represented; yet there is no record of the spoonbill (*Ajaia*) or of the ibis (*Guara*), both of which have been taken in the flesh well to the northward of Rancho La Brea.

Grouse, quail, and meleagrines have been taken in various of the deposits under discussion; yet we find there none of the cracid birds such as *Ortalis* which occurs at present along the Rio Grande valley of Texas.

The absence of the above-mentioned species, particularly the Raptores, from all the bird-bearing deposits thus far known to North America becomes very striking in view of the large number of instances recorded of the southward retraction of species and genera since the Pleistocene period. It is possible that the forms mentioned above were more sensitive to the cold and were driven southward before the deposition of the Pleistocene strata thus far explored, or that they were, on the other hand, more tropical species that have only in Recent time diffused northward to their present range. *Gyparchus* is reported from the Pleistocene caves of Brazil by Winge (*op. cit.*) which fact would support the latter hypothesis. *Polyborus cheriway* would fall in the same category with *Gyparchus*, being represented in the asphalt by its close relative *Polyborus tharus*. The same is perhaps true of the Recent species of *Geococcyx* found in the Sonoran zone of California at the present time but represented in the asphalt only by a longer-shanked form which can scarcely be considered as the direct ancestor of the living *Geococcyx californianus*. The species from the asphalt may be identical with one of the species of *Neomorpha* from South America, comparison between them having been thus far impossible.

Approximately eighty species of true columbine birds inhabit the Americas today and many of the species are forms which feed on the ground and which congregate about water holes to drink; yet there is no specimen in all the material examined which is referable to this group. The commonest species in the

coast region today is the turtle-dove (*Zenaidura macroura*), a bird of wide distribution over the Austral region and even to the tropics. Its habits and its abundance are such that one can scarcely concede as possible that it could have been present during the deposition of the Pleistocene beds of Rancho La Brea and yet not be preserved as a fossil.

Palamedea and *Cariama* have in their present home in South America a distribution and habits not unlike those of the stork, *Euxenura*. Both groups are, however, absent from the fossil collections. The peculiarly isolated positions which these birds occupy in the scheme of classification, as well as the measure of uncertainty as to their proper location systematically, makes any light that palaeontology might throw upon the subject especially desirable. Most careful search was made therefore to see if any part of the skeleton of these birds had been preserved, but nothing was found that resembled either species in the smallest degree.

The parrot order, abundant a few degrees to the southward, is unrepresented in the deposits. This may be due to the fact that the only forest fauna which we have preserved to us (cavern deposits) is of Upper Sonoran and lower Transition zones, and thus local conditions may have been unfavorable for these birds. On the other hand, as suggested in the case of *Ortalis*, they may have been driven southward before the deposition of any of the beds thus far explored.

All trace of true struthious birds is lacking in the collections also. The northward diffusion of such forms as the edentates and *Hydrochoerus* among the mammals, the presence since early Pleistocene time of rheas in South America, the occurrence of tridactyl struthionids in the Pliocene of northern India, and of *Struthiolithus* in the superficial deposits of northern China, increase the probability that some day the discovery of true struthious birds in North America will be announced. The most potent factors that would bring about such distribution are first, the possible northward diffusion of rheids along with edentate mammals and, second, the passage of *Struthiolithus* or its relatives along the line of proboscidean invasion from Asia by way of the land bridge to Alaska.

The earliest occurrence of rheids in South America is in strata now referred to the Pleistocene (the Pampean of Monte Hermosa). If the group had reached that continent by way of the Antarctic at an earlier time, their bones would probably be found with the primitive mammals supposed to have been derived from Australia and known to us from the Santa Cruz beds. The rheas with their true struthious characters could hardly have originated *de novo* in South America; hence the conclusion that they entered from the north, as did the true cats, deer, elephants and other mammals of northern or Old World origin.

Cope's discovery of *Diatryma*³⁴ in the Wahsatch Eocene of New Mexico was at first considered as fixing a very early date for the group of Struthionies in the New World. Lucas,³⁵ however, places this unique specimen in the group of Stereornithes with the great *Phororhacos* of South America (Miocene of Santa Cruz). A wide gulf exists between the ostriches and these South American phororhacids. The latter are more probably a local development brought out in response to the peculiar conditions prevailing there in Tertiary time. There existed in South America no large carnivores among mammals until the northern incursion of machaerodonts and the true felines in relatively late geological time. Edentates were left free to develop to the tremendous extent noticeable in the South American Tertiary and Quaternary. In this region of low pressure among mammals there developed unrestrained the predatory bird *Phororhacos*, to occupy a bionomic place like that of the mammalian carnivore. The reference by Lucas of the North American *Diatryma* to the Stereornithes is tentative. He states the case in these words in part: "Still there are sufficient resemblances between the two to warrant the suggestion that if material comes to light it will be found that the affinities of *Diatryma* are with the Stereornithes and not with the Dromaeognathae."

In view of the indeterminate character of the single specimen of *Diatryma* where its relationship between two such distinct

³⁴ Cope, E. D., U. S. Geol. Surv. Terr. W. of 100th Merid., vol. 4, pt. 2, p. 69, 1876.

³⁵ Lucas, F. A., Proc. U. S. Nat. Mus., vol. 24, p. 545, 1903.

groups as the Struthionies and the Stereornithes are in question, it would seem that the chief value of Cope's discovery is to show us that a group of gigantic terrestrial birds can inhabit a region and leave almost no trace of their occupation of that part of the globe. The same fact is pointed out by Eastman³⁶ in his discussion of *Struthiolithus* and the distribution of the Dromaeognathae. Before the discovery of this species in the superficial deposits in the mountainous regions of northern China no one would have surmised that this great area to the north of India was ever inhabited by struthious birds. Why not expect, then, with perfect propriety, that some day the path of immigration of *Rhea* into South America may be traced in yet undiscovered deposits of North America?

The other principle which encouraged the search for rheids in the asphalt, that of a northward migration of southern forms in the Pleistocene, is applicable whether *Rhea* be considered a product of the southern continent or not. Among mammals we have the northward diffusion of the various edentates and *Hydrochoerus*, which may be considered products of southern soil, and we have also a re-entrance from the south of certain forms which are Neogaic by adoption. For example, we may look upon *Didelphys* as having performed such migration. The objection might be raised that the tropical belt would act as a barrier preventing the plains-dwelling *Rhea* from retracing its steps, but such an objection is reduced to questionable validity by the presence of true rheids in the cavern deposits of Brazil.

The following is a list of lipotypes which are considered by the author as of particular interest:

LIST OF LIPOTYPES

<i>Gavia</i> , sp.	Palamedeidae—all species
<i>Gyparchus papa</i> Auct.	Cariamidae—all forms
<i>Thrasaëtus harpya</i> Auct.	Phororhacidae—all species
<i>Polyborus cheriway</i> (Jaquin)	<i>Gaura</i> , sp.
Cracidae—all species	<i>Plegadis</i> , sp.
Columbae—all species	<i>Ajaia</i> , sp.
Psittaci—all species	<i>Geococcyx californianus</i> (Lesson)

³⁶ Eastman, C. R., Bull. Mus. Comp. Zool. Harvard Coll., vol. 32, p. 127-144, 1898.

Possible Influences Conditioning Present Distribution of Certain Groups.—In considering the relation of past to present distribution of American birds, at least two principles present themselves in explanation of the apparent southward retraction of certain forms since Pleistocene time. The first is typified by the case of *Polyborus tharus*. May this species not have been driven southward across the equator after the time of formation of the asphalt deposits by the advance of a cold period such as sent the mammals of the Ovibos zone as far south as Big Bone Lick and Conard Fissure?

Extremes of climate due to the presence of the ice sheet are thought by Allen³⁷ to have given rise to the periodical movements of birds which finally merged into the present seasonal migration. The polyborine under discussion may thus have been driven southward, but lacked the incipient migratory instinct and furthermore failed to return northward upon the amelioration of the climate. This failure may have been due to the presence of more virile species blocking the return path, or it may have been due to the limiting tendency of the torrid zone which it would have had to recross in a return to the north. No record of the true Polyborinae has yet been found in the deposits of the southern hemisphere to correspond with the Pliocene *Palaeoborus* of New Mexico or to extend the occurrence of the group even back to the Pleistocene, as the Rancho La Brea material does so abundantly for the northern hemisphere. If, on this slender thread of negative evidence, we assume that the group arose in the North Temperate Zone, the explanation suggested above seems a plausible one. The distribution of *Circus*, *Geranoaëtus*, *Sarcorhamphus*, and *Euxenura* would further uphold this view of the question. These birds are typically of the southern hemisphere in latitudes to the south of the tropics or at high elevations and the Tierra Caliente would act as a more or less effective barrier to their northward dissemination.

The second hypothesis offered is that the returning annual isotherm has never yet reached the point at which it stood during the deposition of the fossil remains. Sinclair (*Op. cit.*, p. 19) links the Potter Creek Cave deposits pretty closely with the

³⁷ Allen, J. A., *The Auk*, vol. X, No. 2, Apr. 1893.

Upper San Pedro series of marine deposits and the San Pablo Bay oyster beds at Rodeo. These shell deposits are considered by western palaeontologists to represent a time of higher average annual temperatures than prevail in the region at present. The cases of *Morphnus*, *Micropallas*, *Geococcyx* (?) and *Pavo* make a strong aggregate in favor of this theory. To harmonize the cases of *Circus*, *Polyborus*, *Sarcorhamphus*, *Geranoaëtus* and *Ciconia* with those of the more tropical species, it would be necessary to assume nothing further than that these forms, since the partial amelioration of the climate, had developed powers of resistance to cold and had extended their ranges to the southward instead of remaining intertropical species. The extension of range took place from the tropics southward instead of to the northward again because of overcrowded conditions in the north. The advance of arctic cold toward the equator would drive northern animals into narrower and narrower quarters, while the forms of the southern hemisphere, under like encroachment of the antarctic, would experience the opposite effect. The convergence of all the Boreal species into the Austral on the continent of North America would be in effect like crowding the basal contents of a cone into its apex. The result would be an enormous intensification of the natural attrition of species upon species with a resultant stimulus to the surviving form. In the southern hemisphere conditions would be reversed and the advance of polar cold, whether synchronous with or alternating with the northern fluctuations, would have much less serious effect. Assuming the various faunal zones to be fully populated, the driving of the Patagonian fauna into the wide expanse of Argentina and southern Brazil would serve to dilute greatly the Boreal fauna without materially disturbing the Austral. A form that had been obliged to flee the rigorous conditions resulting from an advance of the cold in North America might find, upon the return of milder conditions, that the path of least resistance to expanding range from the tropics led toward the south.

Bird Remains as Indicators of Climatic Conditions.—Certain appearances in the deposits at Rancho La Brea might be interpreted as evidence that the climate during deposition of the beds was warmer and more moist than it is at present in the region.

The fauna is certainly a rich one and embraces a considerable variety of ungulates of large size which were dependent on a goodly supply of grass and browse. Purely local conditions of dainage may, however, have brought about such a condition. In the fickle streams of the southwest such change of bed may occur in a single season and a deposit laid down under conditions of abundant moisture amounting almost to a peat formation may be left high and dry after a severe freshet to suffer a reversion to almost desert condition. Relatively few of the anserines are found in the collections from the asphalt. Geese of the Recent species become almost upland forms during the rainy season when grass is abundant. *Euxenura* is, according to Hudson's account in *Naturalist in La Plata*, a plains-dwelling form of the open pampa at some times of the year. The sand-hill crane, *Grus canadensis*, is notably a plains feeder in the winter and spring, while the great blue heron, *Ardea herodias*, has been seen by the author on the dry hillsides in midsummer seemingly in pursuit of grasshoppers. The presence of these birds in the asphalt in the limited numbers found is not then a positive indication of open water or of even marshy ground. The water-worn fragments of wood and the leaves in bedded deposit are such as occur in small streams of the region today when the streams may be more or less intermittant. A rich and varied mammalian fauna is taken by some writers as an indication of mild climatic conditions. Such conclusion seems scarcely warranted, however, in view of the present conditions in the desert parts of the world. The writer found deer abundant on the open and thorny desert of Lower California in the region of Cape San Lucas. On the mainland of Mexico, in the desert of Sonora, deer, peccary, and mountain sheep are abundant. The accounts by Roosevelt of game distribution in Africa indicate an abundance and a great variety of game in almost desert regions of that continent. On the Mohave, the Colorado, and the great Nevada deserts, the most ephemeral pools of water, even when highly impregnated with alkaline salts, are the resort of multitudes of waterfowl, while Cope and Shufeldt describe abundant life in the region near Fossil Lake on the Oregon Desert.

There is some very credible evidence that the mammals entrapped in the asphalt pools were in part attracted to the locality by water. Over the top of the asphalt layer there may accumulate after a shower a stratum of fairly pure rain water, so little does the viscid asphalt mix with the water. Such an accumulation remains in the impervious basins until evaporated by the heat of the sun, without loss by seepage through the oil-impregnated earth. Pools of water suitable for the use of cattle and horses thus remain impounded in natural reservoirs after adjacent streams have vanished. Natural reservoirs are of such importance in the southwestern deserts as to have received the local Spanish name of "tinajas," and wild mammals of the desert come from long distances to drink at them. Such conditions would tend to concentrate the remains of mammals of a poorly watered region and furnish the asphalt trap with scores of victims which otherwise would have escaped.³⁸

Summing up the evidence of a warm, moist climate during the Pleistocene, we have the following points, all of which are inconclusive:

1. The presence of species whose nearest relatives are at present more tropical in distribution.
2. The presence of an abundant fauna which is suggestive of favorable conditions of climate.
3. The presence of aquatic species and of waterworn chips laid down in places now dry but showing no great changes in topography.
4. The suggestion that the mammals of Rancho La Brea were in some measure led to the region by the presence of water.

Time Relations as Suggested by a Study of Bird Remains.—Osborn divides the Pleistocene period into three great time subdivisions, namely, Pre-Glacial, Glacial and Post-Glacial.³⁹ The Glacial again shows evidence of division into five periods of fluctuation, during which the ice cap oscillated northward and southward with the changing isotherms. The period also represents a time of high elevation of the land surface in general

³⁸ See Darwin, C., *Journal of Voyage of H.M.S. Beagle, 1845* (New ed. 1909), pp. 128-130.

³⁹ Osborn, H. F., *The Age of Mammals*. New York, 1910.

as compared with the Pre-Glacial. The Post-glacial epoch was characterized by an ameliorated climate and a depression of the land surface. Great river floods and large lakes were the result of this amelioration, and extensive fluviatile and lacustrine deposits appear, while the previously restricted species of vertebrates spread out over parts of the country that were formerly covered by the ice cap.

The faunas of the time are divided by Osborn into three life-zones which are distributed through the Pleistocene, but do not coincide with the three time divisions as given above. They do not necessarily represent consecutive faunas, but rather faunas from different topographic divisions which, in some respects, overlap each other, though in the main consecutive. Characteristic mammals have given the names to these zones as follows: *Equus* Zone, a plains fauna partly earlier than and partly synchronous with the second, the *Megalonyx* Zone, which was a forest and meadow fauna mainly of mid-Pleistocene time. The third, or *Ovibos* Zone, is an impoverished fauna, perhaps corresponding with the Arctic and Tundra period of Europe and synchronous with the last great glacial advance, the period of maximum glaciation, which is recorded in the great terminal moraine.

RELATIONS OF SEVERAL PLEISTOCENE MAMMALIAN HORIZONS; ADAPTED
FROM OSBORN

<i>Equus</i> Zone	<i>Megalonyx</i> Zone
6—Kansas Pleistocene, several localities.	9—Big Bone Lick, Ken.
5—Lake Lahontan, Nev.	8—Samwel Cave, Calif.
4—Fossil Lake, Ore.	7—Potter Creek Cave, Calif.
3—Rock Creek, Texas.	6—Washtucna Lake, Wash.
2—Hay Springs, Neb.	5—Rancho La Brea, Calif.
1—Peace Creek, Fla., Late Pliocene or Early Pleistocene.	4—Ashley River, S. Carolina.
	3—Frankstown Cave, Penn.
	2—Port Kennedy Cave, Penn.
	1—Afton Junction, Iowa.—1st interglacial stage.
	<i>Ovibos</i> Zone
	4—Alaska Ground Ice.
	3—Conard Fissure, Ark.
	2—Scattered middle west.
	1—Big Bone Lick, Ken.

The exact time-relations between the several faunas is not determinable, and the overlap of one column upon another is purposely indefinite. The *Equus* fauna is considered in part older than the *Megalonyx* fauna and this in turn than the *Ovibos*.

It must be stated also that the study of mammalian remains from Rancho La Brea, from the caves of California, and from Fossil Lake, Oregon, is still being actively pursued and the list of species revised. Any statement of time-relations must be considered as purely tentative. Few investigators have had so wide and so comprehensive an acquaintance with the mammalian palaeontology of North America as has Professor Osborn; hence it is considered in this connection that his chronological arrangement of the various mammal-bearing horizons represent the truth as nearly as we have yet arrived at it.

It will be noted that the Fossil Lake horizon is placed by him midway in the tabulation of the *Equus* Zone fauna while Rancho La Brea and the caves occupy the middle and upper parts of the *Megalonyx* Zone. Thus Fossil Lake is to be considered as the earliest Pleistocene horizon on the coast productive of avian remains.

If we apply the criterion of percentage of extinct forms, the evidence furnished by the avian remains would indicate a different time-relation than that suggested by Professor Osborn. The various horizons here discussed show the following sequence when arranged according to the percentage of Recent species of birds recorded fossil:

Rancho La Brea.....	60%	still living
Fossil Lake	66%	still living
Potter Creek Cave	68%	still living
Samwel Cave	72%	still living
Hawver Cave	79%	still living

The application of this principle in the case of fossil birds seems, however, less accurate than in the case of mammals when we consider the migratory nature of many bird species. The Fossil Lake fauna according to this basis of estimate would appear to be younger than that of Rancho La Brea. A glance at the list of species from Fossil Lake shows, however, the large

percentage of migratory forms such as the anserines and the pygopodes. These birds by their migratory habits are rendered largely immune to the effects of climatic change that might have brought about extinction in such forms as the raptors and the scratchers. Ten of the fifteen extinct species recorded from Fossil Lake belong to genera which are at present non-migratory in the region.

Whether or not these genera were migratory during Pleistocene time is, of course, a matter of pure conjecture. Allen⁴⁰ suggests that it was during the Glacial Epoch that the migratory instinct was indelibly impressed upon birds by the pronounced seasonal contrast prevailing at that time. Whether the instinct was at that time incipient or real, it seems proper to conclude that those genera which now display it are the ones which would have profited by its initial operation and have escaped extinction.

There presents itself, then, the very potent suggestion that the relatively small proportion of extinct forms represented in the Fossil Lake horizon is due to the fact that many of the genera there represented possessed or else developed the migratory instinct and were preserved except as influenced by other factors.

The remaining four horizons may more properly be compared as to age upon the basis of percentage of surviving species, and such comparison bears out the conclusions reached by Osborn in his study of the mammals.

Causes of Extinction of Birds.—After a consideration of the varied and in many respects remarkable avifauna of Pleistocene times, it is natural that the causes of extinction of these forms should hold an important place in our attention. Why should we now have but two eagles in southern California where five once flourished? Why does but one condor remain of the five species found fossil? The large phase of the variable Pleistocene *Haliaëtus* has withdrawn toward the north into British Columbia and Alaska, while *Phoenicopterus*, the ciconids, *Polyborus* and the morphnine eagles have withdrawn to the southward.

The gigantic *Teratornis* disappeared, leaving no near relative

⁴⁰ Allen, J. A., The geography and distribution of birds, *Auk*, vol. 10, No. 2, Apr. 1893.

to represent the family among the Cathartiformes. How late did this great bird persist, and did that important factor, man, have anything to do with his disappearance? According to Dr. C. Hart Merriam,⁴¹ the Me-wah Indians of California have a legend concerning a gigantic vulture, Yel-lo-kin, so large that he was able to capture the condor and carry him up through a hole in the sky. The bird myths of these Indians indicate a close acquaintance with the California species. It may be that *Teratornis* persisted until the arrival of man upon the scene, and thus gave rise to the Mew-wah Indian myth of Yel-lo-kin.

Granting the possible truth of such an assumption as the contemporaneity of man and *Teratornis*, the primitive human animal could have had but little cause to direct his efforts against the large raptorial birds. His meagre offensive armament would probably have availed him but little in any event. Thus the only influence he would have been likely to exert would be but the indirect effect through the extermination of large mammals. The possibility of man's having exerted any such influence on the lives of avian species seems remote, in view of the negative evidence afforded by the absence thus far of human remains from western horizons of undoubted Pleistocene age.

Direct extermination, or the sharpening of competition, by incursions of Old World forms, is a theory without the support of any tangible evidence in the case of birds. The procyonids and *Didelphys* are of long standing in America. Felines would greatly influence the larger birds by direct attack either upon the bird or its nest. It seems highly improbable, then, that birds could have been directly influenced by man or the other mammals, but that the chief relation of mammals to the large birds was in the dependence of the latter upon the former for food-supply.

As has been pointed out in an earlier paper,⁴² the large raptorial birds depended in a dual respect upon the large mammals. First, these birds fed upon the bodies of either carnivores or herbivores dying of whatever cause; second, the vulture fed upon the rejected portion of the carnivore's kill. Thus, any factor

⁴¹ Merriam, C. H., *The Dawn of the World*, p. 163, 1910.

⁴² Miller, L. H., *Univ. Calif. Publ., Bull. Dept. Geol.*, vol. 6, p. 2, 1910.

which tended to reduce the numbers of either group of mammals must have reacted also upon the large birds of prey.

It is not at all improbable that the things which brought about the extinction of Pleistocene mammals were also directly operative in bringing about the extinction of many species of birds. Non-raptorial birds, except where migratory, would respond to climatic changes very much as did mammals. Osborn makes suggestions regarding the mammals as follows:

“the Glacial period in North America originated certain new conditions of life which directly or indirectly resulted in extinction.

“These conditions include diminished herds, enforced migrations, the possible overcrowding of certain southerly areas, changed conditions of feeding, disturbance in the period of mating and reproduction, new relations with various enemies, aridity, deforestation; in short, a host of indirect causes.”⁴³

Disease, in all probability a factor in the extinction of some mammals, may likewise have been the determining influence in the case of certain birds. During the winter of 1908-9 in southern California, the bodies of thousands of sea-birds were cast up on the beach within a comparatively short time. Many of these specimens were examined by Dr. F. C. Clark of Los Angeles and by the author. The intestines were found filled with tape-worms. Mildness of the weather coupled with the profound emaciation of the birds indicated that death was not due to violence or sudden cause. While the presence of parasites may not have been the only influence leading to death, it was, in all probability, an important and possibly the determining factor.

If, as is so variously suggested, the rainfall is now much less than it was during the Pleistocene, the influence upon bird life may have been effective over wide areas through the several factors of food, shelter and nesting sites. *Pavo* and *Meleagris*, although not always confined to wooded country, are both forms which might have been strongly influenced by deforestation. The morphnine eagles, with the possible exception of *Geranoaëtus*, are forest-dwelling birds. The local extinction of these birds in California may have resulted from a thinning-out of the forests.

⁴³ Osborn, H. F., *The Age of Mammals* (New York, Macmillan, 1910).

Development of gigantic size in the cathartids is in effect a case of over-specialization in that it works frequently to the detriment of the species. The condors of today are of such unwieldy size that, after a full meal, they experience much difficulty in taking wing from low ground. This fact is reported to have caused the destruction of many individuals which had been led to alight in places from which they could not rise again into the air. *Teratornis* must have attained a bulk almost thrice that of the condor if we may judge from coracoid and furecula. The suggestion conveyed by the sternum is that the pectoral muscles were not so heavy in proportion, yet the weight of the bird must have been far greater than that of the condors. The nature of its food was such that it must have come to the ground to feed. The effort to rise again, gorged with food, must have been a severe tax upon its strength, and slowness in taking wing may have subjected it to frequent danger. The high, compressed beak of *Teratornis* resembling the eagle's in form, though structurally cathartine, indicated the extreme of specialization. The large body size, likewise a phase of specialization, may have militated in the end against the life of the species.

The principle of specific decay or senility of species as a cause of extinction may have suffered somewhat through the too frequent application of it by the palaeontologist, yet there often appear cases in which no other factor seems adequate to explain the loss of a species. Certainly the intersterility of species would lead to inbreeding with its attendant ill effects. Incipient strains of intersterility within a species might, where geographically restricted, lead to the more rapid deterioration of the stock; generation upon generation of individuals, like the succeeding generations of somatic cells, become less and less virile until the species would decline in a manner comparable to the senile decay of the individual. The rapid decline of certain of the less conspicuous species of Hawaiian birds, such as *Palmeria* and *Chaetoptila*, seems almost of necessity the result of such depleting influence. How effective this factor was in robbing us of many Pleistocene birds it is of course impossible to estimate; it would seem proper, however, to look upon it as possibly a contributing cause.

TABULAR ARRANGEMENT OF WEST-AMERICAN PLEISTOCENE
AVIFAUNAS

	Fossil Lake	Rancho La Brea	Potter Creek Cave	Samwel Cave	Hawver Cave	Rodeo
<i>Æchmophorus lucasi</i> Miller	*					*
<i>Æchmophorus occidentalis</i> (Lawrence)	*					*
<i>Colymbus holbœlli</i> (Reinhardt)	*					
<i>Colymbus auritus</i> Linnaeus	*					
<i>Colymbus nigricollis californicus</i> (Heermann)	*					
<i>Podilymbus podiceps</i> (Linnaeus)	*					
<i>Larus argentatus</i> Pontoppidan	*					
<i>Larus robustus</i> Shufeldt	*					
<i>Larus californicus</i> Lawrence	*					
<i>Larus oregonus</i> Shufeldt	*					
<i>Larus philadelphia</i> (Ord)	*					
<i>Xema sabini</i> (J. Sabine)	*					
<i>Sterna elegans</i> Gambel	*					
<i>Sterna forsteri</i> Nuttall	*					
<i>Hydrochelidon nigra surinamensis</i> (Gmelin)	*					
<i>Phalacrocorax macropus</i> (Cope)	*					
<i>Pelecanus erythrorhynchos</i> Gmelin	*					
<i>Lophodytes cucullatus</i> (Linnaeus)	*					
<i>Anas platyrhynchos</i> Linnaeus	*					
<i>Chaulelasmus streperus</i> (Linnaeus)	*					
<i>Mareca americana</i> (Gmelin)	*					
<i>Nettion carolinense</i> (Gmelin)	*					*
<i>Querquedula discors</i> (Linnaeus)	*					
<i>Querquedula cyanoptera</i> (Vieillot)	*					
<i>Spatula clypeata</i> (Linnaeus)	*					
<i>Dafila acuta</i> (Linnaeus)	*					
<i>Aix sponsa</i> (Linnaeus)	*					
<i>Marila valisineria</i> (Wilson)	*					
<i>Claugula islandica</i> (Gmelin)	*					
<i>Harelda hyemalis</i> (Linnaeus)	*					
<i>Erismatura jamaicensis</i> (Gmelin)	*					
<i>Anser condoni</i> Shufeldt	*					
<i>Anser albifrons gambeli</i> Hartlaub	*	?				
<i>Branta hypsibata</i> (Cope)	*					
<i>Branta canadensis</i> (Linnaeus)	*	*	*			
<i>Branta propinqua</i> Shufeldt	*					
<i>Chen hyperboreus</i> (Pallas)	*					
<i>Olor paloregonus</i> (Cope)	*					
Indeterminate anserine					*	
Indeterminate anserine					*	

	Fossil Lake	Rancho La Brea	Potter Creek Cave	* Samwel Cave	Hawver Cave	Rodeo
Indeterminate anserine						
Phoenicopterus copei Shufeldt	*					
Ciconia maltha Miller		*				
Jabiru myeteria (Lichtenstein)		*				
Myeteria americana Linnaeus		*				
Ardea herodias Linnaeus		*				
Ardea paloccidentalis Shufeldt	*					
Grus minor Miller		*				
Grus canadensis (Linnaeus)		*				
Fulica americana Gmelin	*					
Fulica minor Shufeldt	*					
Lobipes lobatus (Linnaeus)	*					
Oreortyx picta (Douglas)						
Lophortyx californica (Shaw)						
Lophortyx, sp.		*				
Dendragapus obscurus (Say)						
Bonasa umbellus (Linnaeus)						
Tympanuchus pallidicinctus (Ridgway)	*					
Pedioecetes phasianellus columbianus (Ord)	*					
Pedioecetes lucasi Shufeldt	*					
Pedioecetes nanus Shufeldt	*					
Palaeotetrix gilli Shufeldt	*					
Indeterminate odontophorid			*	*		
Meleagris, sp.	?	*			*	
Pavo californicus Miller	*					
Gymnogyps californianus (Shaw)						
Gymnogyps amplus Miller		*	*			
Sarcorhamphus clarki Miller	*					
Cathartornis gracilis Miller	*					
Pleistogyps rex Miller	*					
Cathartes aura (Linnaeus)	*	*	*	*	*	
Catharista occidentalis Miller	*					
Catharista shastensis Miller		*	*	*	*	
Teratornis merriami Miller	*					
Elanus leucurus (Vieillot)	*					
Circus hudsonius (Linnaeus)	*	*				
Circus, sp.		*				
Accipiter velox (Wilson)						
Buteo borealis (Gmelin)						
Buteo swainsoni Bonaparte (?)						
Buteo, sp.		*				
Archibuteo ferrugineus (Lichtenstein)						
Aquila chrysaetos (Linnaeus)	*					

	Fossil Lake	Rancho La Brea	Potter Creek Cave	Samuel Cave	Hawver Cave	Rodeo
<i>Aquila pliogryps</i> Shufeldt	*					
<i>Aquila sodalis</i> Shufeldt	*					
<i>Haliaeetus leucocephalus</i> (Linnaeus)		*				
<i>Morphnus woodwardi</i> Miller		*				
<i>Geranoaëtus melanoleucus</i> Auct. (?)			*			
<i>Geranoaëtus grinnelli</i> Miller			*			
<i>Geranoaëtus fragilis</i> Miller			*			
<i>Falco peregrinus</i> Tunstall				*		
<i>Falco</i> , sp.				*		
<i>Falco sparverius</i> Linnaeus				*		
<i>Polyborus tharus</i> Auct.				*		
<i>Aluco pratineola</i> (Bonaparte)				*		
<i>Asio wilsonianus</i> (Lesson)				*		
<i>Asio flammeus</i> (Pontoppidan)				*		
<i>Otus asio</i> (Linnaeus)						
<i>Bubo virginianus</i> (Gmelin)						
<i>Bubo sinclairi</i> Miller			*	*		
<i>Speotyto cunicularia hypogaea</i> (Bonaparte)			*			
<i>Glaucidium gnoma</i> Wagler						
<i>Micropallas whitneyi</i> (J. G. Cooper)				*		
<i>Neomorpha</i> ?, sp.				*		
<i>Colaptes cafer</i> (Gmelin)						
<i>Otocoris alpestris</i> (Linnaeus)				*		
<i>Cyanocitta stelleri</i> (Gmelin)						
<i>Corvus corax</i> Linnaeus						
<i>Corvus braehyrhynchos</i> Brehm						
<i>Corvus annectens</i> Shufeldt				*		
<i>Corvus</i> , sp.				*		
<i>Xanthocephalus xanthocephalus</i> (Bonaparte)				*		
<i>Agelaius gubernator</i> (Wagler)				*		
<i>Sturnella neglecta</i> Audubon				*		
<i>Euphagus cyanocephalus</i> (Wagler)						
<i>Euphagus affinis</i> Shufeldt				*		
<i>Pipilo</i> , sp.				*		
<i>Lanius ludovicianus</i> Linnaeus				*		

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NOTE.—Since the text of this paper went to press, bird remains have been found in the Upper San Pedro Pleistocene at San Pedro, Cal., by Dr. F. C. Clark of Los Angeles. These remains were very generously presented to the present writer by Dr. Clark, and by permission of the latter, were deposited in the Vertebrate Palaeontology Collections at the University of California. Three of the specimens are almost perfect, the several others are too fragmentary for determination. One specimen represents an undescribed species of grebe of the genus *Æchmophorus* but in view of the fact that the active exploration of these beds now going on will possibly bring to light other remains of like nature, a description of the species is thought unwise at present.

Remains of *Bison*, *Equus*, a camelid, rodents, seals, small turtles, and sting rays have also been taken from these beds by Dr. Clark and the writer.

LIST OF SPECIES FROM UPPER SAN PEDRO

Mammals	Birds
Equus	<i>Æchmophorus</i> , n. sp.
Bison	<i>Nettion carolinense</i> (Gmelin)
Camelid	<i>Sturnella neglecta</i> Audubon



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PHYSIOGRAPHY AND STRUCTURE OF THE
WESTERN EL PASO RANGE AND THE
SOUTHERN SIERRA NEVADA

BY

CHARLES LAURENCE BAKER



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INTRODUCTION

Some observations were made on structural and physiographic features in a section of the southern Great Basin during a recent reconnaissance conducted for the Department of Palaeontology of the University of California, under the general direction of Professor John C. Merriam. Since the main purpose of the undertaking was the collection of vertebrate fossils, relatively little time was available for geologic observations. The following notes, therefore, are much scattered and can make no pretence to the completeness and accuracy necessary for a strictly scientific treatment of the geology. However, certain features were noted which have not been described by previous investigators of the region.

The area examined embraces that portion of the southern slope of the Sierra Nevada situated between Jawbone Cañon, northeast of Cinco Station on the California and Nevada Railroad, and Indian Wells, southeast of Walker Pass and some miles south of the Inyo-Kern County line. Most of the field work was done in the El Paso Range, a few miles south and in *en echelon* relation with the above-designated section of the Sierra Nevada. Only that portion of the El Paso Range west of the summit of Black Mountain was studied.

The writer is under great obligation to his field associates, Messrs. S. H. Gester, George E. Stone, and John Guintyllo, and for microscopical examinations of rocks to Professor George D. Louderback, Mr. R. G. Davis, and Mr. John R. Suman. Acknowledgements are also due to Professor Andrew C. Lawson for information concerning erosion cycles and periods of deformation in the southern Sierra Nevada.

THE WESTERN EL PASO RANGE

PREVIOUS INVESTIGATIONS

The only geologists who have written of the western El Paso Range are G. K. Gilbert,¹ H. W. Fairbanks,² and the writer.³ The easternmost portion of the range will be described by F. L. Hess in the forthcoming Randsburg folio of the United States Geological Survey.

GEOGRAPHY

The El Paso Mountains form a low, even-crested, and, for the most part, maturely dissected ridge lying *en echelon* with the southern Sierra Nevada along the northern boundary of the Mohave Desert. They trend east-northeast and west-southwest for their entire length of twenty miles and are about six times as wide near their eastern extremity as near their western. They reach their highest summit in Black Mountain, a short distance west of the region mapped on the Randsburg topographic sheet of the United States Geological Survey. Eastward of Black Mountain the range continues into the region of the northwestern portion of the Randsburg sheet and comes to an end about three miles east of the boundary line between Kern and San Bernardino counties and some six to eight miles north of the mining camp of Randsburg. The southern base of the El Paso Range is skirted by the California and Nevada broad-gauge railroad, a branch of the Southern Pacific System.

The El Paso Mountains are separated on the north from the Sierra Nevada by a southward-sloping alluvium-mantled plain ranging in width from six or eight miles east of Walker Pass to less than two miles at the west, north of Cantil station on the

¹ Report on the geology of portions of Nevada, California, and Arizona, examined in the years 1871 and 1872, Geog. and Geol. Expl. and Surv. west of the Hundredth Meridian, vol. 3, pp. 142 and 143, 1875.

² Notes on the geology of eastern California, Am. Geol., vol. 17, pp. 63-74, 1896.

³ Notes on the later Cenozoic history of the Mohave Desert region in southeastern California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, pp. 333-383, 1911.

California and Nevada Railroad. This whole depression, to the very foot of the El Paso Range, is mantled with debris derived from the Sierra Nevada. The northward slope of the El Paso Range is longer and less precipitous than the southward slope, which rapidly falls off to the south into the depression occupied by Kane "dry lake." The southern base of the mountain ridge forms a remarkably even and straight line (pl. 8, fig. 1). Above this base-line the summit peaks rise to altitudes of less than one thousand feet on the west and to more than three thousand feet on the east. The western portion of the mountain mass is separated into two subsidiary ridges by the deeply-incised tributaries of Red Rock Cañon and Last Chance Gulch.

The mountain ridge is cut transverse to its longer axis by three deep and narrow cañons, named in order from west to east, Red Rock Cañon, Last Chance Gulch, and Goler Gulch. These cañons head in the north flank, cross the range, and drain into the Kane depression to its south. There are springs in the beds of these cañons which furnish a surface flow for a few hundred yards in places where the bedrock is close to the surface of the stream bed, but in none of them is there a permanent stream with powers of continuous erosion.

The upper tributaries of the cañons, situated in the comparatively slightly indurated sedimentary beds of the north flank, follow in general the strike of the strata (pl. 8, fig. 2, and 10, fig. 1) parallel to the longer axis of the range, and have excavated rather wide and flat basins both north and south of Ricardo post-office (pl. 9, fig. 1 and fig. 2) in Red Rock Cañon. But upon entering the more resistant plutonic and metamorphic rocks, which the cañons cut through in directions nearly at right angles to their former courses, the cañons both deepen and steepen very perceptibly (pl. 9, fig. 2), becoming in places almost vertical, while their beds narrow until in some places they are scarcely wide enough for a wagon to pass between the rock walls. The precipitous walls and the narrow bed are especially characteristic of Last Chance Gulch. That gulch, too, has an extremely tortuous course where it cuts through the granite. It heads in tributaries on the southern and southeastern slopes of Black Mountain and then extends for several miles in a westerly direc-



Fig. 1.—Southward-facing fault scarp of the El Paso Range. Basin of Kane “dry lake” to the right.



Fig. 2.—Interbedded basalt flows in the Rosamond series, north flank of the El Paso Range. The northwestward dipping strata of the north flank are shown, and also the strike valleys excavated between the hogbacks of more resistant rock. On the lower slopes in the middle distance is a terrace of horizontally bedded alluvium. The high peak on the middle of the horizon is Black Mountain, separated by a depression from the main granite range on the right.

tion along the strike of the basal beds of the Rosamond series of sedimentary rocks. It thus separates the range in this vicinity into two subsidiary ranges, the basalt-capped Black Mountain on the north and the main granite ridge on the south.

SEQUENCE OF FORMATIONS

The rocks of the El Paso Range may conveniently be divided into the basement complex of metamorphic and plutonic rocks, the superjacent series of sedimentary and volcanic rocks, and the alluvium. The basement complex comprises the rocks of the higher divides and, with the exception of two minor localities, of the whole southern flank. The sedimentaries and volcanics, with the exceptions just noted, are confined to the northern flank. The alluvium mantles in places all the older rocks.

THE BASEMENT COMPLEX OF METAMORPHIC AND PLUTONIC ROCKS

Metamorphic Quartzite-conglomerate and Quartz-schist in Red Rock Cañon.—The lower narrows of Red Rock Cañon have been cut through a metamorphic series of quartzite-conglomerate, quartzite, and quartz-schist of unknown age and thickness. This series comprises the oldest rocks in the western portion of the range. The quartzite-conglomerate is formed of well-rounded, milky quartz pebbles averaging less than an inch in long diameter, embedded in a matrix of impure quartzite with a noticeable percentage of basic minerals which gives the rock a greenish-gray to dark gray color. Under the microscope the quartz is seen to form a holocrystalline fine granular mosaic with schistose structure. About ten per cent of the rock is made up of a green hornblende, which is also recrystallized. Another slide shows about as much epidote as quartz, with an irregular vein of calcite including anhedral grains of a mixture of limonite and hematite. The quartz includes acicular crystals, greenish-yellow in color, which are probably epidote. Good slaty cleavage is developed in portions of this series. Small masses of secondary pyrite are to be seen in the quartzite.

Intrusive Hornblende Diorite-porphyr.—The metamorphic series is cut by a mass of hornblende diorite-porphyr. The main intrusive rock has medium-sized and fairly abundant

phenocrysts of green hornblende and whitish feldspar. The groundmass is microcrystalline. The feldspar of the phenocrysts, making up about fifty per cent of the rock, is andesine, in large part altered to muscovite, calcite, and quartz. The feldspar of the groundmass has about the same composition as that of the phenocrysts and is also altered and silicified. Thirty per cent of the rock is made up of the green hornblende of the phenocrysts and groundmass, in fairly fresh condition. Magnetite phenocrysts are also present.

The apophyses from the main mass differ from it both in texture and color. The dike rock is dark bluish gray in color, with an aphanitic groundmass and lath-shaped phenocrysts of hornblende, some of which are a half inch in length. Small masses of secondary pyrite can be seen in the hand specimen. Under the microscope the rock is seen to be holocrystalline porphyritic with phenocrysts making up forty-five per cent of the total mass. Green hornblende, in large measure altered to chlorite, makes up forty per cent. Ten per cent is made of phenocrysts of a monoclinic pyroxine, probably augite. Labradorite feldspar of the groundmass comprises thirty-five per cent, while the plagioclase of the phenocrysts makes up fifteen per cent. The feldspars are largely altered to an aggregate of muscovite and calcite.

Acidic Igneous Rocks.—East of the intrusion of hornblende diorite-porphyry the southern or main ridge of the El Paso Range is made up of coarse-grained granite cut by dikes of pegmatite and aplite. The relations of this granite to the metamorphic series and the hornblende-diorite porphyry was not ascertained. A dike cutting the metamorphic series about one half mile east of the lower narrows of Red Rock Cañon contained primary oligoclase feldspar, which had been subjected to crushing, and quartz lenses representing either original quartz phenocrysts or amygdules. The original groundmass contained quartz in large amount, which had been recrystallized. An original crystal of titanite was crushed. A small amount of chlorite was present in the quartz, and a vein-like mass of epidote, containing veinlets of quartz, cut the rock. The rock should probably be called an altered quartz porphyry.

THE SUPERJACENT SERIES OF SEDIMENTARY AND VOLCANIC ROCKS

In a previous paper by the writer the extensive bedded deposits of tuffs, tuff-breccias, and lava flows on the northern flank of the El Paso Range were grouped with the Rosamond series on the basis of lithologic similarity and similar fossil content to strata farther south in the Mohave Desert originally given that name by Hershey.⁴

West of Red Rock Cañon the metamorphics are overlain unconformably by a lava flow called by Gilbert an "orange, massive, subspherulitic rhyolite." The writer made no examination of this rock.

East of Red Rock Cañon the quartzite-conglomerate, quartzite, and hornblende diorite-porphyry are overlain unconformably by a loosely-cemented breccia containing angular fragments of the underlying rock. The matrix is mainly silicious sand ranging in size up to coarse grit and fine pebbles.

Farther east, where the Rosamond unconformably overlies the granite, there is at the contact a pure white, silicious, compact rock about twenty feet thick, overlain by several hundred feet of red breccia, with thin interstratified beds of light gray tuff-breccia, grading up into light gray tuff-breccia.

On the east wall of Last Chance Gulch the basal Rosamond lies unconformably upon the granite. The basal beds are coarse water-worn conglomerate with a matrix of dark red granite arkose and boulders and pebbles mainly of granite, some boulders being as large as a foot in diameter. The immediate overlying beds are coarse and of varied hue, sometimes with interbedded red and grayish-white layers, sometimes with cream-colored or yellow or pink or dark red layers. A short distance above the base the rounded conglomerate passes into angular breccia.

The basal sediments in Red Rock Cañon consist of two hundred and fifty feet⁵ of dark red breccia, with thinner interstratified layers of light gray color. Next in the upward succes-

⁴ Some Tertiary formations of southern California, *Am. Geol.*, vol. 29, pp. 349-372, 1902.

⁵ All thicknesses given in the following descriptions are only approximate estimates.

sion comes a light pink spotted tuff-breccia forming one massive bed 100 feet in thickness, and cut by two strike faults of fifteen and fifty feet displacement. The matrix of this bed is a tuff of a lighter shade of pink than the angular fragments of reddish lava which it contains. This is succeeded by beds mainly gray in color with thin interspersed layers of dark red, 150 to 250 feet in thickness. Then come 300 feet of light gray, rather fine, poorly stratified tuff-breccia, capped by a flow of vesicular basalt about fifty feet thick. A second flow of basalt is separated from the first, at an interval of about fifty feet, by beds similar to those just below the lower flow (pl. 8, fig. 2).

In the writer's first description of this section it was stated that there was but one basalt flow, the outcrop of which had been repeated by a normal strike fault. This statement is now definitely known to have been erroneous. In the first examination these basalt flows were studied only in the vicinity of Ricardo post-office, where their relations are obscured by alluvium. It was noted that about three-fourths of a mile to the west the lower flow came to an abrupt end, and taking into consideration the proved presence of strike faults a short distance below the basalt, it was thought that the best explanation for the outcrop of two layers of basalt in the walls of Red Rock Cañon was that a single flow had been repeated by a strike fault gradually diminishing in amount of displacement towards the west and finally coming to an end about three-fourths of a mile west of Red Rock Cañon. But in reality a wide stream channel was excavated in the lower basalt flow before the outflow of the upper one, for still farther west the lower flow suddenly appears and the space in which the lower flow is absent is filled with much cross-bedded sediments. The relations here are very suggestive of conditions similar to those during which the river-channel sandstones and conglomerates were laid down in drainage courses eroded in finer beds of White River Oligocene age in the Big Bad-lands region of South Dakota.

Conclusive evidence that these basalts are interbedded flows and not intrusive sills is furnished by the fact that their upper surfaces have been eroded and that fragments of the basalt are locally found in abundance in the tuff beds in close juxtaposition



Fig. 1.—Basin excavated by Red Rock Cañon in the Rosamond series above the outcrop of the higher interbedded basalt flow, at Ricardo post-office. Typical badland topography of the Rosamond as well as the mantle of Sierra alluvium covering the bevelled surface of the northwestwardly dipping Rosamond illustrated by this view. The dissection of the alluvium and underlying Rosamond is to be noted. Upper surface of upper basalt flow in the left foreground.



Fig. 2.—Basin excavated by Red Rock Cañon and its tributaries in the lower Rosamond below the interbedded basalt flows. In the center of the middle distance is the probable antecedent cañon cut through the metamorphics of the main or south ridge of the El Paso Range.

with the upper surface of the basalt. Gilbert's original interpretation of two interbedded basalt flows, as shown in his cross-section,⁶ is the correct one.

These basalts are quite vesicular, the vesicles being partially or entirely filled with quartz, chalcedony, or natrolite. Three or four miles to the east of Red Rock Cañon the basalt flows, which have gradually become thinner, entirely disappear.

Above the upper basalt flow in the Red Rock Cañon locality are found in upward succession: (1) a light bluish gray arkose of coarse granite and lava breccia, interbedded with fine, green, velvety tuff; (2) about 40 feet of rather fine, well-cemented breccia; (3) 50 to 75 feet of ashy tuffaceous beds, quite coarse and poorly assorted; (4) light brownish tuffs capped by two layers of darker, reddish-brown, more resistant, fine breccia, composed of the usual angular arkosic material and forming vertical cliffs some of which are 50 feet in height.

In Last Chance Gulch the basal beds are succeeded at 150 to 250 feet above their base by a red breccia containing dark brick-red lava fragments in a matrix of dark pink tuff. The lava fragments are mostly rather small, varying up to two inches or more in diameter. They contain moderately abundant small phenocrysts of fairly fresh oligoclase feldspar and a few phenocrysts of what was probably hornblende now altered to an aggregate of iron oxides and chlorite. Some of the feldspar is altered to kaolin. Magnetite is found in small grains. The feldspar of the matrix is also oligoclase. The fragments have the same composition as their matrix and the rock is an andesitic tuff-breccia.

The andesite tuff-breccia is overlain by 100 feet of fine, whitish tuff-breccia containing small angular fragments of plutonic and volcanic rocks and pieces of white fibrous pumice. The pumice is quite abundant at this locality. Above come bluish-gray tuffs similar to those already described in the Red Rock Cañon section.

The highest beds of the Rosamond which were examined are exposed about four miles north of Ricardo post-office. These higher beds are in general finer and not so well indurated as those lower down in the series. In contrast with the badland

⁶ Geog. and Geol. Expl. and Surv. west of the Hundredth Meridian, vol. 3, p. 142, 1875.

topography characteristic of the lower beds the upper member forms low hummocky mounds rising here and there above the mantle of alluvial debris. At the locality four miles north of Ricardo post-office fine buff beds are capped by a dark resistant layer of subangular to angular bowlders, some of which are as large as a foot and a half in diameter, of very vesicular basalt, red porphyritic lava, red lava showing flow structure, chert, finely-laminated slate, and quartz. This capping is very local in extent and is probably a stream deposit.

Fossils are probably to be found throughout the entire thickness of the Rosamond series. They have been reported from the basal beds in the placer diggings in Bonanza Gulch about one-half mile east of the lower narrows of Red Rock Cañon, but no fossils were collected from the basal beds by the writer or his associates. Mr. George E. Stone found the skull and tusks of a mastodon in place about 400 feet stratigraphically below the lower basalt flow in Iron Cañon, the main gulch tributary to Red Rock Cañon on the east, about two and one-half miles east of Red Rock Cañon. The mastodon remains are in rather fine greenish-gray tuff interbedded with coarser conglomerate layers about 200 feet stratigraphically below the massive pink tuff-breccia of the Red Rock Cañon section. This is the lowest definitely known fossiliferous horizon. Fossils were found in the very topmost beds exposed, but are apparently most abundant in the 300 or 400 feet of beds lying next above the upper basalt flow. The fossil remains are fragmentary and were often checked and broken before burial. The fossil forms found include horses, camels, merycodonts, mastodons, canids, and felids. They probably place the age of the Rosamond series as not older than the Upper Miocene. The definite assignment of age to the fauna cannot be made until it has been studied in detail.

THE BLACK MOUNTAIN BASALT FLOW

The even surface of bevelled Rosamond strata is overlain on the summit of Black Mountain by a flow of olivine basalt. The basalt is both vesicular and compact in habit. The flow is a thin one, probably less than 100 feet in thickness at a maximum,



Fig. 1.—General view of the outcrop of the Rosamond on the north flank of the El Paso Range. In the foreground is the metamorphic series and intrusive diorite-porphry overlain unconformably by basal Rosamond. The dark capping of the hogback in the middle distance is the lower interbedded basalt flow. Farther back is the debris slope of Sierra alluvium, with the peaks of the Sierra on the horizon. Characteristic strike valleys, excavated in the Rosamond, are seen in the middle distance.



Fig. 2.—Recent dissection of the alluvium and underlying Rosamond, three-fourths mile northwest of Ricardo post-office. The even surface of the alluvial mantle and the northwestward dip of the Rosamond strata are to be noted. This is one of the best of the fossil localities.



and slopes in all directions from the summit of the mountain in a domical structure. It forms northwardly sloping mesas on the north flank of the mountain and southwardly sloping mesas on the south flank. These mesas have been cut into by deep and narrow V-shaped gullies. Just southwest of the highest peak of Black Mountain is a depression in the basalt some thirty or forty feet deep and approximately three hundred feet in diameter, which may represent the crater from which the basalt was poured out. Both Fairbanks and Hess have expressed the opinion that the basalt had a local origin in Black Mountain, and the present writer's observations would induce him to regard it as only a local flow. The surface slope of the basalt on the northwest side of the mountain has its even contour interrupted by long narrow ridges with their steeper slopes on the downhill side. These may be pressure ridges. Hyalite was present with other and more common minerals of the amygdules.

Mr. John R. Suman gives the following petrographic description of this olivine basalt:

This lava under the microscope is seen to be remarkably fresh and well preserved. It has the intersertal structure characteristic of basic igneous rocks.

A feldspar twinned on the albite law and developed in long rectangular idiomorphic crystals makes up by far the greater part of the rock. This feldspar has a high refraction, a positive sign, and a maximum extinction angle on the trace of the twinning plane of about 35° showing that it is rather basic labradorite. In one instance twinning on the Baveno law was observed. A suggestion of the glomero-porphyrific structure of Judd was seen in the development in one place of quite an aggregation of feldspar crystals in a granular mass. The feldspars were spotted with a black opaque mineral that may have been either magnetite or ilmenite, but owing to its indeterminate nature it will be referred to as "opazite."

Surrounding the feldspar laths and filling in the interstitial spaces were irregular grains of augite with high refraction, high bi-refringence, positive sign, and appearing light green in ordinary plane polarized light. This enclosed the labradorite, in many cases giving the typical diabasic structure.

Olivine in rounded grains was also abundant in this rock and could be distinguished by its yellowish-brown color in ordinary light, high refraction and double refraction, irregular conchoidal fracture, large optic axial angle when viewed in convergent light, and positive sign. It was found included in both the augite and labradorite and evidently was one of the first minerals to form. It showed a slight alteration in

the production in many of the crystals of a reddish-brown margin called by Weinschenk "hyalosiderite." This covered the entire crystals in some cases.

Magnetite, in small patches, was also observed.

This rock, before referred to as an andesite,⁷ is without doubt a basalt, and the term "olivine basalt" seems to apply best.

The topography of the basalt-covered portion of Black Mountain is still well within the youthful stage, for much of the original surface of the basalt remains undissected. Cañon-cutting has exposed the underlying Rosamond, the upper surface of which has been burned red by the basalt, so that it is possible by means of these red streaks to trace the original essentially even surface of the Rosamond at the time of the lava outflow.

ALLUVIUM

Alluvium is found mainly as terraces along the drainage courses and as a mantle of the strata of the Rosamond. It is locally partially consolidated and much eroded.

In the east bluff at the mouth of Red Rock Cañon the alluvium is dissected to a depth of forty or fifty feet. It comprises a heterogeneous mixture of fragments, mainly angular in contour, of all the rocks of the Red Rock drainage basin capped by a more resistant layer cemented by calcium carbonate. Bedding planes are not sharply marked, but their attitude is essentially horizontal. Some isolated patches of alluvium have been left in the form of terraces on the walls of the cañon of Last Chance Gulch above the present drainage channel. Horizontally stratified alluvium, consisting of re-deposited materials of the Rosamond, is exposed with a thickness of from ten to twenty-five feet along a drainage channel cutting through the basalt flows about one-half mile east of Ricardo post-office. Unconsolidated water-worn gravels and boulders are present in the eastern tributaries of the lower Red Rock Cañon, where they mantle the ridge facets at the lower ends of divides between the lesser tributaries. These were probably derived from the basal strata of the Rosamond.

The great development of alluvium is found in the debris slopes of the Sierra, which cover the underlying rocks as far

⁷ By H. W. Fairbanks.

south as the north foot of the El Paso Range. The alluvial material is indistinguishable in texture, structure, and composition from the granite arkoses of the Rosamond series, and at places at the foot of the north flank of the El Paso Range it is difficult to distinguish alluvium from Rosamond. It is the problem of distinguishing residual soil or mantle rock from transported alluvium of the same nature in a region where both are present. The alluvium has been dissected by the shallow valleys of the upper tributaries of Red Rock Cañon and Last Chance Gulch, and where the contact between it and the underlying Rosamond is exposed by such dissection it is seen that the alluvium mantles an even surface bevelling the edges of the upturned Rosamond.

STRUCTURE

The main exposures of the Rosamond series are in the northern more gentle flank of the El Paso Range. The strata dip northwestward at an average angle of 15 degrees. The strike, which is approximately N 25° E in the middle portion of the exposure, curves in a southward direction near the west end of the range. On the south flank of the range were noted two small exposures of the Rosamond series, one on the east wall of Red Rock Cañon near its mouth and the other in the low-lying area just north of Kane "dry lake," some eight or ten miles east of Red Rock Cañon. These two isolated exposures have the same general dip and strike as the main exposures on the north flank.

The lower Rosamond (the strata below the basalt flows) is cut by several normal strike faults with displacements up to fifty feet in amount.

The south flank has a much steeper profile than the north flank. The base of the south front of the range is a nearly straight line and there are no shoulders projecting out from the main mountain mass into the basin area. The stream courses of the south flank are steep and narrow and, with the exception of Red Rock Cañon and Last Chance Gulch, exhibit lack of topographic conformity with the wide broad basin of Kane "dry lake" (pl. 8, fig. 1). From physiographic evidence alone one would come to the conclusion that the Kane Lake basin was a

structural depression and that the south front of the El Paso Range owes its main characteristics to deformation rather than to differential erosion. The elevation of the El Paso Range might conceivably have been produced either by warping or by faulting or by a combination of these two. We have already concluded that there has been tilting of the more gently sloping north flank, where there is only a minor amount of faulting, none of which exhibits itself in the topography. It is next necessary to determine whether the deformation along the range's south flank has been accomplished by tilting or by faulting.

In two localities along the south flank, separated from each other by some eight or ten miles, the Rosamond is found dipping to the northwestward, while between these two isolated exposures and the Rosamond of the north flank lies the more elevated portion of the range composed entirely of the older rocks. This fact in itself would suggest the presence of a fault along the south base. If we follow the two basalt flows in the Rosamond series from Red Rock Cañon southwestward we find that their strike swings more and more to the south until we suddenly come upon the straight escarpment of the range's southern front, where both flows, together with the underlying sediments, abruptly come to an end. We also find in the east wall of Red Rock Cañon just above the cañon's mouth, on the south flank, that the northward dipping Rosamond, traced along the bedding-planes, suddenly comes to an end against the metamorphics with a fault between the two. We therefore conclude that the south flank of the El Paso Range is a fault scarp and that the range is a tilted orographic block bounded on the south side by a "block" fault.

The deformation which formed the existing El Paso Range was limited to a narrow area between the outcrop of the interbedded basalt flows of the Rosamond and the south base of the range. Along the course of Red Rock Cañon this strip is no more than three miles in width, extending only from Ricardo post-office to the mouth of the cañon. Westward from Red Rock Cañon the zone gradually becomes more and more narrow and the range summits lower and lower until the range finally comes to an end about two miles west of the cañon. Viewed along the

major axis the western portion of the range plunges westward like an anticlinal fold.

The zone of northward tilting is limited to the region south of the outcrop of the basalt flows because north of the flows the bevelled surface of the tilted Rosamond beds is mantled by the alluvial debris derived from the bedrock of the Sierra Nevada. The surface of this alluvial debris slopes downward and southward close to the base of the outcrop of the basalt flows (pl. 9, fig. 1). We are accordingly able to distinguish two separate epochs of tilting of the Rosamond, separated the earlier from the later by a period of erosion long enough to develop a peneplain of at least local extent.

It is not certain whether the basalt flow of Black Mountain has been deformed since its outpouring or whether the original slopes of the surface over which it outflowed are preserved with the attitudes which they had at the time of the lava outflow. But the smooth even slope of bevelled Rosamond, covered by the basalt of domical form, without any traces of the presence of valleys at the time of the basalt eruption implies either that the uplift of the El Paso Range came so soon before the basalt outflow that there was little time between these two events for erosion of the surfaces of the newly uplifted range, or else that the deformation which produced the range has been subsequent to the basalt eruption. It is the opinion of the writer, based partly upon his view of the antecedency of the cañons crossing the entire uplift, that the considerable erosion of the range was necessarily contemporaneous with its uplift, and that therefore the deformation was later than the eruption of basalt and caused the warping of the basalt sheet. This view is in harmony with the previously presented conclusions of the writer as to warping and faulting of the late basalt flows in other portions of the Mohave Desert.

There possibly is a fault near the south base of Black Mountain between the northern or Black Mountain range and the southern or granite range. The southward-dipping surfaces of the lava mesas on the south side of Black Mountain dip into the northern flank of the granite range making a very appreciable notch in the cross-section of the range as a whole. Unfortunately,

the structure was not examined in that locality. If this suggested fault is not present this notch must be due to erosion which would probably have taken place between the time of the uplift and the outpouring of the Black Mountain basalt. The fact that the basalt flowed upon an essentially even surface is not favorable to the latter hypothesis.

The western part of the northern or subsidiary range has been much reduced by erosion following the great orogenic uplift, whereas the eastern portion owes a part of its greater height and a form more nearly approaching the original contour of the range, unaffected by erosion, to the protective covering of basalt which has greatly inhibited erosion. But there has nevertheless been a greater amount of uplift in the vicinity of Black Mountain than farther west, as indicated by the superior height of the granite ridge south of Black Mountain, which height gradually becomes less to the westward.

HISTORICAL GEOLOGY

GEOLOGIC HISTORY OF THE CONSOLIDATED ROCK MEMBERS

The rocks, which are probably the oldest in the El Paso Range, were originally sedimentary sandstones and quartz-conglomerates. These rocks have undergone great metamorphism, probably of the dynamo-regional type, which has obscured or destroyed the original structure of the sediments and caused a recrystallization of their constituents. The original conglomerate with its matrix of sand grains and its oval or round pebbles of milky quartz has now become a hard quartzite-conglomerate, which breaks quite as often across the original pebbles as through the matrix or between the matrix and the pebbles. The finer textured sandstones have been changed to hard dense quartzite, and in some cases have developed slaty or schistose structures.

Intruded into the metamorphic series is a diorite-porphry, which probably consolidated at a considerable depth below the then-existing surface, and which, like the metamorphics, has been altered by hydrometamorphism with the formation of the secondary minerals chlorite, epidote, calcite, muscovite, quartz, and

pyrite. Intruding the metamorphics is also a dike rock, probably a quartz porphyry, which has also suffered considerable alteration. The relations of the granite with the other rocks of the basement complex was not ascertained. But it is coarse-grained in texture and is evidently a plutonic rock which consolidated deep beneath the surface and has since been exposed by erosion of great amount. The granite, after its partial or entire consolidation, was intruded by pegmatite and aplite dikes.

The only definite clue to the age of the rocks of the basement complex is furnished by the unconformably overlying and hence younger Rosamond series which is not older than Upper Miocene. There was great erosion after the deposition, metamorphism, and intrusion of the rocks of the basement complex before the time of deposition of the overlying Rosamond series, for the deep-seated rocks of the basement complex were laid bare at the surface and covered by the Rosamond sediments laid down on the surface of the land. Therefore the rocks of the basement complex must be of considerably greater age than the Rosamond series.

The materials of the Rosamond have been derived from three sources: (1) by erosion from the rocks of the basement complex; (2) by erosion from lava flows later in age than the rocks of the basement complex; (3) from pyroclastic materials, comprising ash and pumice, blown out from volcanoes and deposited either by wind action, by the agency of water, or by settling during and after volcanic eruptions. The agencies of deposition were of the continental or terrestrial type and are believed to have been the same as those forming the desert alluvial deposits being laid down at the present day. All the fossils found in the Rosamond series in the El Paso Range represent the remains of terrestrial mammals and tortoises. There is little or no evidence of lacustrine sedimentation in the lower half of the Rosamond of the El Paso Range, and the finer sediments of the upper strata may well be eolian deposits or deposited by any or all of the subaerial processes with their materials derived from the erosion of low-lying areas. Contemporaneous with the deposition of the middle portion of the Rosamond were two outflows of basaltic lava.

GEOLOGIC HISTORY POSTERIOR TO THE TIME OF DEPOSITION OF THE
ROSAMOND SERIES AS INFERRED FROM THE STRUCTURE
AND PHYSIOGRAPHY

The Two Epochs of Post-Miocene Uplift with the Intervening First Cycle of Post-Miocene Erosion.—The Rosamond series both on the north and south flanks of the El Paso mountains was tilted to the northward at a moderate angle after its deposition. It was then subjected to long erosion which bevelled off the tilted beds to an essentially level surface. The peneplain formed by this cycle of erosion is correlated with the one developed on the folded Rosamond beds in the vicinity of Barstow, in San Bernardino County. At the end of the first cycle of post-Miocene erosion or more likely after renewed deformation had caused a new cycle to begin a thin veneer of alluvial debris was spread over the bevelled surface of the Rosamond strata northeast, north, and northwest of Ricardo post-office. This alluvium was derived from the erosion of the recently uplifted Sierra Nevada Range. Because of the coarseness of the arkosic material of the alluvial mantle and the almost total absence from it of the products of mature chemical decomposition, and because an erosion surface similar to that produced by the first cycle of post-Miocene erosion in the El Paso Range was also developed in the Sierra Nevada it is thought most probable that the deposition of the alluvium mantle on the evenly eroded surface of the Rosamond was brought about by a mountain-making uplift in the southern Sierra Nevada. An uplift, to which the present El Paso Range owes its existence, followed the development of the peneplain and caused the development of a great fault along the southern base of the range at the same time that an uptilting took place on the northern flank. But probably before this uplift occurred the basalt flow of Black Mountain was erupted, covering the substantially flat and even erosion surface developed on the uptilted Rosamond series.

Origin of Red Rock Cañon and Last Chance Gulch.—These drainage channels cross the main southern ridge of the El Paso Range in deep, narrow, and precipitous cañons although in their upper reaches they have developed broader, shallower, and

subsequent courses in a region of lower altitude and less resistant rocks. The lower narrows cannot be consequent to the original slope formed by the uplift. They cannot be superimposed because the El Paso Range and the adjoining Kane basin are structural features which do not owe their larger orographic features to erosion. Hence they must be either antecedent in their origin or have cut back through the range by headward erosion and captured and diverted drainages more nearly consequent to the uplift.

There are several facts against the view of the development of these lower cañons by headward erosion. All the other drainage courses on the south side of the range are small and have cut back but a short distance into the mountain ridge. Their valleys have steep gradients out of topographic adjustment with the Kane basin to which they are tributary, but the valleys of Red Rock Cañon and Last Chance Gulch are in topographic adjustment with the basin. Red Rock Cañon and Last Chance Gulch have valleys which are no older in their lower courses just inside the southern scarp than where they first enter the more resistant rocks farther up. No evidence of the former existence of a consequent drainage down the northern flank of the range and around its western end into the Kane basin or eastward into the Salt Wells Valley was found, although these regions were not fully examined in the field. It is apparently hard to account for the devious windings of the narrow but deeply incised Last Chance Gulch, cut in apparently homogeneous granite, if its course was developed by headward erosion, but these meanders may very well have been inherited from a previous cycle. Also the drainage channels of the north flank, developed along the strike of the Rosamond strata, do not follow the foot of the range, but have become subsequent. They have shifted their courses until the broadest, largest, and deepest of them have come to occupy the contact between the Rosamond series and the more resistant basement complex in the manner first explained by Gilbert in his account of the geology of the Henry Mountains of Utah. The fairly well adjusted drainage of the north flank is in marked contrast with the cañons cutting through the range. Finally, no evidence is known of lower gaps in the profile of the range's

longer axis, produced by a greater amount of differential uplift on both sides of the localities of Red Rock Cañon and Last Chance Gulch, which might have given sites to courses of consequent drainage. The evidence thus points strongly to an antecedent origin for the lower courses of Red Rock Cañon and Last Chance Gulch.

Among the most remarkable features noted by the writer in the southern Great Basin must be included those probable antecedent drainage courses which have been developed athwart the courses of the lately uplifted ranges in a region where the present rainfall is so scanty. Even if one assumes that precipitation was greater in former times than now, these antecedent drainage courses bear an eloquent testimony to the slowness of the mountain uplifts. And yet these mountains have probably been uplifted since the close of the Tertiary.

Recent Faulting.—Hess⁸ has recently described rift features caused by the faulting along the southern base of the eastern El Paso Range north of Garlock station, where these features are so striking as to have been noted by the present author from the railway train. There are some suggestions of recent faulting along the south base of the range between the mouths of Red Rock Cañon and Last Chance Gulch, in the nature of truncated shoulders separated by shallow depressions from low hummocks with their courses parallel to the range's south base. One of these low hummocks can be seen at the base of the escarpment in the middle distance in plate 8, figure 1. It is quite possible that there has been a small uplift of the range recently, which has been responsible for the recent trenching of the alluvium at the mouths of Red Rock Cañon and Last Chance Gulch and for the formation of the alluvial terraces higher up in these drainage basins. This view must be regarded as a mere suggestion, however, which is worthy of more extensive investigation.

⁸ Gold mining in the Randsburg Quadrangle, California, U. S. Geol. Surv., Bull. no. 430, pp. 23-47, 1910.

THE SOUTHERN SIERRA NEVADA

The south front of the Sierra Nevada from Jawbone Cañon northeastward to Indian Wells is in a stage of physiographic development older than that found in the range to the east and west. This is due to a deformational history of this section of the Sierra flank different from that of the greater part of the range to the east and west.

THE RICARDO EROSION SURFACE

From the summits above Walker Pass one looks out to the east, north, and west over broad-topped summit mountains. These broad summits have a gently rolling topography manifestly the product of an older erosion cycle than that which formed the valleys which have isolated these peaks one from the other. This old erosion surface is apparently, although not certainly, the same as that of the Chagoopa Plateau described by Lawson in the Upper Kern Basin.⁹ What relation does this old erosion surface bear to the peneplain of the Mohave Desert? In order to determine this relation let us consider the region lying between the crests of the Sierra and the peneplain developed on the Rosamond series north of the El Paso Range.

Above the piedmont alluvial aprons the peaks of the southern Sierra rise rather abruptly. The lower slopes are rounded, while back towards the summits the declivities are rugged and abrupt. Long narrow shoulders run out into the desert with gradually diminishing height. Between these shoulders are broad re-entrants occupied by broad, mature, rather low grade, and open valleys, in topographic conformity with the lower debris slopes, and reaching far back into the range. It becomes at once evident that we have here a topography which has already gotten beyond the most rugged stage of maturity and is near early old age in its development. This advanced stage of topography is only found along the southern slopes; for in rising to the heads of

⁹ The Geomorphogeny of the Upper Kern River Basin, Univ. Calif. Publ. Bull. Dept. Geol., vol. 3, pp. 291-376, 1904.

these drainage channels one finds oneself on a summit upland which is noticeably broad in places and can be traced to the north, east, and west in neighboring summits. The presence of considerable remains of the summit upland between the valleys indicates that this higher portion of the range has only reached the stage of early maturity, since the whole surface is by no means entirely reduced to slopes. We see, therefore, that since the time of formation of the old erosion surface the surface of the summit upland of the Sierra has been uplifted and a new cycle of erosion begun which has reached the stage of late maturity or early old age in the outer slopes of the range and a stage of early maturity near the heads of the drainage courses in the summits.

It was during this last cycle that the debris apron was spread out beyond the foot of the range by deposition of the materials removed by erosion from the mountains' southern slopes. The erosion following the last uplift has dissected the old surface of the Sierra summits and the alluvium derived from this erosion has covered the surface of the peneplain developed on the tilted Rosamond series. So we can conclude that the post-Miocene peneplain of the Mohave Desert region has its contemporaneous counterpart in the old erosion surface of the summit uplands of the Sierra, tentatively correlated with the Chagoopa Plateau surface of the Upper Kern Basin. And since it has become necessary, in deciphering the later Cenozoic history of the Great Basin, to refer to these erosion cycles as datum planes in much the same way as rock formations are used, the writer proposes the name "Ricardo erosion surface" for the product of this post-Miocene cycle of erosion, which antedated the great deformation of the southern Sierra Nevada that has given to the range the altitude and major orographic features which we see in it to-day.

The Ricardo erosion surface where it is developed on the less resistant Rosamond series, and, for that matter, on some of the granitic bedrock surfaces, of the Mohave Desert is an unquestionable peneplain. North of Walker Pass in the southern Sierra, disregarding the effects of tilting, of possible faulting, and of later erosion, it has a maximum differential relief of a thousand feet or more and is an erosion surface in approximately the

middle of the old age stage. As one goes northward the surface rises steadily in altitude until west of Mount Whitney it is on the average 11,000 feet above the sea, whereas in the vicinity of Walker Pass it has an average altitude of from 6,500 to 7,000 feet. In the Mount Whitney region the peaks of the Great Western Divide and the main Sierra crest rise 2,000 feet and more above its general surface, the highest peak of all, Mount Whitney, rising some 3,500 feet above it. Here the stage of erosion reached at the culmination of the cycle was not developed further than early old age. We have good reasons, therefore, for concluding that at the end of the Ricardo post-Miocene cycle of erosion there still existed a residual mountain range on the site of the highest crests of the present Sierra Nevada.

LATEST EPOCH OF FAULTING, NOT AFFECTING THE ENTIRE
SOUTHERN SIERRA FRONT

If one examines the stage of topography of the east flank of the Sierra west and south of Owens Lake, as represented on the Olancho topographic sheet of the United States Geological Survey, and compares it with the stage of topography of the east flank south of Walker Pass on the Kernville topographic sheet, one notes a remarkable difference. The eastern scarp of the Sierra in the neighborhood of Owens Lake is very precipitous, the base of the range approximates a straight line with no broad re-entrants along the drainage courses, or shoulders projecting out into the basin area between the drainage courses. All the cañons cutting into the east front of the range have deep, narrow, steep-walled, and V-shaped courses. The topography of the east front of the Sierra from Indian Wells northward into and beyond Owens Valley is much more youthful than that of the section of the range from Indian Wells southwestward to Jawbone Cañon.

Looking into the Sierra from one of the lower summits in the vicinity of Jawbone Cañon one sees near the horizon line a broad shallow, high-level valley corresponding in stage of development with those opening out on the foot of the range farther east. But as this drainage course is traced down

towards the desert one notes that it becomes incised in a deep and narrow cañon which is totally unlike anything developed along the lower courses of the drainage to the eastward. Recent rejuvenation has evidently taken place in the valleys of the Jawbone Cañon drainage. At the foot of one of these lower summits there is a rather deep valley coming out of the Sierra into the Mohave Desert. The lower course of this valley is a box cañon which comes to an abrupt head at the place where the Los Angeles aqueduct crosses it. In the eastern wall of this cañon is exposed northwestwardly-dipping Rosamond greenish tuff-breccia, overlain unconformably by unconsolidated alluvium of light reddish-brown color and derived from the granitic bedrock of the Sierra. In the opposite cañon wall is exposed the granite. Between the granite and the Rosamond is a fault along which recent displacement has taken place. The plane of the fault has been followed by the cañon. The fault traces approximately north and south, swinging to the westward farther south, and its plane dips from fifty to sixty degrees to the east. The cutting of the box cañon has been accomplished since the deposition of the unconsolidated debris forming its upper walls. The topographic expression of the fault is marked by an abrupt break in the profile. The granite rises above the general level as abrupt hills and mountains while the lower-lying Rosamond directly up to the fault contact is eroded into a much gullied topography. This zone of recent deformation continues westward to Tehachapi and Cajon passes.

Between Indian Wells on the east and Jawbone Cañon on the west there is no evidence of recent faulting such as appears in the region west of Jawbone Cañon. Between Indian Wells and Jawbone Cañon there is a section of the southeastern front of the southern Sierra Nevada exhibiting older topography than the regions of the front to the northeast and to the west which have undergone more recent uplift.¹⁰

¹⁰ For a description of the older topography of this section see the second paragraph under the heading of the Ricardo Erosion Surface.

DISSECTION OF THE SIERRA DEBRIS SLOPES

The distance from the exposures of bedrock on the southern slopes of the Sierra to the base of the north flank of the El Paso Range in the vicinity of Red Rock Cañon and Ricardo post-office is probably not greater than four or five miles. In the entire interval between the ranges the alluvial surface slopes downward to the south at an angle which averages about two degrees. There can be absolutely no doubt that the debris of this slope to within a mile to the north of Ricardo post-office has been derived from the Sierra, for in its finer parts it is composed of disintegrated crystals of the Sierra granite and the larger angular boulders are fragments of this same granite. The alluvium has a characteristic light brown color given it by the feldspars of the Sierra granite. The alluvium, apparently originally spread out rather evenly and in quite uniform thickness over the peneplaned surface of the Rosamond series, has been dissected by shallow gullies and valleys. Just north of the foot of the El Paso uplift a rather broad basin has been excavated in this alluvial mantle and the underlying Rosamond strata (pl. 9, fig. 1, and pl. 10, fig. 2). Further north the debris mantle and the lying Rosamond have been rather intricately dissected into a low hummocky topography. Still farther to the north, near the lower bedrock slopes of the Sierra, a much greater proportion of the original debris-mantled upland surface remains, incised at rather wide distances to only moderate depths by the main drainage courses leading down from the Sierra Nevada, and between these main drainage courses by smaller and shallower gullies. In brief, the impression given the observer stationed on the lower bedrock slopes of the Sierra is of a plane sloping rather gently to the southward, the general smooth surface of which is cut here and there by shallow gullies and valleys.

A general uptilting to the northward of the surface of the debris aprons or a depression of the Kane basin relative to the country farther north would cause dissection of slopes formerly at grade. Any change of climate which would increase erosive forces could cause the dissection of this alluvium. Or it might normally become dissected, without the interposition of uplift

or change of climate, a possible explanation which has been more fully considered by the writer in an earlier paper.¹¹ The depression between the Sierra Nevada and the El Paso Mountains may have been a higher temporary base level, since drained by valleys tributary to the lower base level of the Kane basin, in which case the courses of Red Rock Cañon and Last Chance Gulch would not be antecedent but have developed their cañons across the El Paso Range by headward erosion. But a piedmont alluvial fan spread out during or soon after the uplift of the Sierra, when slopes were steep and debris abundant, would subsequently be dissected when the supply of debris became less, allowing running water to erode in places which were formerly the sites of aggradation.

SUMMARY

1. The oldest known rocks of the El Paso Range are a series of metamorphics cut by intrusives.
2. Unconformably overlying the basement complex is the Rosamond series of fossiliferous sedimentary rocks of an age probably not older than the Upper Miocene.
3. The Rosamond series was tilted at a moderate angle and its strata bevelled by peneplanation. This peneplain is named the Ricardo erosion surface and is tentatively correlated with the Chagoopa plateau of the Upper Kern Basin.
4. Following peneplanation came an eruption of olivine basalt and the uplift of the present El Paso Range. The range has the form of a faulted monocline with its south flank a fault scarp. Two drainage courses crossing the entire range are believed to have been antecedent to the uplift.
5. The south front of the Sierra Nevada directly north of the El Paso Range has not been affected by an uplift which affected the rest of the southern Sierra to the east and west.
6. The piedmont alluvial slope of that portion of the Sierra Nevada situated north of the El Paso Range is at present undergoing dissection.

¹¹ Notes on the later Cenozoic history of the Mohave Desert region in southeastern California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, pp. 374-377, 1911.

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FAUNA FROM THE TYPE LOCALITY OF
THE MONTEREY SERIES IN
CALIFORNIA.

BY

BRUCE MARTIN



UNIVERSITY OF CALIFORNIA PRESS

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INTRODUCTION

In the course of a study of the Monterey series, as it appears along the east shore of San Pablo Bay and in the vicinity of Mt. Diablo, the writer found it necessary to compare the fauna with that of the type section of the Monterey at the town of Monterey. The writer visited the type locality and brought together what seemed to be a representative collection of the molluscan fauna. As comparatively little relative to the palaeontology of the type section has been published it seemed desirable to record such information as is available.

HISTORICAL REVIEW

The first reference to the formations known as the Monterey series in the literature of Pacific Coast geology is by Dr. W. P. Blake¹ in describing a series of sedimentary rocks, mostly diatomaceous shales, which occurs near the town of Monterey. Dr. Blake's observations were made during the latter part of 1854 while he was geologist for the Pacific Railroad Survey. In his description of the formation he refers to it as a "formation teeming with the skeletons of microscopic organisms which appears to overlie and to be conformable to the Tertiary strata that underlie a part of the town of Monterey and to extend to and beyond the Mission of San Carlos." The Tertiary strata underlying the town of Monterey are a part of the formation containing the skeletons of microscopic organisms to which reference is made by Blake. This fact was recognized by him as is indicated in the later part of his report. His separation of the two is probably due to his finding a few casts of foraminifers in the lower horizons instead of the diatoms, which were found in the upper horizon.

The stratigraphic relations noted by Blake were as follows: The Monterey was seen to rest directly upon the granite of Point Pinos and was not found to be covered by any later formation other than Recent or terrace accumulations along the bay shore. Blake's description of the lithology of the beds is as full and complete as can be desired. The fauna that is listed in his report is, however, very meagre and is not particularly characteristic of any division of the Tertiary. The species listed were: *Tellina congesta* Conrad, a few borings of *Petricola cylindracea*, casts of foraminifers, and diatoms. The diatoms were determined by Professor Baily of West Point as belonging to the genus *Coscinodiscus*.

In 1893 Professor A. C. Lawson published an account of the geology² of Carmelo Bay in which he distinctly defined the Monterey series and gave a discussion of its stratigraphy and

¹ Blake, W. P., Proc. Acad. Nat. Sc. Philad., vol. 7, pp. 328-331, 1855. Also Pacific Railroad Reports, vol. 5, pp. 180-182, 1855.

² Univ. Calif. Publ. Bull. Dept. of Geol., vol. 1, pp. 1-59, 1893.

lithology. He also published a list of the fossil marine invertebrates upon which the determination of these beds as Miocene was based. The following species, identified by Dr. W. H. Dall, were noted by Professor Lawson :

- Arca, sp. (nov.?).
- Saxidomus, sp.
- Leda, sp. (nov.?).
- Lucina, like *L. crenulata*.
- Clementia?, sp.
- Young Cardium or small Venericardia.
- Pecten (*Pseudamusium*) *peckhami* Gabb.
- Macoma, sp. (nov.?).

DESCRIPTION OF THE TYPE LOCALITY

Location and Topography.—The territory over which the observations on the typical Monterey were extended comprises an area about four miles square between Monterey Bay and the valley of the Carmelo River, and lying principally east of the main coast road leading from Monterey to Carmel-by-the-Sea. A small area occurs in the higher hills west of this road. Several short excursions were made beyond the limits of this territory, but they have no direct bearing upon the results. This locality lies at the north extremity of the Santa Lucia Range, and while it may be easily separated physiographically from the region to the south of the Carmelo River valley, it must, nevertheless, be considered a part of the range. The physical features show well-rounded hills and flat-topped ridges whose flanks are dissected by numerous streams and ravines. In no case does the elevation exceed eleven hundred feet. From Point Pinos the hills rise abruptly to the southward, attaining an elevation of approximately eight hundred feet two miles southwest of Monterey, where they swing to the eastward, forming a crescent-shaped chain around the town.

Stratigraphy.—The stratigraphic relations of the Monterey series are very simple. At several localities along its western border it may be observed resting almost horizontally upon the eroded surface of the Santa Lucia Granite. On the northern and eastern boundaries the shale passes beneath the Recent or terrace accumulations which flank the hills in the vicinity of Monterey

and Carmelo bays. The western limit of the series may be roughly followed by the outcroppings of the granite in the lower portions of the hills and over the more nearly level territory surrounding the town of Monterey. On the summit of the main ridge, two miles southwest of Monterey, and on the south side of this ridge, both the shale and the granite are mantled by a considerable thickness of brown to yellow sand, which prevented the accurate mapping of the formations. One of the most favorable localities for observing the relations of the shale and the granite is seen in a small creek near the middle of the town of Monterey. The east bank of this stream stands perpendicular for twelve feet or more. At the base of this section the solid granite is exposed. Coarse-grained sandstone and boulders immediately overlie the granite. Passing upward the beds grade into finer sandstone. Near the top of the section the sandstone is replaced by clay shale or mudstone. Several feet back from the precipitous banks of the stream the typical whitish-yellow bituminous shale was found in place, approximately thirty feet stratigraphically above the granite, showing the rapid transition from sandstone to shale. A slight tilting to the eastward is the only movement that has affected the shale, excepting a few minor dislocations due to faulting. The inclination of the strata from the horizontal is seldom greater than fifteen degrees and frequently not over five. In several localities immediately southeast of Monterey the beds were found lying approximately horizontal. A conservative estimate of the thickness of the beds would place it at no less than two thousand feet.

Lithology.—The character of the rocks and the theories as to their origin have been dealt with at considerable length by Professor Lawson in his publication to which reference has been made above, and it does not seem necessary to do more than review the general types of rocks that are found in this series. The series, as exposed at the type locality, consists mainly of white and light yellow shales, usually well bedded and very resistant to weathering. The shale can be separated lithologically into three types: (1) a soft chalk-like rock which appears to be largely of diatomaceous origin; (2) a cherty shale which is very brittle and breaks with a smooth, glassy fracture; (3) an arenaceous and argillaceous shale. In the upper portion of the series the dia-

tomaceous shale greatly predominates. In the lower portions the cherty and arenaceous phases are quite common. Besides these there are variations of local importance, as they are the phases from which the greater number of the fossil marine invertebrates were obtained. One of these localities occurs along the Pacific Improvement Club's driveway approximately one and one quarter miles northeast of Carmelo Bay. Here a section is exposed in which the strata are dipping toward the northeast at an angle of ten or fifteen degrees. The base of the section consists of yellowish-brown limestone and calcareous sandstone which grades upward into a purple, fine-grained sandstone. A short distance above the fine-grained sandstone the typical bituminous shale was encountered, conforming in strike and dip to the strata in the lower portion of the section. As this locality occurs along the western border of the shale area it is believed to be near the base of the series. The limestone yielded eight species of fossil invertebrates. Another locality of equal importance was encountered in the bed of a deep cañon two miles due south of Monterey. Here a friable, fine-grained, gray sandstone outcrops beneath the well-stratified shale. Since this sandstone is only a short distance, horizontally, from the granite it seems certain that its stratigraphic position is not far distant from the base of the series. Like the former locality it yielded a small collection of marine molluses.

FAUNA OF THE TYPE LOCALITY

As is usually the case with the shale formations, the Monterey of the type locality contains relatively few species, though the number of individuals may be large. Casts of small bivalves and univalves are of common occurrence throughout the formation, but the specific and generic characters are not determinable in most cases. The total number of species so far reported from the beds at Monterey does not exceed fourteen, of which six are here reported for the first time. The following species, arranged according to the horizons from which they were obtained, comprise the known molluscan fauna of the type section of the Monterey. Cetacean bones, foraminifers, diatoms, and remains of small crustaceans are also known from these beds.

LOWER PORTION

Pelecypoda.

- Arca obispoana* Conrad.
- Glycimerus*, sp.
- Leda*, compare *taphira* Dall.
- Modiolus*, sp.
- Nucula*, sp.
- Pecten peckhami* Gabb.
- Macoma congesta* Conrad.
- Venericardia montereyana* Arnold.
- Sharks teeth.

Gasteropoda.

- Ficus kernianum* Cooper.
- Trochita*, sp.

MIDDLE PORTION

Pelecypoda.

- Arca obispoana* Conrad.
- Marcia oregonensis* Conrad.
- Macoma congesta* Conrad.

UPPER PORTION

Pelecypoda.

- Marcia oregonensis* Conrad.
- Macoma congesta* Conrad.

Gasteropoda.

- Neverita*, sp. indet.

Several of the species listed above are of sufficient importance to warrant further consideration. *Arca obispoana* was described by Conrad from a shale formation in the Salinas Valley in San Luis Obispo County, California. The exact locality and horizon are not, at present, definitely known. However, it seems most probable that it was obtained from the shale which immediately overlies the Vaqueros sandstone. It has also been reported from a corresponding horizon in the Santa Cruz Quadrangle. *Pecten peckhami* Gabb is most commonly found in the lower Miocene. It has been reported from the uppermost Eocene in the Coalinga region, but its occurrence below the lowest Miocene is exceedingly rare. Middle Miocene is considered the upper limit of its range. *Venericardia montereyana* Arnold was described from the lower middle Miocene shales of the Santa Cruz Quadrangle; its occurrence has not been noted outside of this horizon.

Marcia oregonensis Conrad has not been found below lower Miocene in this part of the coast ranges. It is most commonly found above middle Miocene. *Ficus kernianum* Cooper was first obtained from the lower Miocene of Kern River, Kern County, California. It is believed to be characteristic of middle and lower Miocene. The number of species comprising the fauna of the Monterey is very limited; some of them, however, are confined to a small vertical range and serve definitely to place the beds within middle and lower Miocene.

CORRELATION WITH THE MONTEREY MIOCENE OF CONTRA COSTA COUNTY

Miocene strata, supposed to be of the same age as the Monterey, occur along the east shore of San Pablo Bay and in the vicinity of Mount Diablo. One of the largest and most important of these areas extends from San Pablo Bay southeast toward the town of Walnut Creek. The strata have been folded into a broad syncline whose axis strikes approximately N. 50° W. Along the northern border of the syncline, near Selby Smelter, the beds lie unconformably upon a dark shale which is considered to be of lower Eocene age. Along their southern boundary they rest in part, presumably, upon the Tejon formation, of upper Eocene age. The San Pablo beds lie upon this series. At Selby the section is composed of brownish-gray sandstone and rusty, yellowish shale. The strata are inclined toward the southwest at a high angle. In a few localities they are standing almost vertical. The thickness is between three and four thousand feet. The south side of the syncline is composed of both sandstone and shale. The shale in the lower portion is composed of a white, well-stratified rock which resembles very closely the shale at Monterey. The shale occurring in the upper part of the section is more argillaceous and of a rusty-yellow color. The sandstone is principally a gray, medium-grained rock. The dip of the strata is toward the northeast at angles varying between thirty and forty degrees. The total thickness is very close to five thousand five hundred feet.

The correlation of the Miocene on San Pablo Bay known as the Miocene of Contra Costa County with the type section of

Monterey must depend to a large extent upon the faunal evidence, since there are no similar stratigraphic relations existing at the two localities. On the north side of Carmelo Bay there are beds which may be of Eocene age, but no localities were found where the Monterey shale was in contact with them.

Faunally there appears to be sufficient evidence to correlate the beds at Monterey and the lower portion of the Miocene section on San Pablo Bay. All of the species of marine invertebrates that have been reported from the type section at Monterey have been obtained from the beds at San Pablo Bay with the exception of *Venericardia montereyana* Arnold. *Pecten peckhami* Gabb occurs in the lowest shale at Pinole and in the lower portion of the formation at Monterey. *Marcia oregonensis* Conrad and *Ficus kernianum* Cooper occur in both formations, the former very commonly.

The results obtained in this investigation may be stated as follows: The evidence furnished by the fauna of the type section of the Monterey series supports the general assumption that the deposition of the beds at the type locality was approximately contemporaneous with that of the middle and lower portion of the Monterey Miocene appearing on San Pablo Bay.

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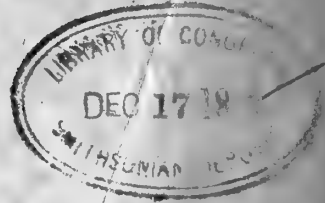
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Issued December 4, 1912

PLEISTOCENE RODENTS OF CALIFORNIA

BY

LOUISE KELLOGG



UNIVERSITY OF CALIFORNIA PRESS
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GEOLOGY

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INTRODUCTION

The Pleistocene rodents described in the following paper were obtained from Potter Creek Cave and Samwel Cave on the McCloud River, Shasta County, California, and from the asphalt deposits at Rancho La Brea, near Los Angeles, California. The specimens are all from the palaeontological collections of the University of California.

Potter Creek Cave has already been fully described and a list of the species found in it given by W. J. Sinclair;¹ a brief description of Samwel Cave is furnished by E. L. Furlong;² while a discussion of the Rancho La Brea beds has been published by J. C. Merriam,³ so that any detailed description of the three localities seems unnecessary. The caves were formed along fissures mainly by percolating water removing limestone in solution and not by the action of streams. The rodent remains of the caves are found in strata of clay with gravel lenses, excavated down to a depth of twenty-five feet, and they are very abundant in places, especially those of *Neotoma*, a form which probably lived in the caves soon after they began to form. The bones of many of the larger animals show evidence of having been gnawed by rodents, and the tooth marks appear to be those of *Neotoma*. *Aplodontia*, *Thomomys*, and *Citellus*, burrowing rodents, come next in order of abundance. *Lepus* is quite common, a fact which might be explained by presence of the lynx, which feeds so largely on rabbits, and, living in caves, brought in its prey to be devoured. The remains of other rodents which do not live under the ground were doubtless washed into the caves by the seasonal rains.

The asphalt deposits were formed from the surface accumulation of tar in which animals were caught, and we find the number of rodents exceedingly small, in fact a minimum as compared with the bones of carnivores. This is explained by the fact that the latter were attracted to these pools by animals entangled in the tar, and rodents would be caught only by straying accidentally into the pools.

¹ *Science*, vol. 17, no. 435, pp. 708-712, 1903.

² *Amer. Jour. Sc.*, Ser. 4, vol. 22, 1906, p. 235-247, 1906.

³ Merriam, J. C., *Mem. Univ. Calif.*, vol. 1, no. 2, 1911.

As to the age of the deposits, those of Potter Creek Cave, containing the greater number of extinct species, are considered older than those of Samwel Cave, and the asphalt beds might be placed between the two, or are perhaps the oldest of the three. It is a noteworthy fact in the case of all of the deposits that, while among the carnivores and ungulates there are genera now extinct, the rodents all belong to living genera, although some are described as new species. The persistence of rodent forms is quite remarkable, as they have changed but little through a long period.

Inasmuch as the rodents are considered especially good indicators of environment and climate as shown in the life zones, it was hoped that they might furnish some evidence as to changes in climate during Pleistocene time; but when we find in the caves forms which belong to the present Canadian Zone mingled with those of the Transition and even Upper Sonoran, and all found at the various levels at which rodents occur in the deposits, it is difficult to draw conclusions, and this wide range of forms would not necessarily indicate that the climate differed greatly from the present one of the regions in which the deposits occur.

The rodent fauna of the caves is not one which accords with the present topography of the region, a fact which is pointed out very forcibly by Dr. Sinclair in reference to Potter Creek Cave, when he says that "the present mountainous character of the country is entirely out of harmony with the existence of mastodons, elephants, and tapirs." The rodent forms *Castor*, *Aplodontia*, and *Microtus* suggest that the cave regions of Shasta County were more humid at the time of accumulation of these deposits than they are at the present day. Two forms of ground squirrel and three of the rabbit group would indicate a fairly level country with grass and brush, while three forms of tree-squirrels would show that the country included forest areas. Presuming that the region was better watered and partly forested, it is possible to account for the number of forms belonging to the Canadian Zone. These two factors combined might permit the presence of a fauna of a higher zone, although the climate would not necessarily be much colder than it is to-day.

The rodents of the Rancho La Brea deposits are close to the

forms living in this region at the present time, and are definitely of the Upper Sonoran Zone, and of a plains country. It is therefore difficult for us to believe that any marked changes in climate or topography have occurred in this region since the period of accumulation of the remains representing the Rancho La Brea fauna.

LIST OF RODENTS ARRANGED ACCORDING TO EXISTING LIFE-ZONES

POTTER CREEK CAVE

UPPER SONORAN	TRANSITION	BOREAL
<i>Citellus b. douglasi</i>	<i>Citellus b. douglasi</i>	<i>Arctomys flaviventer</i>
<i>Lepus californicus</i>	<i>Eutamias</i> , sp.	<i>Callospermophilus chrysodeirus</i>
<i>Sylvilagus auduboni</i>	<i>Microtus californicus</i>	<i>Sciurus albolimbatus</i>
	<i>Thomomys microdon</i>	<i>Sciuropterus a. klamathensis</i>
	<i>Thomomys leucodon</i>	<i>Aplodontia m. fossilis</i>
		<i>Neotoma c. occidentalis</i>
		<i>Lepus a. klamathensis</i>

SAMWEL CAVE

UPPER SONORAN	TRANSITION	BOREAL
<i>Citellus b. douglasi</i>	<i>Sciurus g. fossilis</i> , n. subsp.	<i>Callospermophilus chrysodeirus</i>
<i>Peromyscus m. gambeli</i>	<i>Castor subauratus</i>	<i>Sciurus d. albolimbatus</i>
<i>Sylvilagus auduboni</i>	<i>Peromyscus m. gambeli</i>	<i>Sciuropterus a. klamathensis</i>
	<i>Microtus californicus</i>	<i>Aplodontia m. fossilis</i>
	<i>Thomomys microdon</i>	<i>Neotoma c. occidentalis</i>
	<i>Thomomys leucodon</i>	<i>Erethizon epixanthum</i>
		<i>Lepus a. klamathensis</i>

RANCHO LA BREA

UPPER SONORAN
<i>Citellus b. captus</i> , n. subsp.
<i>Peromyscus m. gambeli</i>
<i>Microtus californicus</i>
<i>Thomomys b. pallescens</i>
<i>Perodipus agilis</i>
<i>Sylvilagus auduboni</i>
<i>Sylvilagus b. cinerascens</i>

SPECIES IN CAVE FAUNAS

ARCTOMYS FLAVIVENTER Aud. and Bach?

An incisor and the anterior portions of two lower mandibles from Potter Creek Cave represent this species. *Arctomys* is now not to be found in the Shasta region. One incisor is larger and has a more marked orange color than those of specimens from the Sierra. In the first character it approaches the Alaska form, but the color seems to be a variable character. The material is tentatively referred to *A. flaviventer*.

CASTOR SUBAURATUS Taylor

Castor occurs in Samwel Cave only, and is represented by three upper molars, right M¹, left M², and right M³.

A new species, *Castor subauratus*,⁴ has recently been described from the San Joaquin Valley, California, and although

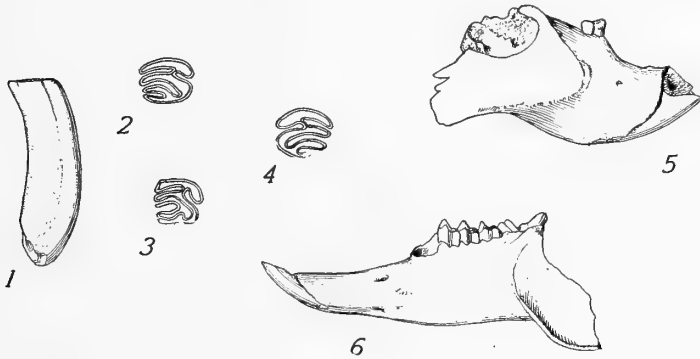


Fig. 1. *Castor subauratus*. Right M¹, posterior view, no. 19508.

Fig. 2. *Castor subauratus*. Right M¹, oclusal view, no. 19508.

Fig. 3. *Castor subauratus*. Right M³, oclusal view, no. 17318.

Fig. 4. *Castor subauratus*. Left M², oclusal view, no. 19507.

Fig. 5. *Sciurus g. fossilis*, n. subsp. Right lower mandible, no. 19506.

Fig. 6. *Lepus a. klamathensis*. Left lower mandible, no. 9575.

Figs. 1 to 6 natural size.

the specific differences do not include any points in regard to the teeth as separating it from *C. pacificus*, the more northern form, it is probable that these three molars belong to the California species. Mr. Taylor considers *C. subauratus* to be a long-isolated form and one which crossed the mountain barrier from the north. The Shasta region is the known northern limit of the species.

CITELLUS BEECHEYI DOUGLASI (Richardson)

A number of specimens of this ground-squirrel were found in both Potter Creek and Samwel caves at depths of from one inch to ten feet. All are lower jaws with the exception of fragments of two skulls, found one in each of the caves. No differ-

⁴ Taylor, W. P., "The Beaver of West Central California," Univ. Calif. Publ. Zool., vol. 10, p. 167 (1912).

ence can be detected between the fossil forms and those of to-day. The presence of the ground-squirrel in both caves indicates that some of the surrounding country during the time of accumulation of the deposits was rather dry and open, although not necessarily low zonally. Now, as then, *Citellus b. douglasi* can be found associated with *Callospermophilus chrysoideirus*, *Sciuropterus klamathensis*, and *Sciurus albolimbatus*, forms of the Canadian Zone, showing that it has a wide range of habitat as far as temperature is concerned.

CALLOSPERMOPHILUS CHRYSODEIRUS (Merriam, C. H.)

Three specimens of this squirrel, all lower jaws, were found in each of the caves, but at a greater depth in Potter Creek Cave than in Samwel Cave. The fragmentary nature of the material makes a subspecific differentiation impossible, and yet the teeth of the specimens from Potter Creek Cave are slightly heavier than in the living species. The specimens from Samwel Cave unfortunately lack teeth.

EUTAMIAS, sp.

A portion of a lower mandible without teeth from Potter Creek Cave represents a form of *Eutamias*, but from this one fragment the specific status cannot be determined. Its small size would place it nearest to *Eutamias amoenus*.

SCIURUS GRISEUS FOSSILIS, n. subsp.

Type no. 19506, from Samwel Cave. Anterior portion of right lower mandible with P_4 and broken incisor.

This type, which is the only specimen of *Sciurus griseus* found in either cave, has such width across the anterior portion of the mandible as to make it strikingly unlike the living forms of *griseus* which attain their maximum size here in the west, and yet do not approach the fossil form in that respect. The incisor is broken, but the small fragment of it left shows that it is not of especially large size. The P_4 is much worn. It is not larger than that of the living form, but the fact that the mandible is so extremely wide seems sufficient ground for subspecific differentiation. It is unfortunate that more material representing

this new form is not available for, judging from the size of the mandible, the skull might exhibit striking and interesting differences in other respects. Measurements comparing the fossil form with the two largest specimens of *S. griseus* from the collection of the California Museum of Vertebrate Zoology are given below.

MEASUREMENTS

	No. 19506	No. 11362*	No. 11359*
Width of mandible at P ₄	14.3 mm.	11.8	11.
Width of mandible at M ₂	13.7	10.6	10.7

* Calif. Mus. Vert. Zoology.

SCIURUS DOUGLASI ALBOLIMBATUS Allen

This species is scantily represented by two lower mandibles from Samwel Cave and a portion of the skull with some upper teeth from Potter Creek Cave, but the material is sufficient to establish its status under this species.

SCIUROPTERUS ALPINUS KLAMATHENSIS Merriam, C. H.

Four lower mandibles, two from each cave, have been referred to this form. This species represents a zone of high altitudes to-day, and seems especially fond of red fir, *Abies magnifica*, as a habitat, but it has been found as low as 4500 feet elevation, where red firs do not exist. As has been mentioned above it occurs in the same locality with *Citellus b. douglasi*, so there is no apparent anomaly in their being found together in the caves. Their scarcity, however, and that of the two preceding genera, *Arctomys* and *Callospermophilus*, would indicate that these three animals and others which follow (*Aplodontia*, *Neotoma cinerea*, and *Lepus klamathensis*), all forms of the Canadian Zone, were here probably near their lowest limit of distribution.

APLODONTIA MAJOR FOSSILIS Sinclair

This form was described by W. J. Sinclair,⁵ the type being a right mandibular ramus from Potter Creek Cave, lacking the coronoid process and part of the angle. The subspecific characters given are that the dental foramen is wider transversely than in the living species, that the ridge in front and below the

⁵ Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, no. 7, p. 147, 1905.

masseteric fossa is usually continued across the lower side of the ramus to the inner prominence of the angle, and that the wall in front of the fossa above the angle, on the inner side of the ramus, is vertical for a relatively long distance below the opening of the alveolar canal. A large number of mandibular rami and a few fragments of skulls showing the upper tooth rows and palate are found in both caves, and a careful study of these, together with five skulls of *Aplodontia major* from the collection of the California Museum of Vertebrate Zoology taken in the Shasta region, shows that not only is the shape of the dental foramen not constant, but that the other two characters given vary according to the age of the individual, the continuation of the ridge across the ramus and an excessive vertical height generally indicating age. In taking measurements of the upper and lower tooth rows in the fossil specimens, a range of variation was found, from a Samwel Cave specimen with a lower tooth row of 16.7 mm., up to one from Potter Creek Cave measuring 20.5 mm. The conclusion is that these specimens represent individuals of all ages from very young to very old. On the whole, the lower tooth row of the fossil specimens averages slightly longer than in the living species, the average length of twenty-five specimens from Potter Creek Cave being 18.6 mm.; so that this factor, taken in conjunction with the fact that the ridge across the rami of the fossil specimen is, on the whole, slightly more pronounced than in all but one of the five specimens of *A. major*, would support the view that the fossil form is a distinct subspecies.

PEROMYSCUS MANICULATUS GAMBELI (Baird)

A portion of the skull with left upper tooth row from Samwel Cave has been referred to this widely distributed species of the genus, as it presents no characters which might distinguish it specifically.

NEOTOMA CINEREA OCCIDENTALIS Baird

Of all the rodents the most abundant remains from both caves are those of *Neotoma*. They occur at varying depths in abundance, but unfortunately consist chiefly of lower mandibles. A new species, *Teonoma spelaea*, has been described from Potter

Creek Cave by W. J. Sinclair,⁶ the type being the "anterior two-thirds of a skull of an adult individual, in which the teeth are not much reduced by wear," and the main points of differentiation being that in the fossil form "the rostrum and incisive foramina are decidedly shorter . . . than in *T. cinerea* . . . the premaxillae extend farther back beyond the nasals, the nasals taper more posteriorly, and the frontals have a greater inter-orbital width." Also in the lower mandibles of *T. spelaea* "the enamel loops of the molars [are] more evenly balanced on the two sides of the axis of the tooth row." According to E. A. Goldman⁷ in his revision of the genus *Neotoma*, typical *N. cinerea* is not considered to range into northern California, but instead that region is occupied by *N. c. occidentalis*. The following comparisons are made with specimens of that subspecies.

The type of *Teonoma spelaea*, no. 5362, is the only specimen available from which all the measurements in support of the various specific characters can be obtained; moreover the skull is that of a young adult individual which may not have attained full size. There are two other portions of skulls from Potter Creek Cave, nos. 3550 and 6341, but they are broken so that measurements of all the points cannot be taken. In Samwel Cave all the specimens found were lower mandibles, so no corroborative measurements can be obtained from that source. Taking, therefore, the measurements of the type only as given in the description already cited, and comparing them with those of three specimens of young adult females of *N. c. occidentalis*, from the collection of the California Museum of Vertebrate Zoology, it is found that in the type of the fossil form the incisive foramina are longer, and the rostrum, that is the distance from the base of P⁴ to the anterior face of the incisor, is longer. The extension of the premaxillae is less than that of one of the specimens with which it is compared, and greater than that of the other two, showing that this is a variable character. The frontal width is less than a millimeter greater. The main points in which the fossil form differed from *N. c. occidentalis* were in a longer upper tooth row and larger teeth, points which,

⁶ Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, no. 7, p. 147, 1905.

⁷ N. Amer. Fauna, no. 31.

if taken in conjunction with the fact that the rostrum and incisive foramina really were shorter, would further strengthen the specific differences of *T. spelaea*; but in the light of the fact that the two latter points have been disproved, the fact that the tooth row is longer would hardly seem a ground for specific differentiation. In regard to the enamel loops of the lower molars being more evenly balanced in the fossils, no difference between them and those of *N. c. occidentalis* could be found and the writer has placed all the specimens from both caves under this living species.

Some of the lower mandibles from both caves have been referred to another species, *N. fuscipes*, but there is a well-marked difference in the shape of the mandibles of the two forms, and the fossil specimens can all be readily distinguished as belonging to the *N. cinerea* group. *N. cinerea* and *N. fuscipes* have been taken in the same localities, but as a rule they do not occupy the same territory and it is evident that the fossil specimens are those of the former group, which now lives among rocks and might have lived in the caves, rather than those of the latter group, which build houses of sticks above ground.

MICROTUS CALIFORNICUS (Peale)

Three specimens only of this genus occur in the caves, two from Samwel Cave and one from Potter Creek Cave. The species *M. californicus* is one which inhabits comparatively dry ground. It is, therefore, not surprising to find it in the cave deposits, but the fragile nature of the skull would make its preservation uncommon under any circumstances. A lower mandible from Samwel Cave has a complete set of teeth, and the one specimen from Potter Creek Cave is a portion of the skull with dentition, so that the species can be definitely placed.

THOMOMYS MICRODON Sinclair

This seems to be a well-defined species described by Sinclair⁸ as differing from *Thomomys mazama* "in having a very prominent ridge on the side of the fossa, marking externally the position of the alveolus of the superior incisor, and with a deep fossa above the ridge." Also the rostrum is short and broad.

⁸ Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, p. 146, 1905.



Fig. 7. *Thomomys microdon*. Anterior portion of skull, left side, no. 5738.

Fig. 8. *Thomomys leucodon*. Anterior portion of skull, inferior view, no. 4649.

Fig. 9. *Thomomys leucodon*. Anterior portion of skull, left side, no. 5622.

Fig. 10. *Thomomys leucodon*. Anterior portion of skull, inferior view, no. 5622.

Figs. 7 to 10 natural size

The writer has referred a number of lower mandibles—about a dozen from each cave—to this form on account of their small size, and one portion of a skull from Potter Creek Cave which corresponds closely to the type specimen. In Samwel Cave the specimens were found at depths varying from near the surface to thirty-six inches, in Potter Creek Cave from four inches to one hundred and sixty.

THOMOMYS LEUCODON Merriam, C. H.?

There are six specimens, one an anterior portion of a skull without teeth, no. 4649, from Samwel Cave, another anterior portion of a skull with incisors, P^1 , M^1 , and M^2 , no. 5622, and four lower mandibles from Potter Creek Cave, which, on account of their size and shape, have been placed under the *leucodon* group of *Thomomys*. There are certain characters shown by these specimens, especially the fragments of skulls, in which they differ from specimens of *T. leucodon navus* from the collection of the California Museum of Vertebrate Zoology. No typical specimens of *T. leucodon* were available, but the skulls of the subspecies *navus* do not differ from those of the typical form in the points mentioned.

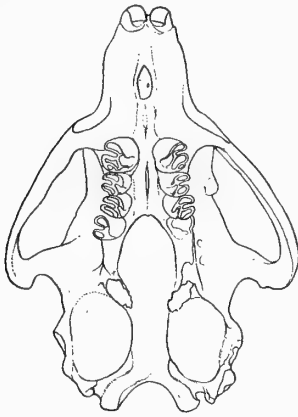
In the fossil specimen, no. 4649, from Samwel Cave the in-

incisive foramina are wide, and open, and they are two very distinct parallel ridges running from these foramina to the base of the premolars. The skulls of *Thomomys l. navus* show incisive foramina differing in that some are more open and that the ridges are sometimes present and sometimes lacking, due probably to the age of the individual. In no. 5622 the incisors apparently pass abnormally far back of the anterior roots of the zygomata, but the specimen is broken so that the incisors are exposed, and it is possible that the length appears abnormal compared with unbroken skulls. In this specimen the incisive foramina are not as wide open, nor are the ridges as apparent. One lower mandible has very small teeth, and yet it is evidently not that of a young individual, and the angle of the jaw is much extended. If these various characters were all combined in one individual there would seem to be ground for separation of a subspecies, but in view of the fact that each one presents only a slight difference, and that the material is so fragmentary, they have been placed under the living species. They seem to come under the *T. leucodon* group rather than under *T. monticola*, because in *T. monticola* the root of the incisor curves down abruptly in front of the anterior root of the zygomata, while in *T. leucodon* the root of the incisor slopes off more gradually and passes almost directly back of the root of the zygomata.

ERETHIZON EPIXANTHUM Brandt

The genus *Erethizon* is known only from Samwel Cave, but it is the most fully represented of all the rodents. A nearly complete skeleton with the skull, no. 11376, was found, and also a skull with the left ramus of the lower jaw, no. 8901.

A comparison of the fossil specimens with a Recent individual from the collection of the California Museum of Vertebrate Zoology, no. 16216, from the Whitney Creek, Tulare County, California, and with five skulls from the collection of the U. S. National Museum, nos. 108991, 109142, and 109143 from Tuolumne Meadows, and nos. 109276 and 11082 from Mt. Dana, California, showed no points of difference either in the skeleton or skull which would separate the fossil form from the living species. Specimen no. 11276 is a comparatively large skull, and



11

Fig. 11. *Erethizon epixanthum*. Inferior view of skull, no. 11276, $\times \frac{1}{2}$.

the auditory bullae seemed to be unusually long, anteroposteriorly, and inflated, but it is that of a young individual, and it seems to be a fact that the bullae shrink and contract with age, so that the general shape of the bullae rather than their size would constitute a dependable character and, in this case the form of the bullae of the fossil specimen is similar to that of the living species. Even such a small series of skulls of the living species showed so much variation that no comparative measurements are given.

MEASUREMENTS OF SPECIMENS FROM SAMWEL CAVE

	No. 11276	No. 8901
Length of skull from anterior face of incisors to back of occiput	107.5 mm.	
Anteroposterior diameter of bullae	21.2	19.
Transverse diameter of bullae	14.2	12.4

LEPUS CALIFORNICUS Gray

There are about two dozen specimens consisting of lower mandibles and two portions of skulls from Potter Creek Cave referable to this species. There are some slight points of difference, however, in the fossil forms, such as proportionately great length of the lower tooth row and diastema in relation to the size of the mandible. The upper tooth row is slightly longer, and the anterior width of the incisive foramina somewhat greater

than in the living species, but there is such variation in the measurements, dependent upon age and sex, that such slight differences hardly seem a sufficient ground for even subspecific separation. It seems rather remarkable that *L. californicus*, which is so abundant among the Potter Creek Cave rodents, should not be represented in Samwel Cave.

LEPUS A. KLAMATHENSIS (Merriam, C. H.)

This form of the varying hares is represented by four mandibles from Potter Creek Cave. Eleven mandibles and a portion of a skull with the left upper tooth row, except for P³, and the anterior root of the zygomata are known from Samwel Cave. In size these specimens might be confused with *Sylvilagus auduboni*, but there are distinctive differences that make their determination fairly certain. In the mandible of *L. a. klamathensis* the inner point of the posterior columns of the lower molars curves away from the anterior column, while in *S. auduboni* the two columns are practically parallel, and in addition the angle is sharper and begins farther back in *L. a. klamathensis* than in *S. auduboni*. Furthermore, in *L. a. klamathensis* with age a ridge develops on the outer side of the anterior root of the zygomata, which is not so pronounced in *S. auduboni*.

SYLVILAGUS AUDUBONI (Baird)

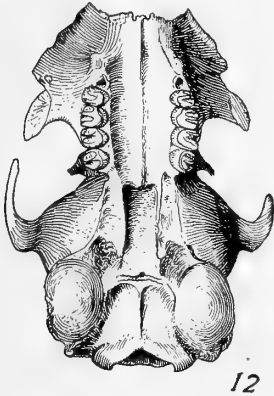
Nine specimens from Potter Creek Cave and seven from Samwel Cave, all mandibles except two, a right and left upper jaw without teeth, are referred to this species. It is possible that these are young specimens of *L. klamathensis*, but they would be extremely young to be as small as they are, and the teeth in these specimens seem to indicate full-grown individuals. It is interesting to note that this species was common at a point so far north as this region.

SPECIES FROM RANCHO LA BREA

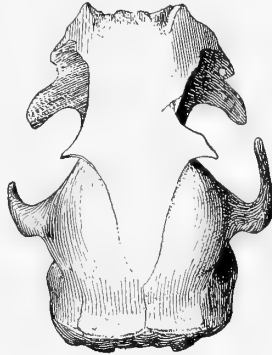
CITELLUS BEECHEYI CAPTUS, n. subsp.

Type no. 11264, a portion of the skull without nasals, premaxillae and incisors, Cotype no. 12404, a left ramus of the lower jaw with P₄, M₁, M₂. Both specimens from locality no. 1059, Rancho La Brea, Los Angeles County, California.

In the skull the width between the premaxillae and the anterior width of palate are less than in *Citellus b. fisheri*. The bullae are relatively long and narrow. In the lower jaw, the tooth row is long and the teeth heavy in proportion to the size of the ramus; the coronoid process, angle, and condyle are small.



12



13



14



15



16

Fig. 12. *Citellus b. captus*, n. subsp. Inferior view of skull, no. 11264.

Fig. 13. *Citellus b. captus*, n. subsp. Superior view of skull, no. 11264.

Fig. 14. *Citellus b. captus*, n. subsp. Right lower mandible, no. 12404.

Fig. 15. *Thomomys b. pallescens*. Right side of skull, no. 11269.

Fig. 16. *Sylvilagus auduboni*. Left upper tooth row, no. 1870.

Figs. 12 to 16 natural size.

On the whole, this form seems to be a relatively small one, although comparisons with *Citellus b. fisheri* show only slight differences in measurements of some of the parts. Taken as a whole the known differences seem sufficient ground for at least subspecific differentiation. The comparative measurements are

with Recent specimens from the collection of the California Museum of Vertebrate Zoology, which correspond to the fossil forms in stage of wear of the teeth, and are therefore considered to be of comparable age.

MEASUREMENTS

	No. 11264	No. 1407*
Least temporal breadth	13. mm.	15.
Anterior width between premaxillaries	11.	13.6
Anterior width of palate at P ³	8.3	9.1
Posterior width of palate back of M ³	8.2	9.1
Length of upper tooth row	11.7	11.9
Anteroposterior diameter of auditory bullae	12.3	11.2
Transverse diameter of auditory bullae	8.4	11.2
	No. 12404	No. 3183*
Length of lower tooth row	11.8 mm.	11.
Anteroposterior diameter of P ₄	2.5	2.
Anteroposterior diameter of M ₁	2.5	2.3
Anteroposterior diameter of M ₂	2.8	2.5
Transverse diameter of P ₄	2.2	2.1
Transverse diameter of M ₁	3.	2.7
Transverse diameter of M ₂	3.2	3.

* Calif. Mus. Vert. Zool.

PEROMYSCUS GAMBELI (Baird) ?

This genus is represented by only one specimen, a right ramus of the lower jaw, with M₁. It is a small form near the size of *P. gambeli*, the smallest of the *Peromyscus* species.

MICROTUS CALIFORNICUS (Peale)

This species is represented by abundant material. One of the distinguishing skull characters of *M. californicus* is the form of the incisive foramina, which are of uniform width, instead of narrowing anteriorly or posteriorly as in other species. In one specimen, no. 18700, a portion of the skull, the incisive foramina are of this shape. Other specimens referred to this species are the anterior portions of a right and left ramus of the lower jaw with P₄ and incisor; two right rami with incisor and condyle; the anterior portion of a left ramus with incisor; one with incisor and M₁ and M₂; and a portion of a skull with palate and M² and M³ on either side.

THOMOMYS BOTTAE PALLESCENS Rhoads

The specimens of *Thomomys* represented in the Rancho La Brea fauna show quite a range of variation due to differences in age, the younger individuals with a short rostrum and slender jugal and with the rami of the lower jaw small, the older ones with more elongated rostrum and larger rami. They have all been placed under the subspecies *T. b. pallescens* because they present no greater range of variation than is present in this species. The teeth of two specimens, no. 1212, a left ramus of the lower jaw with M_1 and M_2 , and no. 12418, a right ramus of the lower jaw with incisor and P_4 , M_1 , M_2 , are slightly different from those of *T. pallescens*, but in the case of no. 1212 the effect is partially due to a break in M_2 which gives it a very broad appearance. However, the teeth of the fossil form are slightly heavier than those of typical *T. pallescens*.

PERODIPUS AGILIS (Gambel)

One specimen, a portion of the skull showing the premaxillaries and frontals and three teeth, P^4 , M^1 , M^2 , embedded in a piece of asphalt, represent this species. The teeth make it referable to *Perodipus* rather than to the externally closely related genus of pocket rats, *Dipodomys*.

SYLVILAGUS AUDUBONI (Baird)

This species is the best represented rodent found in the Rancho La Brea deposits. There are eleven specimens, mostly mandibles. There are two fragments of skulls, one of which has a full set of teeth on the left side. The fossil forms are those of fairly young animals, thus bearing out the theory already stated by Dr. J. C. Merriam that the very young animals through lack of discretion, commonly fell victim to the asphalt. The specimens have been referred to *S. auduboni* instead of to the subspecies *sanctidiégi*, because the latter is based mainly on a geographic distribution, and although it is supposed to differ from *S. auduboni* in having narrower and more slender jugals and a broader palatal ridge, a comparison of skulls of the two forms did not bear out the latter distinctions.

SYLVILAGUS BACHMANI CINERASCENS (Allen)

Of this more uncommon brush rabbit only three specimens occur, portions of three right mandibles, with dentition. The teeth of one are so broken that their true shape is indistinguishable, and those of the other two show that they belong to very young individuals. The small size of all three makes them referable to this form, which is the smallest species of the genus found in this region. There seem to be some slight differences in the shape of the teeth between the fossils and Recent specimens of *S. b. cinerascens*, but this can be accounted for on the ground that the fossil teeth are unworn.

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TAPIR REMAINS FROM LATE CENOZOIC
BEDS OF THE PACIFIC COAST REGION

BY

JOHN C. MERRIAM



UNIVERSITY OF CALIFORNIA PRESS

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INTRODUCTION

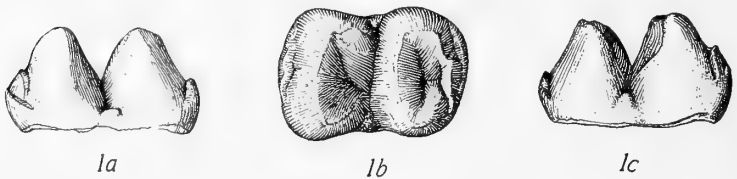
The only certainly known remains of Tapiridae from the Pacific Coast province of North America consists of two specimens. One is a single tooth obtained many years ago from the Auriferous Gravels of California. The other specimen is a portion of an upper jaw with teeth, recently discovered in marine deposits near Cape Blanco, Oregon. As this material is of considerable importance in a study of late Cenozoic history of the Pacific Coast region, it is desirable to place on record such information relating to it as is available.

For the California specimen, which was presented to the University some years ago, the writer is indebted to Dr. Wm. J. Sinclair, through whom it was given to the University by Mr. Benjamin Pownell.

For the privilege of examining and describing the second specimen the writer wishes to acknowledge his indebtedness to Mr. Frank M. Anderson and to Mr. Bruce Martin of the California Academy of Sciences.

SPECIMEN FROM AURIFEROUS GRAVELS OF CALIFORNIA

A lower molar tooth presented by Mr. Benjamin Pownell to the University of California some years ago is the only available specimen representing the Tapiridae in California. This tooth was originally in the collection of Dr. Snell, and as suggested by Dr. Wm. J. Sinclair, who obtained it from Mr. Pownell, it may be the tooth to which reference is made by Wm. P. Blake and later by J. D. Whitney. In a note on the occurrence of fossil remains of the tapir in California published in 1868, Blake¹ stated that remains of this animal had been found at a depth of forty feet below the surface in the auriferous gravels at Wood's Creek near Sonora, Tuolumne County, California. The specimens were said to have been presented to Blake by Dr. Snell of Sonora. The material consisted of a lower molar and possibly an epiphysis of a cervical vertebra. The tooth was determined by Professor Owen of the British Museum as the "crown of the left lower molar tooth of a tapir." The specimen mentioned by W. P. Blake is referred to by J. D. Whitney² in 1879 in his discussion of the Auriferous Gravels.



Figs. 1a to 1c. *Tapirus haysii californicus*, n. subsp. M_2 (?). No. 8747, natural size. From the Auriferous Gravels of California. Fig. 1a, outer view; fig. 1b, superior view; fig. 1c, inner view.

The tooth presented to the University by Mr. Pownell is a left lower molar. It is apparently M_2 . It seems to be distinguished from M_3 mainly by the relatively greater width of the posterior half of the tooth. The anterior and posterior transverse ridges are unworn and show only faint indications of notches between protoconid and metaconid, and between hypoconid and entoconid. There is an anterior and a posterior

¹ Blake, Wm. P., *Amer. Jour. Sc.*, ser. 2, vol. 45, p. 381, 1868.

² Whitney, J. D., *Mus. Comp. Zool.*, vol. 6, p. 250, 1879.

cingulum. The posterior cingulum is narrow transversely. On the anterior side of the crown there are two basal ridges. One is median and is partly confluent with the anterior ridge of the protoconid. The other anterior basal ridge lies below and in front of the one just described, and forms a distinct shelf on the external side of the anterior end of the tooth. It reaches nearly to the extreme outer border of the tooth. On both the outer and inner sides of the tooth small tubercles are developed between the bases of the anterior and posterior transverse ridges. The inner tubercle is very faint, but the outer one is a noticeable feature of the tooth (see figs. 1a to 1c).

The specimen just described does not differ greatly from M_2 and M_3 of *Elasmognathus bairdii*. It is distinguished by the slightly larger anteroposterior diameter of the anterior basal ridges, and by the smaller size of the external basal tubercle between the metalophid and hypolophid. In the only specimen of *E. bairdii* available for comparison the posterior molars are somewhat worn and the characters of the transverse ridges are not as clearly shown as in the fossil specimen.

In such figures of the dentition of *Tapirus terrestris* as are available, the characters of M_3 seem very close to those of the fossil from California, though the details of form are not clearly discernible on any figures of *T. terrestris* at hand.

The type specimen of *Tapirus haysii* figured by Leidy³ seems to show anterior and posterior cingula, and an external basal tubercle between the metalophid and hypolophid. The width or transverse diameter of the tooth is, however, relatively much greater compared with the length or anteroposterior diameter, the relation being as 22.3:27 in *T. haysii*, and 17.8:25.3 in the California specimen. As the teeth compared are both presumed to represent M_2 of the left side, it would seem that the considerable variation in width, amounting to at least twelve per cent, may represent specific or subspecific difference. In *Elasmognathus bairdii* the ratio of width to length is intermediate between that in the California specimen and that in the type of *T. haysii*.

³ Leidy, J., in Holmes, Post-Pleiocene Fossils of South Carolina, pl. 17, figs. 7 and 8, 1860.

The tooth from California represents a form approaching *Elasmognathus bairdii* of the Recent fauna in certain characters. In some respects it is intermediate between *E. bairdii* and *Tapirus terrestris*. Though the California specimen shows some resemblance to *T. haysii*, the considerable difference in form of M_2 makes it very difficult to believe that the two are specifically identical. The specimen seems at least as near *E. bairdii* as to any described species, but the nature of the cingula and of the tubercles between metalophid and hypolophid seem to distinguish it from that form. The writer considers that a tentative recognition of the distinguishing characters of the California specimen, together with an indication of its geographic location, is more desirable than a very doubtful reference to one of the described species. This form is therefore tentatively distinguished as *Tapirus haysii californicus*.

MEASUREMENTS

	No. 8747 ⁴	<i>E. bairdii</i>	<i>T. haysii</i>
M_2 , anteroposterior diameter.....	25.3 mm.	22	27
M_2 , greatest transverse diameter	17.8	17.8	22.3

⁴ From the Auriferous Gravels of California.

SPECIMEN FROM MARINE BEDS AT CAPE BLANCO, OREGON

The tapir specimen from Cape Blanco, Oregon, was obtained in June, 1911, by Mr. Bruce Martin while collecting in the marine beds of that region for the California Academy of Sciences. It was found in the bluff about three miles south of Cape Blanco and one-half mile north of the mouth of Elk River. At this locality the formations comprise two lithologic phases: (1) an upper, gray-buff sand, which is loosely cemented and breaks down readily; (2) a lower, blue-gray, argillaceous sandstone, which is better cemented and forms steeper cliff walls than the upper zone. There is no evident discordance between the upper and lower zones.

A considerable marine fauna obtained from the upper sand by Martin seems quite certainly to represent a phase of the Pleistocene near that of the San Pedro stages. The marine fauna of the lower sand is distinctly older than that in the upper zone, and shows some resemblance to that of the upper Merced series.

The lower fauna is not yet well enough known to permit definite reference to a stage of the standard time scale, but seems to be not older than late Pliocene or younger than the earlier portion of the Pleistocene.

The section from which the tapir tooth was obtained has been described by Diller,⁵ who refers to an upper horizon as the Elk River Beds. A collection of marine shells from these beds examined by Dall was referred to as "probably Pleistocene, all the species seeming recent, but they may be of the Merced horizon. . . . They are not older than the newer Pliocene." The lower zone at Elk River as described to the writer by Martin is possibly referred by Diller to the Cape Blanco Beds, the equivalent of the Empire beds. The fauna from the exposures of the Blanco is considered by Diller as Miocene. Mr. Martin believes that the lower horizon of blue-gray argillaceous sandstone is later than the Empire formation which occurs lower down in the section in the cliff farther north. According to Martin the fauna of this blue-gray argillaceous sandstone is much more recent in character than that of the Empire Beds farther north. The tapir specimen is reported from the lower beds.

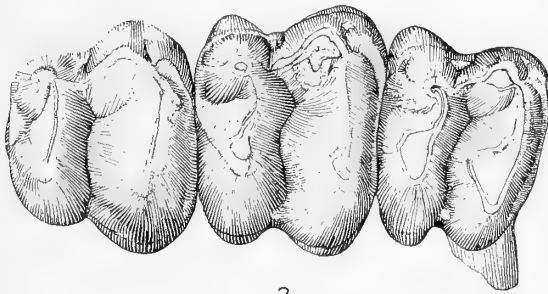


Fig. 2. *Tapirus*, near *haysii californicus*, n. subsp. Superior molar series, natural size. From early Pleistocene or late Pliocene marine deposits three miles south of Cape Blanco, Oregon.

The tapir specimen obtained at Cape Blanco consists of a portion of a maxillary bone with the three molar teeth well preserved and but little worn (fig. 2).

⁵ Diller, J. S., U. S. Geol. Surv. Bull., 196, p. 30, 1902.

In the portion of the maxillary present there is nothing to distinguish the Cape Blanco form from *Elasmognathus bairdii*.

The molars do not agree exactly in all characters with those of any species available for comparison. From *Tapirus terrestris* they differ considerably in the much smaller parastyle of M². From *T. roulini* they are distinguished by the relatively smaller size and more nearly quadrate form of M². From *T. indicus*, they are separated by the more nearly square cross-section of M², and by the tendency to development of an external cingulum on the outer side of the metacone pillar of M². The Cape Blanco form approaches *Elasmognathus bairdii* in the nearly quadrate form of M², and in the presence of a weak cingulum on the outer side of the metacone pillar of M². There is also a faint suggestion of a tubercle on the inner side of M¹ between the protocone and hypocone pillars as in *E. bairdii*. It seems possible to distinguish the Cape Blanco form from *E. bairdii* by the weaker external cingulum on the outer side of M², by the absence of a cingulum on the corresponding region of M³, and by the absence or imperfect development of the tubercle on the inner wall of the molars between protocone and hypocone. There is also a less distinctly noticeable evenness of the molars in form and size in the Cape Blanco form than in the Recent *E. bairdii*.

With *Tapirus haysii* Leidy from the Pleistocene of southern and eastern United States it is not possible to make an entirely satisfactory comparison, as no good figures are available. The specimen figured by Leidy⁶ from the Brasos River near San Fillipe, Texas, is somewhat worn and the diagnostic characters are not clearly shown. The dimensions are very near those of the Cape Blanco specimen. This specimen is evidently near *Tapirus haysii*, and may be referred to tentatively as *Tapirus*, near *haysii californicus*.

⁶ Leidy, J., in Holmes, Post-Pleiocene Fossils of South Carolina, pl. 17, fig. 1, 1860.

MEASUREMENTS

	Cape Blanco specimen	<i>E. bairdii</i>	<i>T. haysii</i>
M ¹ , anteroposterior diameter	21.5 mm.	19.5	21.5
M ¹ , greatest transverse diameter	27.3	24	27.5
M ² , anteroposterior diameter	24.8	22.5	25.5
M ² , greatest transverse diameter	30.5	25.9	32
M ³ , anteroposterior diameter	25.7	21.8	
M ³ , greatest transverse diameter	30	25.5	

SUMMARY

The tapir specimens from the Auriferous Gravels of California and from the marine beds of Cape Blanco, Oregon, both represent species not distinctly removed from the existing *Tapirus (Elasmognathus) bairdii*.

The California specimen seems to be near *Tapirus haysii*, but shows differences which appear to be of at least subspecific value. This form is tentatively referred to as *Tapirus haysii californicus*, n. subsp.

The Cape Blanco specimen is near *Tapirus haysii*, and shows indication of relationship to *Elasmognathus bairdii*. It is probably near the form from the Auriferous Gravels, and is referred to as *Tapirus*, near *haysii californicus*.

The Auriferous Gravel and Cape Blanco specimens both seem to represent a stage of evolution quite certainly not earlier than late Pliocene, and probably not older than early Pleistocene.



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THE MONTEREY SERIES IN CALIFORNIA

BY

GEORGE DAVIS LOUDERBACK

UNIVERSITY OF CALIFORNIA PRESS

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PART I

THE SANTA CLARA VALLEY REGION OF VENTURA
COUNTY AND ITS RELATIONSHIP TO THE
COASTAL REGION TO THE NORTH
AND WEST¹

INTRODUCTION

In the southern coastal region of California the Tertiary formations are extensively developed and present many problems of geological interest. Furthermore, on account of the remarkable development of their petroleum contents that has taken place in recent years, they have assumed a marked economic interest. An understanding of the general relationships, correspondences, and correlations of the rocks of the various districts into which the region may be divided is therefore of importance to the student of any of the various problems involving these formations.

As one after another of the West Coast Tertiary formations has been more carefully studied there has gradually arisen what may be looked upon as a standard depositional series applicable to this coastal province, to which the formations in the more newly studied localities are naturally compared and referred.

During the summer of 1910 the writer had the opportunity of studying the oil fields of Ventura and Los Angeles counties and of comparing the formations there associated with the oil with those of similar associations further north. In the reports of the Geological Survey on these districts,² one formation name previously used and originally applied in the central Coast Ranges is found applied to the local Tertiary, but the associated formations, both above and below, are all given new names—

¹ Presented before the Cordilleran Section, Geological Society of America, at the Berkeley meeting, April 1, 1911.

² Eldridge and Arnold, Bull. 309, U. S. Geol. Surv., 1907.

Modelo, Puente, Sespe, Topatopa,—presumably to emphasize their lack of correspondence with established formation groups, or the marked dissimilarity of the conditions under which they were formed. For, besides using one of the “standard” names, one of the authors of the bulletin presents a “Standard California Section” (p. 143) and makes comparisons with it. Furthermore, in the descriptions of the formations, special attention is called to the dissimilarity even between formations as close together as the two sides of the Santa Clara Valley, and the difficulty of correlating or even of using the same formation names for the two areas is pointed out and discussed (e.g., p. 21).

It was therefore with considerable interest that the writer entered the southern field to get a better understanding of those conditions which produced there a different province of deposition from that of the country north of Santa Barbara. It must be admitted that the descriptions in the bulletin of the various stratigraphic members gave hints of some striking similarities between the Santa Clara region and the central Coast Range region, but in several ways the order of events and the major divisions appeared to show abnormalities that required explanation.

Unfortunately opportunity was not given to make careful detailed studies of contacts or sections such as are necessary for an accurate understanding of the details of formational relationships. However, some of the more general features appeared to indicate so definitely the general relationships that it is believed a statement of them will aid in a better understanding of an important period of sedimentation.

PREVIOUSLY DESCRIBED SECTION NORTH OF SANTA CLARA VALLEY

The most complete Tertiary section of the southern California region that has been described is that found to the north of the Santa Clara Valley in Ventura County, commencing with the Topatopa range anticlinal axis and running southeastward towards the valley. The following section has been prepared from the descriptions in Bulletin 309, plate 1 of which may be consulted for the areal distribution of the formations:

GEOLOGIC COLUMN

FOR FORMATIONS NORTH OF SANTA CLARA VALLEY, VENTURA COUNTY
(ACCORDING TO DESCRIPTIONS IN BULL. 309, U. S. G. S.)

Fernando Formation (Pleistocene to upper Miocene)	}	Conglomerate, sandstone, and arenaceous clay
---	---	--

UNCONFORMITY

Modelo Formation (middle Miocene)	{	Upper shale, 200-1500 ft.	{	Granular, siliceous to earthy, fissile shale, brown, gray, or yellowish; carrying calcareous layers and lenticular limestone concretions
	{	Upper sandstone, maximum 900 ft.	{	Chiefly of white subangular quartz, slightly yellow by iron; much dark chert in fragments also present
	{	Lower shale, 400-1600 ft.	{	Indistinguishable lithologically from upper shale
	{	Lower sandstone, 200-2000 ft.	{	Massive, heavy bedded, white to yellowish gray, locally gritty with pebbles of dark chert and sandstone; scattered yellow weathering limestone concretions, often stained dark by petroleum; concretions 1-5 ft. in diameter, very characteristic

Vaqueros Formation (lower Miocene)	{	500-600 ft.	{	Siliceous shale and limestone, gray but yellow weathering, indistinguishable lithologically and faunally from Modelo shale
	{	About 700 ft.	{	Deep maroon, brown and gray shale
	{	500 ft. About 500 ft.	{	Gray shale Chiefly shale with limestone lentils

Sespe Formation (Eocene)	{	Upper Sespe, 500 ft.	{	Rusty (ochreous) to greenish gray, calcareous sandstone separated by bands of shale
	{	Middle Sespe (Red beds), 1240-1800 ft.	{	Sandstone and shale, occasionally conglomerate; 400-800 ft. Heavy sandstone often coarse and gritty with thin shale beds, occasionally conglomerate; 500 ft.
	{	Lower Sespe, 400 ft.	{	Massive sandstone, occasionally conglomerate; 300-400 ft. Coarse conglomerate; 40-100 ft.
	{	400 ft.	{	White sandstone and green and pink clays and shale

Topatopa Formation (Eocene)	{	5500 ft. exposed	{	Hard submassive sandstone and quartzite, greenish gray, clear or mottled with white, and shale; sandstones usually light gray to white
-----------------------------------	---	------------------	---	--

UNCONFORMITY

Granite

VAQUEROS-MONTEREY SERIES OF MONTEREY-SANTA BARBARA
COASTAL REGION

As developed in Santa Barbara County not many miles directly west of the Santa Clara Valley locality, and in San Luis Obispo and Monterey counties to the north, the Vaqueros deposition commences characteristically as a greenish gray to rusty yellow, or whitish, sandstone, with here and there pebbly or conglomeratic layers, especially near the base. As we pass higher into the series terrigenous shales become the dominant type, and finally siliceous (diatomaceous) shales so characteristic of the "Monterey". Fairbanks³ places the base of the Monterey in the San Luis quadrangle at the base of the clay shale above the zone of dominant sandstones. Arnold in the Santa Maria⁴ and the Summerland⁵ districts in Santa Barbara County places the zone of dominant terrigenous shales in the Vaqueros, and considers that the siliceous, biogenic shales usher in the Monterey. Both consider that the Vaqueros and the Monterey form a conformable series.

APPARENT CONTRASTS BETWEEN THE TWO REGIONS

Without discussing at this point the relative merits of the two systems of criteria, let us compare the general course of events as shown by the Vaqueros-Monterey period of sedimentation along the coast from Monterey to Summerland, a distance of about 200 miles, with the series described by Eldridge and Arnold for the region north of Santa Clara Valley, 20 miles or less east of Summerland.

We note in the latter that the Vaqueros deposition is inaugurated as a shale, passes into siliceous shale and then the Modelo follows conformably as thick sandstone followed by siliceous shale, then more sandstone and more siliceous shale. The Modelo is correlated with the Monterey by Arnold.⁶

³ U. S. Geol. Surv., folio 101, San Luis, California, 1904, p. 4.

⁴ U. S. Geol. Surv. Bull. 322, 1907.

⁵ U. S. Geol. Surv. Bull. 321, 1907.

⁶ U. S. Geol. Surv. Bull. 309, 1907, p. 143.

The Santa Clara district would then appear to be exceptional in (1) the opening of Vaqueros sedimentation, (2) its closing phases, and (3) the opening of the supposed correlative of the Monterey, the Modelo. As products of deposition are so abundant here, and as the district is so close to the edge of the Monterey-SanLuis Obispo-Santa Barbara region, these exceptional features naturally call for further explanation.

THE OPENING OF THE "VAQUEROS" DEPOSITION

In examining the Santa Clara region formations in the field, the writer was continually met by the fact that at the base of the shales called Vaqueros there lies everywhere a sandstone, usually several hundred feet thick, with conformable relationship to the shales, which corresponds closely in general nature and appearance to that found at the base of the clay shales elsewhere, in other words, to the normal opening stage of Vaqueros-Monterey deposition. It has the lithologic character and stratigraphic position of the sandstones to which Fairbanks in the San Luis region would restrict the term Vaqueros. But Eldridge and Arnold have separated it from the Vaqueros and grouped it with another formation—the Sespe, calling it the upper Sespe (Eocene or Oligocene).

A careful study of the Santa Clara bulletin has been made by the writer to learn if possible why these sands were separated from the Vaqueros and united with the Sespe, but without results. According to this report,⁷ under the heading "Relation of Upper Sespe Beds to Vaqueros Shale," "No sharp lines of distinction separate the upper Sespe terrane from the underlying red beds or the overlying Vaqueros. On the contrary, there is a perceptible tendency for the terranes to shade one into another. Fossils of value have not yet been collected from this transitional zone. There is, therefore, some uncertainty as to whether the beds in question should be referred to the Eocene or the Miocene. . . . Tentatively, however, the line between the Sespe (Eocene) and the Vaqueros (lower Miocene) formations has been drawn at an indefinite horizon in the rusty beds described, at a point where

⁷ U. S. Geol. Surv. Bull. 309, pp. 11 and 12 (1907).

sandstone no longer predominates but is largely replaced by shale, yet below the lowermost lower Miocene fossils found.”

With such a lack of a definite division plane between shales and sandstones, or rather such a gradation between them, the only logical procedure would seem to be to construct the series on the plan of its nearby, definitely determined and lithologically similar correlative.

Further evidence of this relationship was obtained by an examination of the “Upper Sespe” for palaeontological data. At various horizons fossils were found, although mostly in a broken condition and not distinctly determinable. About fifty feet above the base of the “Upper Sespe” in the hills to the south of Tar Creek, where this formation is about 500 feet thick and is mapped⁸ as a strip one-half to three-quarters of a mile wide, a layer was found made up practically entirely of one species, *Scutella fairbanksi* Merriam,⁹ which is considered a characteristic fossil of the Vaqueros zone.

There seems, therefore, no reason for hesitating to disconnect these sands from the Sespe group and unite them definitely with the Vaqueros-Monterey. The exceptional nature of the opening of this period of sedimentation in the Santa Clara region therefore disappears.

THE SESPE FORMATION

The term Sespe was originally used by Watts¹⁰ in the form “Sespe brownstone formation,” which he said “consists of sandstone shales and conglomerate all being more or less brown in color.” Eldridge and Arnold¹¹ employed this term in the expression “Sespe formation,” as shown in the columnar section above given and added to the brownstone formation the yellowish (ochreous) sandstones above and a white sandstone below.

The exact relationship of the Sespe brownstone formation to the Vaqueros the writer did not work out. In a general way

⁸ Bull. 309, Plate I.

⁹ This determination was kindly checked by Professor J. C. Merriam.

¹⁰ Bull. Cal. State Mining Bureau, no. 11, pp. 11 and 12.

¹¹ U. S. Geol. Surv. Bull. 309, pp. 7-12.

in the Sespe region it underlies the latter with the same attitude,—that is, apparently conformably, but that relationship is subject to doubt.

At the least, the local representative of the Vaqueros as redelimited to include the so-called “upper Sespe” shows a sudden and permanent change in the type of sedimentation from that of the “brownstone” or “red beds,” so that even with a conformable relation there is a natural line of demarcation between them, and a special name will probably always be desirable for the red beds, even if they are included within the series above or below them.

This brownstone series is a rather local phenomenon. It runs west a few miles into the Santa Barbara region, but as far as known is not found to the north of the Santa Ynez river. Its extent east and south is also rather limited. It appears to be confined to a territory including southern Santa Barbara and Ventura counties and possibly part of Los Angeles County. Passing beyond the limits of this region the Vaqueros retains its general features, but the Sespe has disappeared, and as far as now known nothing just like it is found elsewhere in California.¹²

These relationships would at least suggest that the Sespe brownstone formation is not a member of the Vaqueros-Monterey series, and may be separated from it by a time break or unconformity. At the April, 1912, meeting of the Cordilleran Section of the Geological Society of America, Mr. Robert Moran reported the unconformable relationship of the Vaqueros and Sespe in the restricted sense as delimited above, as seen in southern Ventura County, and in the writer's opinion the mapping of these groups and the relationships of the Vaqueros-Monterey volcanics to the Sespe in the Semi region appear to offer good evidence to support this view.

No special reason has been put forward for attaching the white sandstones below the brownstone formation to the Sespe

¹² The writer has seen beds that suggest the Sespe type of deposition on the hills to the west of the Carrizo plains, but their stratigraphic relationships were not determined. The reddish to purplish shales above the fossiliferous Tejon sandstones in the Mt. Diablo range may be a corresponding facies of deposition.

in preference to the Topatopa, and it would seem that here, too, unless a good reason for a different arrangement were forthcoming, the line should be drawn where the distinct and characteristic change in sedimentation takes place,—that is, at the base of the red beds.

This idea is strengthened when the present state of our knowledge of the fauna of these formations is taken into account. Fossils are very rare in the “red beds,”—in fact, have not yet been reported in any of the red or reddish brown colored strata. Elridge and Arnold report¹³ that “In Sespe Canyon fragments of grayish-yellow sandstone, coming either from some horizon unrecognized but well up in the red beds or from a horizon corresponding to that of the rusty beds just described, have been found bearing well marked Eocene fossils among which are the forms *Venericardia planicosta* Lamarek and *Turritella uvasana* Conrad. Beds of a similar nature, with an abundance of Tejon (Eocene) fossils, also occur along the northern edge of the Silver Thread oil field, west of Santa Paula Cayon, overlying certain pink and gray sandstones that are believed, on lithologic grounds, to belong to the Sespe.” The list of fossils given includes at least nine characteristic Tejon forms found at the type locality. The available evidence is to the effect, therefore, that the Sespe is a phase of the Tejon (Eocene). If this be so, then the Topatopa and Sespe are two local depositional facies of the Tejon. It seems peculiar that with the type locality for the Tejon only 20 or 25 miles away, and with a good supply of characteristic Tejon fossils, the term Tejon was not used for the rocks of this district.

UPPER PART OF “VAQUEROS-MODELO” SERIES

Region North of Santa Clara Valley.—If we pass up from our newly established base of the Vaqueros (“upper Sespe”) and compare the depositional types with those of the corresponding series along the Monterey-San Luis Obispo-Santa Barbara coast region, we find the sandstone, 500 feet, which would correspond to Fairbanks’ Vaqueros, followed by dominant terrig-

¹³ Bull. 309, p. 11.

enous shales which correspond to his lower Monterey shales in the San Luis area, or Arnold's upper Vaqueros shales in the Santa Maria district, then siliceous (diatomaceous) shales corresponding to the siliceous shales generally recognized throughout the Monterey-San Luis Obispo-Santa Barbara region as Monterey.

These siliceous, biogenic shales are separated in the region north of Santa Clara Valley by a thick sandstone (Lower Modelo sandstone), from other siliceous shales above, and these by another sandstone (Upper Modelo sandstone) from a third body of siliceous shale still higher. Of this last shale, it is said:¹⁴ "This shale is indistinguishable from that separating the two Modelo sandstones already described. . . . Were the upper sandstone to disappear, the shales above and below would become a *single mass, uniform in their general features from top to bottom*;¹⁵ were both sandstones to disappear it would be *difficult to distinguish these rocks* from the upper portion of the Vaqueros formation." In other words, were the two sandstones not present, the upper part of the series would become a uniform succession of siliceous diatomaceous shales and correspond in character and stratigraphic position exactly with the siliceous Monterey shales of the coast region to the west and north.

The Modelo Sandstones.—A study of the field relations¹⁶ of these sandstones leads to suggestive results. In upper Hopper Cañon the lower Modelo sandstone is well developed and is probably over 2000 feet thick. This thickness diminishes rapidly towards the south, so that in 5 or 6 miles it is only a few hundred feet and within 8 or 9 miles it has apparently disappeared or is so insignificant as to attract no attention. No formation corresponding to it has been recognized south of the Santa Clara Valley, nor to the west in the Sulphur Mountain district.

The upper sandstone has not been recognized over so large an area, nor is its maximum thickness so great nor its tapering so rapid, but its relationships seem to be similar. It lies in

¹⁴ Bull. 309, p. 19.

¹⁵ The italics introduced by present writer.

¹⁶ These descriptions may be followed on map, plate I, Bull. 309, U. S. Geol. Surv.

the same general territory as the lower sandstone—that is, east of Sespe Creek, north of Santa Clara Valley, and does not cross the Piru drainage basin to the east. It appears to die out before the south side of the Santa Clara Valley is reached.

These sands, then, are strictly local facies which grow thicker as they approach the mountain mass to the north, from which they were probably derived; and to the west, south, and southeast (to the east they pass under later formations and their extent is unknown) they thin down either to negligibly small layers or to complete extinction.

Region South of Santa Clara Valley.—To the south of Santa Clara Valley, the development of the Vaqueros-Monterey series is simpler and the correspondence with the normal coast type more readily discernible. Fossils are abundant in the lower layers, so that the horizon is readily identified. The whole series is thinner, in particular by loss of the Modelo sandstones and a considerable decrease in the terrigenous shales. It may be noted that these shales show variation in thickness on the north side of Santa Clara Valley similar to that shown by the Modelo sandstones,—that is, they decrease in thickness towards the south, west, and southeast, although they do not, as far as observed, entirely disappear.

There appears to be no reason to doubt that the formations south of the Santa Clara Valley represent as a whole practically the same duration of deposition as do those to the north, and that the particular differences of the latter are due simply to an original position nearer inshore, during at least a large portion of the period, and more directly related to a special source of supply of terrigenous detritus—the mountainous region of northern Ventura County. This relationship was indeed suggested as a possibility by Eldridge and Arnold:¹⁷ “South of the river this division does not appear to hold, yet one or another of the characteristics of the Miocene, taken as a whole, north of the river reappears on the south side, suggesting that the beds on both sides of the valley from base to summit should be included in a single formation.”

¹⁷ Bull. 309, p. 21.

Results.—From the above considerations it is evident that the division of the series at the base of the lower Modelo sandstone is an artificial division which holds in only a small part of the Santa Clara field, and that the line as drawn to the west of Sespe Creek and south of Santa Clara river is the same as that used by Arnold in the Santa Maria district,—that is, the base of the siliceous shales.

LITHOLOGICAL TYPES AND NOMENCLATURE IN VARIOUS FIELDS

It should be particularly noted that the distinction between Vaqueros and Monterey or Modelo has been actually made in the field by Hamlin,¹⁸ Fairbanks, Eldridge, and Arnold, in the Salinas Valley, San Luis quadrangle, Santa Maria district, Summerland district, and Santa Clara Valley districts, on a strictly lithologic basis,—that is, on a change in the type of sedimentation, and we may represent the correlation of depositional types in these districts by the following table in order to show how the application of the nomenclature and the position of the divisional lines have varied.¹⁹

¹⁸ U. S. G. S. Water Supply and Irrig. Paper no. 89, 1904.

¹⁹ It is evident that the questions here considered have nothing to do with the determinations of horizons as indicated by faunal zones within the Vaqueros-Monterey Series.

NOMENCLATURE OF DEPOSITIONAL FACIES OF MONTEREY SERIES

Region north of Santa Clara Valley and east of Sespe Creek Eldridge and Arnold	Region south of Santa Clara Valley Eldridge and Arnold	Santa Maria and Summerland Districts Arnold, Anderson, and Johnson	San Luis Quadrangle Fairbanks
UNCONFORMITY	UNCONFORMITY	UNCONFORMITY	UNCONFORMITY
Siliceous shale Upper sandstone Siliceous shale Lower sandstone	Chiefly siliceous shales	Chiefly siliceous shales	Chiefly siliceous shales
Siliceous shale Terrigenous shale (with calcareous concretions especially in lower part, and subordinate sandstone layers)	Terrigenous shales (with limestone concretion)	Terrigenous shales (limestone concretions)	Terrigenous shales (and limestone concretions)
Sandstone, with subordinate shale occasionally pebbly	Sandstone and conglomerate	Sandstone and sandy shales	Sandstone and conglomerate
Red Beds (Sespe brownstone)	Bright red and gray sandstones and clays, with one layer, rusty conglomerate	Sespe Formation	Vaquero Sandstone
Modelo Formation	Modelo Formation	Monterey Shale	Monterey Shale
Vaqueros Formation	Vaqueros Formation	Vaqueros Formation	Vaqueros Formation
Upper Sespe Formation	Upper Sespe Middle Sespe	Upper Sespe Middle Sespe	Upper Sespe Middle Sespe

RELATIONSHIPS OF DIFFERENT SECTIONS OF THE SERIES

The foregoing table is a comparison of the general features of several sections of the Monterey-Vaqueros series, the division lines being drawn on a lithological basis—the only basis on which actual divisional lines have been drawn in the areas represented. But a careful comparison of different sections of the Santa Clara Valley region gives very suggestive evidence, as explained above, that much of the terrigenous shale in the Sespe district corresponds to diatomaceous shale south of the Santa Clara Valley, and that much of the Modelo sandstones corresponds to contemporaneous deposition of siliceous shales south of the valley.

A study of numerous sections along the coast to the north of Point Conception has led the writer to similar conclusions for other areas. In the Santa Maria district conglomerate at one point is seen to take the place of sandstone within a few miles (as in the region between Suey Creek and Huasna Creek); sandstone at one point is replaced by terrigenous shales within a moderate distance (as in the Casmalia Hills). The rapid fluctuation in thickness of the terrigenous basal members of the conformable series which grade into biogenic calcareous and then siliceous shales, the terrigenous members retaining the same faunal facies, indicates that the terrigenous material at one locality is strictly contemporaneous with detrital material of a different grain and with biogenic material at others. This relationship is suggested practically everywhere that the series is developed.

In particular, it is frequently observable that the terrigenous material is definitely related to older land masses in many localities, and that the biogenic shale increases in amount in definite directions—often in directions that point to greater distance from an old shore line, as was brought out for the Santa Clara region and will be indicated for several other localities in a later part of this paper.

CONCLUSION

It results from these relationships that in the region observed the "Vaqueros" is merely a depositional facies, as is also the "Monterey shale," the former type including the lower sandstone and conglomerate and intercalated shale, according to the usage of Fairbanks and Hamlin, the latter the predominant clay shales, limestone and diatomaceous beds. Eldridge, Arnold, and R. Anderson throw the usually intermediate strata—predominately terrigenous shale and limestone—into the Vaqueros type. In the territory mapped by Fairbanks (San Luis Folio) we must hold that Vaqueros sandstone of one portion corresponds to Monterey shale of an adjoining portion, and the same holds in the Santa Clara district mapped by Eldridge and the Santa Maria district mapped by Arnold, Anderson, and Johnson.

The use of these terms as "formations" representing definite time intervals is misleading and gives a wrong picture of this great depositional series as a whole. The correlations usually put forward are merely formal and not real. Stratigraphically the one thing we can generally recognize definitely is the series, the lower portion of which, from several feet to several thousand feet, is usually terrigenous and is distinguished from underlying beds, either by unconformity, distinctive fauna, or marked change in depositional type. It was brought to a close by an unconformity representing important orogenic movements throughout the whole California coastal region, or at least throughout the whole region in which its deposition had taken place. It represents, in fact, a depositional cycle, and emphasis should be placed on the series as a whole, and a single name should be used to designate it. It represents historically, areally, and economically one of the important periods of deposition in West Coast geologic history, and to be appreciated it should be presented as a major stratigraphic unit—which it is. Its most important relationships and essential characteristics are lost when it is presented merely as two or more different "formations." The name "Monterey Series" was proposed some years ago²⁰ by Lawson,

²⁰ Univ. of Calif. Bull. Dept. Geol., vol. I, pp. 1-59 (1893).

and has been used by him and some others consistently ever since for the rocks of this depositional cycle. It will be used in this paper in the further discussion of the subject.

The Vaqueros sandstone, the Monterey shale, the Modelo sandstone, are mere depositional facies, and while rocks designated by any of these names may be analogous in different localities, they are frequently not correlative. The "Modelo formation" is an artificial and, as far as evidence goes, meaningless group, not even applicable throughout the region of the Santa Clara Valley oil fields and it should be abandoned.

PART II

CRITICAL REVIEW OF OUR KNOWLEDGE OF THE MONTEREY SERIES IN CALIFORNIA AND HISTORY OF ITS NOMENCLATURE

PURPOSES

In the light of the ideas developed in Part I of this paper, it is proposed to review critically the literature that has had most influence on present day conceptions of the California Middle Tertiary, with the purpose (1) of determining if possible the extent to which these ideas will apply to other areas; (2) of critically examining the evidence presented for various other interpretations and the bases for the diverse nomenclature; (3) of bringing out the main characteristics of the Monterey series in the different areas in which it has been studied.

EARLY NOTICES—PREVIOUS TO 1893

Probably the first reference that occurs in the literature to the most peculiar member of this series is in an article by W. P. Blake, published²¹ in 1855 and entitled "Notice of Remarkable Strata containing the remains of Infusoria and Polythalamia in the Tertiary Formation of Monterey, California." This is frequently referred to as the paper in which the formational name

²¹ Proc. Acad. Sci., Philadelphia, vol. 7, pp. 328-331 (1855).

“Monterey” was first definitely given and defined. It is a historically interesting paper in that it is the first notice of that type of deposit that is so widespread and important, both geologically and economically, in California—the siliceous, chiefly diatomaceous, earths and shales. A careful reading, however, shows no intention to either name or define any stratigraphic unit,—the whole purpose was to announce the occurrence in thick deposit of this remarkable type of strata. A partial section is given, the lowest member of which was not estimated as “it extends downward under the chamisal for a long distance.”

“This interesting formation, teeming with the skeletons of microscopic organisms, appears to overlie and to be conformable with the tertiary strata that underlie a part of the town of Monterey and extend to and beyond the Mission of San Carlos. These strata rest upon a porphyritic granite” (p. 330). These latter strata are said to contain fossil shells, the more abundant of which Conrad described and named *Tellina congesta*, which at San Carlos is associated with *Lutraria Traskii*, also a new species.

“A stratum of the Monterey formation similar in texture to the stone which is used for buildings, but different in color, also contains casts of *Tellina congesta* in great numbers” (p. 331). This is the only mention Blake makes of “Monterey formation,” or any similar expression, and it is evident from the context that he was not naming a stratigraphic unit, but simply meant the formation or type of material at Monterey—a mere locality designation—a common practice among the geologists who explored the west at that period and for 20 or more years later.

As further evidence of this, it may be noted that Blake published two *geological* descriptions of the territory about Monterey the following year (1856), without once mentioning these rocks by such a designation. In the Pacific Railroad Report,²² he described them as “the Tertiary formations,” and uses the term Monterey only in the following expressions, “the base of the formation at Monterey,” “A stratum of the Monterey rock”

²² Reports of Explorations and Surveys to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean. Vol. 5 (1856), Part II, Chapter XIII, esp. pp. 180–182.

(p. 180). In the Report of the Superintendent of the Coast Survey,²³ they are again called "Tertiary Strata" (p. 391), and Monterey is only used in the expression "strata about Monterey." In Map no. 59, the formations in the "Vicinity of Monterey Bay" are plotted, and the strata under discussion are mapped as "Tertiary," not as "Monterey shale" or other similar designation, although in Map no. 58, of San Francisco harbor, the "San Francisco Sandstone" is so designated and "Tertiary" written after it. This is really not a very important point, and would not here be discussed were it not that in several publications of the U. S. Geological Survey²⁴ it is distinctly stated that the "Monterey formation" (as a stratigraphic unit) was named and described in the paper above referred to.

These formations were also referred to or described by other early geologists, such as Trask,²⁵ Whitney,²⁶ and Becker,²⁷ who generally referred to their most characteristic type as bituminous "slates."

DECADE 1893-1903: RECOGNITION OF SERIES AS STRATIGRAPHIC UNIT AND EXTENSION OF KNOWLEDGE OF ITS AREAL DISTRIBUTION

Carmelo Bay, Lawson, 1893.—The first definite application of a local name to the series as a stratigraphic unit was made by A. C. Lawson in "The Geology of Carmelo Bay," published in 1893.²⁸ "The Miocene formations are abundantly developed . . . The series was among the first which attracted the attention of the earlier writers, Trask and Blake, and it has since become famous for the 'infusorial' remains which it contains, being known to collectors as the Monterey formation."²⁹ This name,

²³ Report of the Superintendent of the Coast Survey showing the progress of the Survey during the year 1855 (1856), Appendix no. 65, pp. 390-392.

²⁴ Bull. 191 (1902), Prof. Paper 47 (1906), Bull. 321 (1907), Bull. 322 (1907).

²⁵ Report on the Geology of the Coast Mountains, etc. Assembly Journal, 5th Session, 1854, Legislature, State of California, Appendix, doc. no. 9; 6th Session, 1856, Appendix, doc. 14.

²⁶ California Geological Survey, Geology, vol. I (1865).

²⁷ U. S. Geol. Surv., Bull. no. 19 (1885); Monograph 13, p. 185 (1888).

²⁸ Bull. Dept. Geol. Univ. of Calif., vol. 1, pp. 1-59 (1893).

²⁹ In the meaning given by collectors and prospectors, formation means any type of deposit or product—really a rough petrographical term, as "stalactite formation," "lime formation."

under the form of the '*Monterey series*' will be adopted as the local designation of the series" (p. 7).

That by "local designation" he meant to include the whole depositional province, is shown by the statement: "The rocks of the Monterey series, as displayed in the vicinity of Carmelo Bay, are representative of the Miocene wherever it occurs for several hundred miles along the coast of California" (p. 22). A rather full description and discussion of the origin and relationship of the series follows, and it is plotted on the map of Carmelo Bay, Plate I, as the "Monterey Series (Miocene)."

That it was not intended to so designate merely a lithologic type is indicated by the following: "Near the base of the series at the town of Monterey there are some sandstones. There are also occasional lenses of a dense yellowish to mauve-colored fossiliferous limestone, and . . . there are some beds which are both calcareous and gritty" (p. 24). Volcanic ash is also described in the series.

A list of fossils is given as determined by Dall, in addition to those reported by Blake, and the conclusion reached that the series is Miocene.

Point Sal, Fairbanks, 1896.—In 1896, Fairbanks³⁰ described representatives of this series from Point Sal under the designation "Miocene." He notes 1000 feet of "bituminous shales" carrying *Pecten peckhami* Gabb, including limestone, calcareous sandstone, marly rocks and flints, below which are "gypsiferous clays" 1800 feet, three strata of ash, and finally 2000 feet of soft sandstone, shale, and conglomerate.

Santa Catalina Island, W. S. T. Smith, 1897.—In 1897 W. S. T. Smith described³¹ diatomaceous Miocene shale, volcanic tuff and limestone on Santa Catalina Island, associated with *Tellina congesta*, Conrad. The diatom remains were discussed by G. J. Hinde.

San Clemente Island, W. S. T. Smith, 1898.—In 1898 he described "Miocene" beds on San Clemente Island,³² beginning as sandstones and passing into yellowish to grayish white shales,

³⁰ Bull. Dept. of Geol. Univ. Calif., vol. 2; see pp. 9-18 (1896).

³¹ Proc. Calif. Acad. Sci., 3rd Ser. Geology, vol. 1, no. 1 (1897).

³² U. S. Geol. Surv., 18th Annual Rept., 465-496 (1898).

the bulk of which consists of diatoms, associated with radiolaria and foraminifera, and showing abundant impressions of *Pecten peckhami* Gabb.

Southern Coast Ranges, Fairbanks, 1898.—In the same year, Fairbanks published a general account of the Geology of the Southern Coast Ranges,³³ particularly in the vicinity of San Luis Obispo, in which he describes the “Monterey series (Lower Miocene). With the beginning of the Neocene a subsidence commenced and continued through, or nearly through the Miocene. Finally, almost the whole Coast Range region was submerged and a thickness of rocks in many places of more than 7000 feet was deposited. The most characteristic feature of the series is the bituminous shales. They form its upper portion and reach a thickness of 5000 feet. Below them are limestones, clays, volcanic ash, sandstones, and conglomerates. . . . The sandstones and conglomerates at the bottom of the series are most prominently developed in the region lying east of the Rinconada Valley, between it and the main granite range” (p. 561).

Point Reyes Peninsula, F. M. Anderson, 1899.—In a paper on the geology of the Point Reyes³⁴ Peninsula, 1899, F. M. Anderson describes the there developed representative of this period of deposition under the head of “Miocene Sediments,” consisting of conglomerates up to 300 feet thick, resting on the granite, and occasionally very coarse, followed everywhere by light yellowish sandstones and then whitish, thin bedded siliceous shale. The latter is said to be the “white Miocene shale of the Monterey series, well known in the Coast Ranges.” On the Point Reyes peninsula “The series is entirely conformable, and doubtless all belongs to the same period of sedimentation.”

Coast Range Bituminous Rock Districts, Eldridge, 1901.—In 1901 (or 1902) Eldridge published a general survey of “the Asphalt and Bituminous Rock Deposits of the United States”³⁵ in which the Monterey rocks of California were given the following general description.

³³ Jour. of Geol., vol. 6 (1898), this series described pp. 561–563.

³⁴ Bull. Dept. Geol. Univ. Calif., vol. 2, pp. 119–153. Miocene, pp. 134–141.

³⁵ U. S. Geol. Surv., 22d Annl. Rept., Part I, pp. 209–452. The main points of this paper were presented later in Bull. 213, pp. 296–305, 1903.

“Lower Neocene (Monterey).—The rocks of this age usually embrace a heavy body of sandstones, conglomerates, and shales at the base, in which the form *Ostrea titan* is often found; overlying these in some places is a body of gypsiferous clays that, in the region of Point Sal, for example, attains a thickness of nearly 2000 feet; above all is the salient feature of this series, a great body of more or less siliceous shales, everywhere of considerable thickness and locally embracing at least 2000 or 3000 feet. This succession is not, however, strictly adhered to at all points. The formation is distributed the entire length of the Coast Range from Cape Mendocino to beyond Los Angeles. It borders the coast and occurs in the interior, forming a conspicuous terrane along the great valley of California drained by the San Joaquin and Sacramento rivers.”

A few of his local descriptions will be referred to. “Monterey shale” was described from the Santa Cruz district. “For the Coast Range, in general it has already been stated that the lower portion of the Monterey frequently consists of sandstones. The sands here referred to” (in local description) “may be the equivalent of these; or, on the other hand, it may be that they are simply a shore deposit of uncertain age laid down prior to the deposit of the Monterey shale, and derived in large measure from the adjoining granite or brought into their position by coastwise currents” (pp. 383, 384).

The Monterey was also reported and briefly described from the Salinas Valley region, San Luis Obispo district, the Santa Maria district, Los Alamos district, the southern coastal strip of Santa Barbara County, the Chino district (Puente Hills), and the Asphalto district (McKittrick). In many of these localities it is said to lie unconformably below the “San Pablo (Middle Neocene).” Sandstones are often reported as intercalated in the shales, or at the base of the shales and either definitely or doubtfully referred to the Monterey.

Point Arena District.—As Eldridge’s is the only published account of the Point Arena district, it is presented here in more detail than the other districts mentioned.

“This district embraces a small area of Monterey shale lying along the coast about 110 miles north of San Francisco. The

shales form a low, rolling bench between ocean and Coast Range, 2 or 3 miles wide, and from 100 to 200 feet above the sea at the shore to 300 or 400 at the base of the range proper. The bench is cut transversely by streams from the mountains, and along them the shales are well exposed, displaying several folds with axes trending N. 50° W."

"The shales of the Monterey in this locality are interlaminated with sandstones varying in thickness from a foot or two up to 30 or 40.—The shales are brown on fresh fracture, weathering to a greenish-gray; they are also clearly bituminous, not only for the locality in question but along the whole of this portion of the coast" (p. 379).

Berkeley Hills, Lawson and Palache, 1902.—In 1902, Lawson and Palache published³⁶ the Geology of "The Berkeley Hills," in which is described "The Monterey Series," resting unconformably on the Chico (upper Cretaceous), and composed chiefly of siliceous shales and cherts carrying *Tellina congesta*, *Pecten peckhami*, fish scales and foraminifera. The series also is said to contain sandstones and limestones, the former carrying unrecognizable species of *Tapes*, *Cytherea*, *Anthomya*, *Macoma*, *Lucina*, *Tellina*, and *Neverita*. Furthermore, "it should be observed that this formation, as exposed on Skyline Ridge, does not represent the entire Monterey series. The series in Contra Costa County, only a few miles to the eastward, is made up of an alternation of four fossiliferous sandstone formations and three formations of 'bituminous shale,' aggregating in all several thousand feet in thickness" (p. 367).

Middle Coast Ranges, Lawson, 1903.—This Contra Costa County Section had been presented by Professor Lawson before the Cordilleran Section of the Geological Society of America³⁷ in December, 1901, as follows:

Monterey	Upper	Stage 7, sandstone, 1800 ft.
		Stage 6, bituminous shale, 670 ft.
	Middle	Stage 5, sandstone, 1200 ft.
		Stage 4, bituminous shale, 1400 ft.
		Stage 3, sandstone, 600 ft.
	Lower	Stage 2, bituminous shale, 250 ft.
		Stage 1, sandstone, 400 ft.

³⁶ Univ. Calif. Publ. Bull. Dept. Geol., vol. 2, see pp. 363-371.

³⁷ Geological Section of the Middle Coast Ranges of California, Bull. Geol. Soc. Am., vol. 13, pp. 544-545 (1903).

San Pedro, Arnold, 1903.—In 1903, Ralph Arnold,³⁸ in “The Palaeontology and Stratigraphy of the Marine Pliocene and Pleistocene of San Pedro, California,” stated that “The oldest formation exposed in the immediate vicinity of San Pedro is the Miocene, or Monterey series. The shales of this formation are exposed along the sea cliff in the eastern end of San Pedro Hill and also on Deadman Island” (p. 12).

Petroleum Districts, Eldridge, 1903.—In Contributions to Economic Geology for 1902,³⁹ Eldridge gave an outline of the geology of the various oil districts of California. He described formations referable to the Monterey series in the following localities: Coalinga (“100 or 200 feet of clays and sandstones that may prove to be Lower Miocene; 200 feet of siliceous shales typical of the Monterey (Upper Miocene)”); McKittrick (“principally of siliceous shales with their chalky, earthy, or more argillaceous modifications”); Sunset (“local developments of gritty sands, brown and yellow limestones, and gypsiferous clays, perhaps a lower division of the Miocene, the upper division consisting of siliceous shales, typical of the Monterey”); Kern River Field (called Lower Miocene); La Graciosa District (Monterey shale); Summerland Field (siliceous shales of the Monterey); Santa Clara Valley (Lower Miocene, and Monterey shales); Los Angeles Field (siliceous shales of Monterey type); Puente Hills (“Lower Miocene, and Monterey”).

It is to be noted that while Eldridge definitely refers certain formations in these fields to the Monterey (or to the Monterey shale), yet he suggests that certain underlying sands or shales may be Lower Miocene and *therefore* older than the Monterey. This foreshadows the erection of a separate formation group and name for these lower beds that is definitely put forward by others the following year.

General Character of Decade 1893–1903.—We see, then, that from 1893 to 1903 the unity of the series was accepted by the various workers in California Tertiary geology, the name Monterey for the whole series was the only local designation used, and its areal distribution was recognized along the coast from Point Arena to San Clemente Island.

³⁸ Calif. Acad. Sci. Memoirs, vol. 3 (1903).

³⁹ U. S. Geol. Surv. Bull. 213, pp. 306–321, 1903.

A few of the workers used the term Miocene instead of Monterey, although all believed that it represented the same series and displayed everywhere the same peculiar lithologic types which up to that time were considered characteristic of the Monterey period of deposition in the California coastal province.

Advantage of Local (Provincial) Name.—Even at that time it was evident that the term Monterey was preferable to Miocene, because the former designated definitely a series of deposits, representing a depositional period in a certain province of sedimentation, while the latter represents a time interval referred to a far distant standard and not necessarily coextensive in time with the period of deposition here under consideration. Its determination as Miocene is dependent upon the estimated relation and meaning of faunal characteristics, the interpretation of which has varied up to the present and will probably continue to vary. Furthermore, J. C. Merriam had already in 1898 described the San Pablo formation,⁴⁰ which in Contra Costa County and, as since determined, at many other localities, overlies the Monterey. This series, originally referred by Merriam to the “middle Neocene,” has been considered by some to be Pliocene, and by others upper Miocene—this latter view being probably the prevailing one among palaeontologists at the present time. Throughout the Coast region, wherever it comes in contact with the Monterey, it is believed to rest upon the latter unconformably, and over considerable areas the unconformity is very marked and represents a considerable amount of orogenic disturbance. If we accept the Miocene age of the San Pablo, therefore, the Monterey, the period of orogenic disturbance, and the San Pablo would all be included under the designation Miocene.

PERIOD OF 1904 TO THE PRESENT (1912)

Opening of the Period.—The year 1904 was very prolific of publication on the California Miocene and marked the beginning of the dismemberment of the Monterey series and the multiplication of formational names, both within the limits of this series and throughout all the Tertiary terranes, so that after a

⁴⁰ Bull. Dept. Geol. Univ. Calif., vol. 2, no. 4, May, 1898.

few years the array becomes confusing and rather discouraging to one who wishes to acquaint himself with the real essentials of the geological history of that time.

Salinas Valley, Hamlin, 1904.—It was Homer Hamlin who suggested the term “Vaquero sandstone” for the sandy lower portions of the Monterey series in the Salinas Valley region. In 1904 in a paper on the Water Resources of the Salinas Valley, California,⁴¹ he defines it as follows: “Vaquero sandstone.—In the Salinas Valley, the Vaquero sandstone is a well defined formation. So far as observed in this region it rests unconformably on the Basement complex and on stratified terranes older than the Neocene, being thus in this locality the oldest known member of the Neocene; in other localities Neocene formations are found below the Vaquero sandstones, indicating that it is not the basal member of the Neocene.

“The Vaquero formation is a rather coarse, uniformly gray, white or light-yellow quartzose sandstone with an occasional stratum of granitic pebbles. It is of great thickness along the eastern slope of the Santa Lucia range, especially in Los Vaqueros Valley; hence the designation proposed by the writer for this series of sandstones. . . . The following fossils have been found in the Vaquero sandstone: *Balanus*, sp. ?; *Mytilus*, sp., probably *matthewsonii* Gabb; *Ostrea tayloriana* Gabb (Young) ?; *Ostrea titan* Conrad ?; *Pecten magnolia* Conrad; *Turritella hoffmanni* Gabb ?; *Chione matthewsonii* Gabb; *Chione* n. sp. (large, characteristic of this horizon); *Mactra* aff. *catilliformis* Conrad; *Pecten estrellanus* Conrad; *Pecten* (Chlamys) n. sp., S.; *Pecten* (*Plagioctenium*) n. sp. A.”

San Luis Quadrangle, Fairbanks, 1904.—Fairbanks adopted Hamlin’s nomenclature for the San Luis Folio, which was published (appearing in fact earlier) the same year. He places in the “Vaquero Sandstone” that lower portion of the series which is made up of sandstone and conglomerate “because of their extensive occurrence on Los Vaqueros Creek.” Beyond the quadrangle it reaches a great thickness, especially “along the southern side of the granitic area.” It may be 5000 to 6000 feet thick.

⁴¹ U. S. Geol. Surv., W. S. and Irrig. Paper no. 89.

Within the quadrangle itself it varies only up to about 500 feet in thickness.

The "Monterey shale" includes the clay shales and limestones, and the siliceous shales in all from 5000-7000 feet thick. He considers that it lies *conformably* over the Vaquero sandstone, and states that "it seems probable that these sandstones and conglomerates were in origin, partly at least, contemporaneous with the bituminous Monterey shale, the former representing the shore deposits, and the latter representing deposits formed at a considerable distance from land." The "Monterey shale" is also shown to contain volcanic ash beds. The conformable series, Vaquero sandstone—Monterey shale, is separated from both earlier and later deposits by marked unconformities.

It will be noted that the separation of the series is on a purely lithologic basis, and the Vaquero sandstones of one part of the field are believed to be contemporaneous and to have originally graded laterally into the Monterey shale in another part. They are, therefore, merely depositional facies of the same series of deposits, as believed by the present writer. The unfortunate thing about Fairbanks' work is that he omitted the outward sign of the essential unity that he believed in—the name of the series as a whole, and presented it in his columnar section as two separate entities, representing two different periods of deposition, which idea his descriptions oppose.

San Mateo County, Haehl and Arnold, 1904.—In this same year (1904) Haehl and Arnold in discussing the "Miocene Diabase of the Santa Cruz Mountains in San Mateo County, California,"⁴² presented these two divisions as representing different time intervals,—different faunal stages. They described "the lower Miocene" as "a series two or three thousand feet thick of massive, coarse, yellowish sandstone layers, interbedded with a few layers of varying thickness of dark colored argillaceous shale, the whole overlain by three or four hundred feet of thin bedded siliceous shales. The lower part of this series of beds, including most of the sandstone, appears to have the same fauna and occupy the same stratigraphic position as the Vaquero sandstone of the Salinas Valley. The name 'Vaquero' will, therefore, be used

⁴² Proc. Am. Phil. Soc., vol. 43, pp. 16-53 (1904).

to designate the lower Miocene sandstone in the area under discussion" (p. 19). A fossil list, the most complete published up to that time, is given with those fossils supposed to be characteristic of this horizon indicated by asterisks.

Returning to the overlying shales, they say "These shales represent at least a part of the Monterey series,⁴³ which is supposed to be of middle Miocene age" (p. 20). A list of fossils is given for the Monterey and those characteristic of the horizon designated. It is said, however, "The upper part of the Vaquero sandstone series, at least that part showing alternating beds of sandstone and shale with a tendency to grade from sandstone vertically upward into shale, may be the inshore equivalent of some of the Monterey shale found at the typical locality in the region around Monterey." The faunal character of this overlapping portion is not explained.

The Formation-Faunal Stage Fallacy.—Irrespective of whether we agree or do not agree with Haehl and Arnold's determination of the particular beds in San Mateo County as "lower Miocene" and "middle Miocene" respectively, this idea of the "Vaquero sandstone" and the "Monterey shale" as representing two different time intervals determinable by fossils paved the way for much confusion which actually followed. The fundamental trouble lay in this idea: These formations, where studied, could be divided lithologically into two groups called by two formational names; palaeontological studies showed that there were two distinguishable faunas supposed to represent two different time intervals; therefore these two faunas correspond to the two "formations," which latter must then have been deposited in these two different periods of time. The far-reaching effects of this fallacy will be shown in following the later history.⁴⁴

⁴³ Thus using Monterey series not in accordance with its previously established usage, but corresponding to the "Monterey shale" of Hamlin and Fairbanks.

⁴⁴ As far back as 1895, G. H. Ashley had published in the Proc. Cal. Acad. Sci., 2d Series, vol. 5, pp. 273-367, and in brief form in Jour. of Geol., vol. 3, pp. 434-454 (1895), a discussion of the "Neocene Stratigraphy of the Santa Cruz Mountains of California," in which he attempted to establish two series—the Pescadero and the Monterey-Merced. He considered each of these to be a practically conformable series with perhaps slight local breaks in them. In the former he included stratigraphically the San Francisco sandstone of Telegraph Hill and other parts of San Francisco, and of San Bruno Mountain (generally accepted as

San Pablo and General, Merriam, 1904.—In the same year, J. C. Merriam⁴⁵ in "A Note on the Fauna of the Lower Miocene in California" was careful to regard the distinction between lithological types, faunal facies and faunal zones. He said: "One of the most characteristic phases of the Miocene in California is the Monterey shale. The fauna of this formation, as we know it, is limited to foraminifera, radiolaria, fish, cetaceans, a crustacean and a few mollusca. Among the last, *Pecten peckhami*, the indefinite *Tellina congesta* and a *Leda* are the most common forms. The fauna belongs to a deep water facies and must not be confused with the faunas of sandy, shallow water deposits. At many places where sandstone is interstratified with the shales, a very sudden change of the fauna is noticed, nearly all of the typical shale species dropping out, but reappearing in shaly layers above" (p. 377).

Depositional and Faunal Facies.—If we take this statement in connection with the fact that in western Contra Costa County, as had been shown by Lawson in the section quoted above, p. 199, the Monterey series is made up of a succession of sandstones (Vaquero type) and bituminous shales (Monterey type), and

Mesozoic, possibly Jurassic), the sandstones and shales of Pt. San Pedro (recently shown to be Eocene), the conglomerates and sandstones exposed between Pescadero point and Pigeon point, said to be the best developed part of the series and from which apparently it received its name (classed in the Santa Cruz Folio, 1909, as Chico Upper Cretaceous), and various other sandstones, including those called Vaquero by Arnold and Haehl. From palaeontological evidence he considered the series partly Miocene and largely Eocene (?). He was inclined to believe that the "Metamorphic" rocks of the San Francisco peninsula were part of the series, but separated them as a concession to current geological opinion. He also considered the Monterey (Miocene) and the Merced (Pliocene) as forming a conformable series.

Such a system which grouped together formations belonging to entirely different and differently conditioned periods of sedimentation and so widely separated in time and by widespread and important unconformities, and which placed the chief division of all the formations from Mesozoic to Quaternary in the midst of a conformable series (the Monterey Series) was so evidently out of touch with the facts that it found no adherents and had practically no direct effect on the development of the understanding and nomenclature of the Tertiary formations. It may, however, be looked upon as sowing the seed that led to the use of palaeontological criteria for dividing the Monterey Series into two formations and that bore its first fruit in the paper above discussed.

⁴⁵ Bull. Dept. Geol. Univ. Calif., vol. 3, no. 16, pp. 377-381, March, 1904. This paper, treated here in the order convenient for logical discussion, was in reality the first paper on the California Miocene to appear in 1904.

that in a section 4280 feet thick the Monterey shale type occurs within 400 feet of the bottom, and within 1800 feet of the top, and also in the middle part of the section, and that when it recurs its fauna recurs, we have a key to the proper understanding of the Monterey series. The shale with its fauna may occur practically at any part of the series, if the conditions of deposition (and therefore of faunal environment) are favorable. It does not correspond to a faunal time zone, except to the general zone of the Monterey series deep water fauna. Its relationship to shallow water faunal zones can only be determined if it contains frequent intercalations of fossiliferous littoral sands. The faunas generally published as of the "Monterey shale" stratigraphic formation are mixtures of the Monterey Series "shale fauna" and that of occasional littoral sands from the upper part of the series. As example, it may be noted that the faunal list just referred to as given by Haehl and Arnold for the Monterey shale contains all the forms given by Merriam for the "shale fauna" and found apparently in the "Vaquero" zone as well as in the upper part of the series. It merely happens that in the areas studied by Fairbanks, Haehl and Arnold, the lower part of the series is chiefly sand (or conglomerate), and therefore does not carry the "shale" fauna, and that after the shale appears it shows no more fossiliferous sands to the top of the series—so that the "Vaquero" fauna is not found intercalated in the supposed later fauna.

Faunal Zones.—That the littoral deposits of the series do show faunal zones is brought out by Merriam in the paper just referred to. "The upper division has its nearest affinities with the San Pablo, from which it can be distinguished by the presence of *Clypeaster* (?) *brewerianus*, *Trochita costellata*, several new species of *Modiola* and other forms." "The fauna of the lower division is much more characteristic than the upper: that is to say, it differs more decidedly from that of the beds immediately above and below it" (p. 378). He gives a faunal list and proposes that it be called the zone of *Agasoma gravida*.

Turning then to a general discussion of the formations in the southern portion of the State, he concludes that the *Agasoma* zone is widely developed and suggests that it may be divisible

into two horizons—the zone of *Turritella hoffmanni* and that of *T. ocoyana*, the former being the older, and as it is not found to the east of the Great Valley, it may mean that “the sea had not reached as far east in the earliest Miocene as it did later, and that the thick shale beds over the lower sands of the western region were formed while sandy *T. ocoyana* beds were being deposited in the east” (p. 381).

Southern Coast Ranges, F. M. Anderson, 1904.—F. M. Anderson this same year presented in abstract form⁴⁶ the “Stratigraphy of the Southern Coast Ranges of California,” with special reference to the interior ranges. He makes use of the twofold division, calling the lower the Pescadero sandstones (after Ashley), which he says reach a thickness of 11,000 feet, in the Carrisa [Carrizo] Valley of 14,000 feet,—alternating sandstones and shales, the former predominating; and the upper, the Monterey shales, 3400 feet, including 200 feet of sandstone, and some volcanic ash.

Coalinga Region, F. M. Anderson, 1905.—The following year Anderson published⁴⁷ a “Stratigraphic Study in the Mount Diablo Range of California,” dealing especially with the territory in the vicinity of Coalinga and south. He recognized the Monterey shales, which he claimed were 5500 feet thick at Carnera [Carneros] Springs, below which are sands and shales.” In the light of stratigraphic studies farther north, it is evident that the entire series of sands and shales below the Monterey Shales should be regarded as a distinct member of the Miocene, and the name *Temblor Beds* is suggested to embrace this aggregate of strata” (p. 170). Various lists of fossils are given for different localities, many forms of which correspond to the “Vaquero sandstone” list given by Haehl and Arnold, and to Merriam’s Agasoma zone (*Turritella ocoyana* stage), while some appear more like the “Monterey shale” types of Haehl and Arnold. As Anderson materially revised his stratigraphy in a later paper, further discussion is postponed until the later report is taken up. For the present the point to note is the introduction of the term “Temblor” as a stratigraphic unit, supposed to be

⁴⁶ Geol. Soc. Am. Bull., vol. 15, pp. 581–582 (1904).

⁴⁷ Calif. Acad. Sci. Proc., 3d series, Geology, vol. 2, pp. 155–248 (1905).

characterized by a definite fauna, representing a definite time interval. Its correlation with formations in other parts of the State is hinted at, but not definitely stated. Anderson refused to compare it with the "Vaquero sandstones" of the Salinas Valley, because they "lack thus far any faunal description" and Fairbanks' correlation of these with "beds occurring south of the Santa Lucia Range is not supported by any faunal evidence." He made no reference to the Pescadero series, nor in his later publications does he ever refer to it again. Nor is it used by any other writer.

California Formations and Faunas, Arnold, 1906.—In 1906 Arnold published a monograph on the "Tertiary and Quaternary Pectens of California,"⁴⁸ in Part I of which he presented the California post-Cretaceous geologic column, defined briefly the standard formations, listed their faunas and indicated their supposed characteristic species.

He emphasized the fallacy that was discussed above (p. 204) by making the "Vaqueros sandstone"⁴⁹ a definite formation *underlying* the "Monterey shale" and equivalent to the "Agasoma zone." From the list of localities given it is evident that he considered the lower Miocene beds of Contra Costa discussed by Merriam, the Salinas and Los Vaqueros Valley beds described by Hamlin, the sandstones of the San Luis region discussed by Fairbanks, the Temblor beds of Anderson, the Santa Cruz Mountains beds previously described by himself and Haehl, the Poso Creek beds (Ocoya Creek beds of Blake and others) of the Sierra Nevada foothills, and various deposits in southern California, as being *Vaqueros* or representing the horizon of the Agasoma zone.

He described the "Monterey shale" as a "very characteristic shale formation . . . underlain conformably by the Vaqueros sandstones at most localities, but at a few it rests directly upon older rocks." The faunal list is made to include some forms "found both below and above it, or in its included sandstones." Of the definitely determined species given, it may be noted that

⁴⁸ U. S. Geol. Surv. Prof. Paper, no. 47 (1906).

⁴⁹ From this time forward, without any particular explanation, the form *Vaqueros* replaces *Vaquero* in the literature, apparently to conform to some rule of etymology.

they are either characteristic of the "shale facies" or are found in the Vaqueros (or Temblor, which he considers equivalent). He admitted that "As suggested by Doctor Lawson, the shale probably has an inshore equivalent of sandstone, whose fauna is doubtless entirely different from that of the shale and *probably shows a marked resemblance*⁵⁰ to that of the underlying Vaqueros and overlying Contra Costa County Miocene." This hypothetical marked resemblance is, however, apparently not considered to amount to identity, and the two depositional facies are presented as independent formations representing different time intervals. The upper faunal zone of the littoral facies described by Merriam (*loc. cit.*) is evidently misinterpreted as a formation "lying between the Monterey shale and the San Pablo," and called by Arnold (supposedly after Merriam, though I can learn of no such usage) the "Contra Costa County Miocene."

Santa Clara Valley Oil Fields, Eldridge and Arnold, 1907.—The year 1907 produced a rich harvest of California Tertiary literature in the form of bulletins on the oil districts of the Southern Coast Ranges. The first⁵¹ of these was on "the Santa Clara Valley, Puente Hills and Los Angeles Oil Districts." The part on the Santa Clara Valley district has already received considerable attention in Part I of the present paper and need not be discussed at length here. It is noteworthy in adding to the Vaqueros sandstone the terrigenous shales and limestones and a certain fraction of the siliceous shales (all previously assigned to the Monterey by Fairbanks and others) because in the lower part there was found within them a "Vaqueros fauna," the name being appropriately changed to "Vaqueros formation"; and in the creation of a "Modelo formation" including the residue of siliceous shales and certain intercalated sandstones, the base of the Modelo being placed at "the sharp line" between the underlying siliceous shale and the Modelo sandstone. However, on the south of the valley and in the western part of the field, the line is drawn between siliceous shale and underlying terrigenous beds following the usage of others. This field is a

⁵⁰ Italics not in the original.

⁵¹ U. S. Geol. Surv. Bull., 309 (1907).

good example of the impossibility of practically applying the faunal division idea, and the inconsistency to which the mixed notion of faunal and formational unity of the Vaqueros may lead.

Puente Hills, Eldridge, 1907.—In the section on the Puente Hills Oil District,⁵² by Eldridge, a new term is introduced for what is evidently the local representative of the Monterey series—the Puente formation. This is said to be “the equivalent of at least a part of the Modelo formation, and possibly including some of the Vaqueros” (p. 103).

The “Puente formation” is said to consist of 2000 feet of shale, chiefly earthy but with minor siliceous layers and some thin sandstone layers and limestone lenticles; followed by a heavy bedded concretionary sandstone, 300 feet in the western part of the hills, 1000 feet in the eastern portion; and wanting in the southern portion; then 300–400 feet of siliceous shale with a few sandstone beds and quartzo-calcareous concretions. The relations of this massive concretionary sandstone to the over- and underlying shales suggests strongly the relation of the massive concretionary Modelo sandstone of the Santa Clara District to its over- and underlying shales. And its rapid thinning out and perhaps disappearance towards the sea is remarkably suggestive of the Modelo conditions.

Eldridge hesitates to finally accept the equivalence of the Puente to the “Monterey” (using this in the sense of “Monterey shale” of Arnold, for example) because of “the marked lithologic similarity of portions of the lower division of the Puente formation to certain strata in the Santa Clara Valley and elsewhere in the Coast Range that have been determined by their fossils to be lower Miocene and possibly Oligocene—lower than the Monterey.” Here again we have the formation-faunal stage fallacy. Nevertheless “from geologic conditions to the south of the Puente Hills in the Santa Ana Range, however, the writer is inclined to consider the entire succession of beds described above as the local equivalent of the Monterey.” As in the Santa Clara Valley, this series underlies the “Fernando formation” unconformably.

⁵² *Loc. cit.*, pp. 102–137.

Los Angeles, Arnold, 1907.—In the part dealing with “the Los Angeles Oil District,” Arnold⁵³ uses the same term Puente, and divides the Miocene representatives into the “Puente sandstone” and the “Upper Puente shale.” These he believes to correspond to the deposits of the same name in the Puente Hills. But his Puente sandstone here is fossiliferous and yields a fauna that he considers to be characteristic of the “lower Miocene throughout the southern San Joaquin Valley and as far south as the Santa Ana Mountains” and “equivalent⁵⁴ in general to the Vaqueros sandstone of central California.” It apparently corresponds to the Agasoma zone and the stage of *Turritella ocoyana* and *T. variata*.

The lower portion of the “Puente sandstone” is described as argillaceous, and as possibly equivalent to the “lower Puente shale” of the Puente Hills.

The “upper Puente shale” is said to consist of alternating sandstones and shales throughout, the lower 1000 feet being thick bedded and grading into the Puente sandstone with “no sharp line of demarcation,” the upper thousand feet thin bedded. Most of the shale in the lower part of the “Upper Puente shale,” and also “many of the shale beds interstratified with the *Puente sandstone*,⁵⁵ are of the hard white siliceous variety characteristic of the Monterey shale in the Coast Range.” They carry abundant remains of micro-organisms.

We have here then a continuous series of deposits at least 4000 feet thick, carrying sandstones from top to bottom and interbedded throughout with clay shales, and siliceous shales of the Monterey type, the sandstones more abundant in the lower portion, but a 50-foot stratum at the top, the lower sandstones more or less fossiliferous and showing a fauna similar to the Vaqueros of the central ranges. Thus again we get repetitions of “Monterey shale” and “Vaqueros sandstone” in a way similar to the western Contra Costa County area already described.

⁵³ U. S. Geol. Surv. Bull. 309, pp. 138–198 (1907).

⁵⁴ The correlation table on p. 143 of that bulletin does not agree with the description in the text.

⁵⁵ Italics not in original.

Summerland District, Arnold, 1907.—In the “Geology and Oil Resources of the Summerland⁵⁶ District” which appeared this same year, Arnold describes the “Vaqueros formation” and the “Monterey shale.” These designations were used and were easy of application because the territory studied lies within that coastal belt where the Monterey period of deposition opened with a sandy facies with subordinate shales (785 feet thick in the locality described) graded into predominant clay shales with calcareous shales and concretions (1650 feet near Summerland) and finally into dominant diatomaceous shales and siliceous cherts with occasional ash beds. The lower sands and terrigenous shales are said to contain no characteristic fossils, but their “stratigraphic position and lithologic similarity” to the fossiliferous beds already described in the Santa Clara District “leave no doubt in the mind of the writer as to its correct correlation” with the Vaqueros. The dominant diatomaceous shales in the upper part of the series are called “Monterey shale” and contain besides the microscopic organisms a few species of the shale fauna of Merriam. Here we return to the distinction based on lithologic types, but divided as in the Santa Clara District (and not as originally by Fairbanks farther north) for reasons already discussed.

Santa Maria District, Arnold and Robert Anderson, 1907.—In their bulletin⁵⁷ on the “Geology and Oil Resources of the Santa Maria Oil District, Santa Barbara County,” Arnold and Robert Anderson used the same classification that was used in the Summerland district just described. The Vaqueros formation was placed in the “Tejon-Sespe-Vaqueros terrane,” as they considered that the purpose of the bulletin did not warrant the time necessary to trace the lines between the constituent members. A table of “Vaqueros (lower Miocene)” fossils and localities is given (p. 32). The “Monterey shale (middle Miocene)” is said to follow the Vaqueros conformably, the division being placed on lithologic ground at the end of the calcareous shales and beginning of the dominantly siliceous shales. The Monterey shale is said to be 5200 feet thick.

⁵⁶ U. S. Geol. Surv. Bull. 321 (1907).

⁵⁷ U. S. Geol. Surv. Bull. 322 (1907); also earlier briefer account in Bull. 317 (1907).

“The Vaqueros and Monterey terranes taken as wholes are distinct units, representing *periods of deposition of entirely different character*.⁵⁸ As indicated by the rocks, deposition was continuous between the Vaqueros and Monterey and the change in character came suddenly, although less so in some places than in others. The general nature of the Vaqueros series is detrital; that of the Monterey organic. The former contains many well preserved molluscan forms, the latter few. Close to the line between the two, beds predominatingly of a gravelly or sandy nature or those bearing fossil mollusks are considered part of the Vaqueros; those of a fine texture and of flinty or opaline or chalcedonic nature, part of the Monterey” (p. 34).

“A paucity of recognizable molluscan fossils is one of the prominent characteristics of the Monterey in this region, as in most others in the Coast Ranges where it outcrops. Moreover, the other fossils that it contains are of little value in indicating its age. *Its position in the geologic column is determined by the lower Miocene fossils found just below its base in the Vaqueros*⁵⁹ and by the upper Miocene fossils found at or near the base of the Fernando formation which lies unconformably above it” (p. 47). Yet it is said “These shales make up the Monterey formation and are probably representative of the whole of middle Miocene time” (p. 33).

We have here a confession of the flimsy evidence upon which the “period of deposition” of the siliceous shales is determined. The alternation of organic shales and sandstones (“Vaqueros”) found in the Los Angeles district and the rapid fluctuation in the relative proportions of “Monterey” and “Vaqueros” in the Santa Maria district (see p. 191) apparently did not lead the writers to see that these two types were merely depositional facies, and that the line drawn between them in the Santa Maria field while lithologic, and having an important economic and geologic bearing, in no sense represents a horizon or division line between the “lower Miocene” and “middle Miocene.”

Whatever period of time referred to the European scale the rocks of the Monterey series of the Santa Maria district repre-

⁵⁸ Italics supplied.

⁵⁹ Italics not in original.

sent, it seems certain that the organic shales at some points represent part of the earlier half of the period, and the sandstones or terrigenous shales represent part of the later half at other points.

Coalinga-McKittrick Region, F. M. Anderson, 1908.—In 1908 F. M. Anderson⁶⁰ published "A Further Stratigraphic Study in the Mount Diablo Range of California," dealing particularly with that part of the range between Cantua Creek and McKittrick. He used the same terms for the rocks under discussion as he did in his former paper, the "Temblor beds" and the "Monterey shale." He considered the Temblor to be the more persistent of the two and also "best characterized by fossils, and is therefore the most easily recognized faunally" (p. 18). Their usual thickness is given as 450–550 feet. The Monterey shale is said to be 5000 feet thick north of the Temblor ranch house and to decrease to 250 or 300 feet near Coalinga⁶¹ (the "Big Blue" of the oil men doubtfully referred by Anderson to the Monterey).

Anderson again criticized very strongly (pp. 38–39) the use of the term "Vaquero sandstone" because the "type" locality (Los Vaqueros Valley) lacked "faunal or even stratigraphic description," nor is it delineated on any published map. He admits, however, that "most of the strata that have been described under the name 'Vaquero sandstone,' as far as known, represent a well characterized horizon of the Lower Miocene, and as such are without doubt to be correlated with the Temblor beds of the Mount Diablo range" (p. 39).

As to the siliceous shales, "the Monterey shales occurring in the Middle Miocene of California have generally been called by that name; hence little is to be said regarding their correlation with the same in the Mount Diablo range. In general, however, there is a tendency to trust too far to lithological characters in their identification, and it is not unlikely that error

⁶⁰ Calif. Acad. Sci. Proc., 4th Ser., vol. 3, pp. 1–40 (1908).

⁶¹ In his earlier publication (see *loc. cit.*, p. 207 of this paper) some of the beds evidently belonging to the Monterey series were included in his "Coalinga beds," but in this paper they are removed from that category and placed with the Temblor, and the term Coalinga is therefore not here discussed. Diatomaceous shales near Coalinga in the previous paper referred to the Monterey are in this paper called Eocene or Oligocene.

has thus originated more than once in the application of this name." Nevertheless it may be pointed out that Anderson nowhere gives a characteristic fauna for his "Monterey shale" and really makes the division on lithologic grounds himself. In fact the fossils which he reports from the Monterey shale are the same that are found in the diatomaceous shale which he first called Monterey but which in his later paper he placed in the Eocene or Oligocene because he considered that it lay unconformably below sandstones carrying a Temblor fauna.

We find here again an unrealizable ideal system of two formations, two faunas, two periods of deposition—and an actual condition of the lithological division of a series dependent on depositional facies varying from place to place in relative thickness.

Geological History of Coast Ranges, Lawson, 1908.—In this same year in the Report of the State Earthquake Investigation Commission⁶² on the California earthquake of April 18, 1906, Lawson outlined briefly the geological history of the Coast Ranges. Without discussing the ideas of others he showed that his view of the unity of the Monterey series had been unaffected by the numerous publications that had dismembered it and given its parts and different areas various names and interpretations. He says "Miocene time in the Coast Range region was characterized by a progressive subsidence with oscillations of the coast. The Miocene sea gradually transgressed the continental margin from the southwest, and as it did so spread a formation of arkose sands and conglomerates over the greater part of the Southern Coast Ranges. This was followed, as the water deepened with progressive subsidence, by a remarkable deposit of bituminous shales" (p. 9).

He notes the oscillatory nature of deposition in the Bay of San Francisco region (giving 9 divisions instead of the 7 he previously reported—5 sands and 4 bituminous shales). "This series is known as the Monterey series." "While the oscillation of the coast so clearly recorded in the strata near the Bay of San Francisco is not apparent in the southern Coast Ranges, it is by no means certain that they were not affected in a similar

⁶² Carnegie Inst. of Wash., vol. I, Part I (1908).

way. The vertical movement involved was not great, and such a movement might have extended over the deeper portions of the area of deposition in Monterey time without effecting a sufficient change in the depth of the water to alter the character of the sediments" (p. 10).

I have pointed out above that similar oscillations did take place in the Santa Clara Valley region, Los Angeles district and Puente Hills.

Santa Cruz Folio, Branner, Newsom, and Arnold, 1909.—Considerable areas of rocks representing the Monterey series have been mapped by Branner, Newsom, and Arnold in the Santa Cruz quadrangle, the folio⁶³ for which appeared in 1909. They are presented as two formations separated by an unconformity, and presumably representing different time intervals in the geologic scale.

"The Vaqueros sandstone, of lower Miocene age, is one of the most important formations of the quadrangle. . . . The sandstone varies in texture from fine grained beds to conglomerate, but is usually medium grained. Generally it is brown or buff in color. . . . The Vaqueros in general lies conformably above the San Lorenzo formation, and there is often a gradual change from one formation to the other. . . . Southwest of Ben Lomond Ridge, Big Basin, and Butano Ridge the thin sandstone at the base of the supposed Monterey shale, tentatively included with the Vaqueros, overlaps unconformably the San Lorenzo, the Butano and the pre-Cretaceous diorite" (p. 4).

"The relation of the Vaqueros sandstone to the overlying beds is not so clear" (?) "as are its relations to the underlying strata. Around the northwest end of Butano Ridge the diatomaceous shale (supposed Monterey) rests directly on the Butano, and the thin sandstone (regarded as possibly Vaqueros) is absent. Elsewhere in the quadrangle there is commonly a marked difference in the dips of the Monterey strata and those of the Vaqueros sandstone, and an unconformity is therefore believed to exist generally between the two formations. Inasmuch, however, as the line of contact nearly always occurs in densely wooded or chaparral-covered regions and where the rocks

⁶³ U. S. Geol. Surv., Santa Cruz Folio, California, no. 163 (1909).

are much crushed and folded, it is not possible to say with certainty that there is at all places an unconformity between the Vaqueros sandstone and the overlying strata."

The fact that everywhere else the Monterey series exhibits a conformable relation throughout and that even within this area the sandstones underlying the shale in some places are distinctly conformable below them, and that where unconformable relations are suggested by different dips the contact areas are not distinctly visible should make one doubt the correctness of this determination which the authors themselves speak of in a doubtful way. However, even if the suspected unconformity does occur, it must be a very local and minor feature and can hardly be accepted as marking a time boundary between two distinct formations, which as has been frequently pointed out, are "determined" in general by quite different characteristics which change at various horizons.

The idea expressed (p. 10, col. 3) that "after the deposition of the Vaqueros sandstone at least a portion of the region appears to have been raised, and was probably folded and faulted; in parts of the area considerable erosion appears to have taken place," does not seem diastrophically probable. That within part of that comparatively small area such activities as uplift, folding, faulting, considerable erosion and then subsidence, should take place, while over other parts of the area and in the neighboring regions quiet deposition was going on is hardly to be expected and should be backed up by very definite or strong evidence before it can be accepted.

Again the authors say "There are few localities where the Vaqueros sandstone is fossiliferous, but at those places the rocks yield an abundant fauna of unmistakable lower Miocene age. As would be expected in a formation composed largely of conglomerates and coarse sandstones, the Vaqueros contains a shallow water or littoral fauna" (p. 4, col. 3).

In other words, all of the sandstones and conglomerates not found above diatomaceous shale were placed in this "formation" on a lithologic basis, while the fauna found in a few localities was considered "characteristic" of the horizon supposedly represented by them all.

"The fauna is characterized by a great abundance of individuals of several species of the genus *Agasoma* . . ."

Turning now to the "Monterey shale," "middle Miocene," it is said that "In the Santa Cruz quadrangle the Monterey shale consists chiefly of diatomaceous shale with here and there intercalated sandstone beds. . . . The diatomaceous shale composes the greater part of the formation."

"Locally the Monterey shale contains abundant fossils, leaving no doubt as to its age. . . . Some of the areas of diatomaceous shale supposed to be of Monterey age have thus far yielded no determinable fossils" (p. 3).

"Few species are known in the formation, but this paucity in the number of species is partly compensated for by the abundance or rather widespread distribution of *Pecten peckhami* Gabb, *Yoldia impressa* Conrad, *Arca obispoana* Conrad, and *Tellina congesta* Conrad. The first two of these are found sparingly also in the San Lorenzo formation (Oligocene); nevertheless their great abundance in the Monterey make them more or less useful for purposes of correlation."

We have the admission here that two of these forms are found in the "Oligocene," and therefore cannot be considered characteristic of the "age" of the shale, and it may be added that *Tellina congesta* is one of the shale fauna that is found very low in the Monterey series in Contra Costa County and it is doubtfully determined by Anderson⁶⁴ in the shales near Coalinga considered by Arnold and others to be Eocene or Oligocene; and that *Arca obispoana*⁶⁵ is reported from the Vaqueros (Temblor of Anderson) associated with an *Agasoma* fauna in the vicinity of Coalinga. One may hardly look upon these as "leaving no doubt" as to the "middle Miocene" age of the formation. A fossil list of 15 is also given with those "supposedly characteristic of formation" indicated. For eleven of these specific determinations are given of which all but two have been reported from other localities as associated with "characteristic" Vaqueros or San Lorenzo fossils. The two not so found

⁶⁴ Anderson, Proc. Cal. Acad. Sci., 4th Ser., vol. III, p. 16 (1908).

⁶⁵ Arnold, U. S. Geol. Surv. Bull. 396, p. 17 (1909), and Bull. 398, p. 86 (1910).

(*Maetra montereyana* Arnold and *Venericardia montereyana* Arnold) have not as far as known to the writer been reported from any locality but that of original discovery, and their geologic relations are unknown.

The thickness of the "Monterey shale" is given as $5000\pm$ feet, of the Vaqueros sandstone $2700\pm$.

In the Santa Cruz Folio, then, the rocks of the Monterey series have been presented as two distinct formations apparently separated lithologically, faunally, and representing two epochs of deposition (lower Miocene and middle Miocene respectively), and separated in part by an unconformity. But a critical estimation of the evidence presented indicates that the divisions have been made throughout on lithologic difference (depositional facies), that the unconformity is not evident where exposures are clear but only suspected in certain areas where contact areas are hidden and even if present we have no reason to suspect that it marks the time of supposed depositional or (and) faunal change. Furthermore, the supposed characteristic fauna of the Monterey is chiefly a shale facies, whose forms are known to the base of the Miocene and in large part into strata supposed to be Oligocene (San Lorenzo) or Eocene (Coalinga Tejon shale) and containing no element that is even fairly surely known to characterize a "Monterey shale" or "middle Miocene" time period. It is evident that this area which seemed at first to offer especially good grounds for the distinction is on no stronger basis than others already discussed.

Environment of Tertiary Faunas, Arnold, 1909.—A general statement of Arnold's views appeared this same year.⁶⁶ As the individual papers in which his evidence is presented have already been discussed, this general paper (in which no evidence is presented) may be passed over without discussion.

Coalinga Oil District, Arnold and R. Anderson, 1910.—In 1910 Arnold and Robert Anderson published⁶⁷ an extensive report on the "Geology and Oil Resources of the Coalinga District." The "Vaqueros sandstone (lower Miocene)" is de-

⁶⁶ Arnold, *Environment of the Tertiary Faunas of the Pacific Coast of the United States*, Jour. of Geol., vol. 17, pp. 509-533 (1909).

⁶⁷ U. S. Geol. Survey, Bull. 398 (1910). See also the Preliminary Report, Bull. 357 (1908), and the Palaeontological Report, Bull. 396 (1909).

scribed, and extensive fossil lists given. These terrigenous beds are the same as those called "Temblor" by F. M. Anderson. The Temblor is considered the equivalent of the Vaqueros of the coast because of "the large number of species common to the two" (p. 87).

The "Monterey shale" is considered to be probably absent, although it is stated that the "Big Blue" referred to the Monterey by F. M. Anderson "corresponds in stratigraphic position to the Monterey shale (middle Miocene) of regions near the coast, but nothing has been discovered to indicate that it may belong to that formation" (p. 76).

Cantua-Panoche District, R. Anderson, 1910.—A brief statement of the geology to the north of the Coalinga district, in the Cantua-Panoche region, was given by Robert Anderson in Contributions to Economic Geology, 1909.⁶⁸ Under the caption "Lower Miocene" (pp. 64 et seq.) is described "the continuation of that described as the Vaqueros sandstone (lower Miocene) in the report of the Coalinga district." The fauna in the hills surrounding the Vallecitos (30–35 miles north of Coalinga) is said to differ in aspect "from that in the Coalinga district or from any other well known fauna of the Coast Ranges. This fauna, together with the presence in the formation . . . of considerable masses of siliceous diatomaceous shale, which occurs only in thin zones in the northern part of the Coalinga district and is absent in the southern part, suggests a possible equivalence of the formation to the lower portion of the Monterey shale in the region nearer the coast and a gradual transition westward from the sandy and gravelly strata at the eastern edge of the Coast Range to the purely organic sediments in the coastal belt." The fauna is said to be characterized by such forms as *Turritella ocoyana*, *Pecten andersoni*, *P. propatulus*, and teeth of *Desmostylus*, which would seem to place it in the *T. ocoyana* zone or F. M. Anderson's Temblor. Robert Anderson remarks that "Any correlation of sandy fossiliferous strata with the Monterey shale is difficult to make, owing to the scant knowledge of the fauna of Monterey time. Hence the suggestion of the possible equivalence of the formation to the lower part of the Monterey shale

⁶⁸ U. S. Geol. Survey, Bull. 431-A, pp. 54–83, 1910.

is conjectural." The beds are said to be 1700–1800 feet thick around the Vallecitos and to consist of sandstone and conglomerate interbedded with thick layers of siliceous diatomaceous shale.

McKittrick-Sunset Region, Arnold and Johnson, 1910.—A discussion of the territory to the south of the Coalinga district is contained in the "Preliminary report on the McKittrick-Sunset Oil Region" (1910) by Arnold and Johnson.⁶⁹ The "Vaqueros sandstone (lower Miocene)" is described as for the most part uniformly arenaceous, but near Annette and upon the southwest side of the Carrizo Plain the sands evidently in part *grade into light colored shales closely resembling the Monterey*⁷⁰ (p. 43). It is given as from 60 to 2400 feet thick. These are of course F. M. Anderson's "Temblor beds."

The "Monterey shale (lower middle Miocene)" in which F. M. Anderson and others had included "the whole of the prominent series of white shale extending uninterruptedly from just east of Polonio Pass southeastward along the flank of the Temblor Range nearly to Temblor ranch, and to the great area of shale embracing practically all of the range from the head of Salt Creek southeast to the limits of the region studied," was separated into two formations, "one of which is thought to be the equivalent of the Santa Margarita (?) formation (upper middle Miocene) in the Coalinga region, while the earlier more closely resembles the Monterey (lower middle Miocene) as it has been described in other parts of the state. Definite palaeontologic evidence for the separation in the McKittrick-Sunset region has been scant. . . . The main consideration involved in the present separation of the rocks, however, is one of convenience to the prospector. Since there is a marked difference in the physical appearance of the rocks, it simplifies an understanding of the geologic and structural conditions" . . . (pp. 55–56).

"The lowest portion of the series is usually made up of calcareous and arenaceous shales which represent a transition into the sandstones and fossiliferous beds of the Vaqueros. These grade upward into typical siliceous and argillaceous shales that

⁶⁹ U. S. Geol. Surv. Bull. 406 (1910).

⁷⁰ Italics not in original.

contain evidence of organic origin. Prominent zones of nodular calcareous shales are characteristic of this middle portion of the series. The upper third of the formation includes an indefinite zone of sandstone beds that are irregularly intercalated in limy-siliceous shales. The succession and character of these sediments coincides very closely with those of the lower division of the Monterey in the Santa Maria district. The upper division, so prominently developed near Lompoc, in the Santa Maria district, is absent from the McKittrick-Sunset region, unless the basal organic shales of the formation here described as Santa Margarita (?) formation are the same as those described as upper Monterey in the Santa Maria report" (pp. 56-57).

The Vaqueros and Monterey together are given as conformable, but with supposed unconformable relations to the over- and underlying formations. We may be sure that the Monterey series is represented here, and that it shows many similarities of depositional progress to that of the Southern Coast Ranges. Evidence for age and divisions as given does not appear to be particularly good in the area studied, but the attempted discriminations are made on the basis of ideas developed elsewhere.

Geologic Record of California, J. P. Smith, 1910.—In the "Geologic Record of California" (1910) a summary by J. P. Smith,⁷¹ a geologic column is presented exhibiting a standard marine section for the Coast region of which the Tertiary part is as follows:⁷²

⁷¹ Jour. Geol., vol. 18, pp. 216-226 (1910).

⁷² *Loc. cit.*, plate following page 217.

		FORMATION	
Pliocene		Merced	Sandstones of Lake Merced with <i>Cardium meekanum</i> and <i>Scutella interlineata</i>
		San Diego	Purisima Sandstones of San Diego and Half Moon Bay with <i>Pecten healeyi</i>
Miocene	Upper	San Pablo	Sandstones of San Pablo Bay and the Coalinga region, with <i>Pecten pabloensis</i> and <i>Pecten oweni</i>
	Middle	Santa Margarita	Sandstones of Salinas Valley, with <i>Pecten estrellanus</i> , <i>Ostrea titan</i> , and <i>Tamiosoma gregaria</i>
		Monterey	Monterey Shales with <i>Pecten discus</i> and <i>Pecten peckhami</i>
Lower	Vaqueros	Sandstones of Monterey and San Luis Obispo counties, with <i>Turritella inezana</i> and <i>Mytilus mathewsoni</i>	
Oligocene		Astoria	San Lorenzo Sandstones and shales of Santa Cruz County
Eocene	Claiborne	Tejon	Sandstones of Ft. Tejon, Martinez, and Merced Falls with <i>Venericardia planicosta</i>
	Midway	Martinez	Sandstones of Martinez with <i>Pholadomya nasuta</i>

In a later table⁷³ he gives the faunal zones, and their occurrence at various localities. He recognizes a lower "Vaqueros" zone ("zone of *Pecten magnolia* and *Turritella inezana*"), and an upper "Vaqueros" zone ("zone of *Agasoma* and *Pecten andersoni*"), including the *Turritella ocoyana* zone and the Temlor beds of the interior districts.

Throughout runs the fallacy that the Monterey and Vaqueros each represent a definite time interval and a life-time zone. The untenability of some of the division lines here given has already been discussed, some of the others will be taken up later.

Sargent Oil Field, Jones, 1911.—Early in 1911 W. F. Jones published a description of "The Geology of the Sargent Oil Field"⁷⁴ at the southeastern end of the Santa Cruz Mountains

⁷³ Not numbered, but just in front of p. 226.

⁷⁴ Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, no. 3, pp. 55-78, Feb. 18, 1911.

just north of Pajaro River. He recognized a "Miocene Series" lying unconformably above the Franciscan and unconformably below the San Pablo. He divided it "on lithological grounds" into a lower portion chiefly sandstones (1500 feet), which he said is "probably of Lower Miocene age," and an upper, chiefly bituminous shales with occasional limestones (3000 feet), called "Monterey Shale." The former is described as "very similar to the Temblor beds of the Monte Diablo range described by F. M. Anderson." "There are several thick beds of siliceous shale in the terrane which has tentatively been called Lower Miocene, but the presence of large amounts of sandstone, clay shale and conglomerate distinguish it from the overlying Monterey." The upper shales ("Monterey shale") are said to lie conformably on the lower beds, and at two localities overlap the latter (as is normal for a conformable series) and lie directly on diorite or Franciscan sandstone. It is evident that the relations described are typical of the Monterey series throughout most of the coastal part of the province.

Kern River Region, F. M. Anderson, 1911.—In November, 1911, F. M. Anderson⁷⁵ published "The Neocene Deposits of Kern River, California, and the Temblor basin." He describes the representatives of the Monterey Series in the Kern region, on the east side of the southern San Joaquin Valley, under the heading "Temblor⁷⁶ Group, which he divides into a "basal member," 350–600 feet thick, and an "upper member," 1260 feet thick. He described the basal member as essentially sandy. "Some of the lower beds consist largely of volcanic ash, pumice, and sand. . . . Basal conglomerates are visible in only a few places, but a stratum of at least 50 feet is exposed at one point north of the Kern River" (pp. 90–91).

The upper member "contains a smaller percentage of sand and other detrital matter, and a greater percentage of organic material than any other portion of the Neocene. And of the detritus present a great portion is of clay and shaly matter."

⁷⁵ Proc. Cal. Acad. Sci., 4th Ser., vol. III, pp. 73–148 (1911).

⁷⁶ Anderson renewed his attack on the legitimacy of the term *Vaqueros* as explained above, and insists on the use of *Temblor*. Footnote, p. 106.

“In this member clays and shales probably form in the outcrop about 50 per cent of its volume, and of this percentage about one-half is organic. Some layers are chiefly composed of diatomaceae and other minute organisms” (p. 92).

He gives fossil lists as collected from three “zones,” A, B, and C, and these lists include forms already familiar on the west side. “As will be seen the faunas of the three prominent zones already described belong to the lower division of the Neocene, and are characteristically Lower Miocene. The upper division as far as known is almost without fossils, and is barren of any forms that are serviceable for stratigraphic correlation” (p. 102).

As for the lowest zone (A), “It was at first thought that this horizon might prove to be older than the typical Temblor, on account of the number of large pecten species it contained, but there is now quite abundant proof that a horizon older than the Temblor has not been recognized either here or in any part of the Temblor basin. . . . It may be supposed that the occupation of the Temblor basin by the sea was transgressional and progressive and that there are older beds belonging to the Neocene in the outer coast ranges; but if this is true it has yet to be shown” (p. 107).

In regard to zone B, he said “Any question which may arise as to its exact stratigraphic position is more likely to involve only a choice between the Temblor and the Monterey. But thus far in the study of the West Coast Miocene, the Monterey has not been regarded as the habitat of such species as *Agasoma gravidum*, *Turritella ocoyana*, *Cytherea mathewsoni*, *Dosinia whitneyi*, *Yoldia impressa* and a score of other species given in the lists. . . . And furthermore it must be added that while Zone B is rich in species, some of which have often been found in the Monterey shales, the species most widely characteristic of the latter, namely *Pecten peckhami*, has not been found at all in any part of the Kern River area” (p. 107).

It is hard to see how this is a point against its “Monterey” age, seeing that *P. peckhami* has been found farther west in rocks lying below the “Vaqueros” or “Temblor” and considered by Arnold, R. Anderson, F. M. Anderson and others, Eocene or Oligocene, as well as in the latest “Monterey shales.” It can

only mean a peculiarity of geographical distribution of the species.

The mixture of faunal elements previously supposed characteristic of Monterey and Vaqueros respectively may be related to the mixture of depositional types—bands of diatomaceous shales with intervening sandstones, as in western Contra Costa County. If there really are life-time zones in the Monterey series, it may mean a transitional fauna. In either case it shows the imaginary character of the supposed time independence of the two formations “Monterey shale” and “Vaqueros sandstone” or “Temblor beds.”

But Anderson takes a different view and says “It is quite impossible to recognize in the outcrop in any part of the Kern River area that member of the Miocene which forms its most characteristic feature in many parts of the Coast, that is, the Monterey Shales.”

“In the series as described in the preceding pages, . . . there is one portion that bears some resemblance to the Monterey, namely, that portion which is most strongly characterized by shales, some of which are organic to a considerable extent. It will be noticed that nearly every class of materials commonly found in the Monterey has been found in the upper part of the Temblor group” (p. 109). This statement is very interesting when we consider that the actually applied criterion for the “Monterey” has everywhere been the “materials . . . found in the upper part of the Temblor group.”

“But if this collection of strata really represents the Monterey, it is hardly comparable in thickness or character to known exposures of Monterey not far away.” It may be pointed out here that the change from McKittrick to the Kern is hardly quicker or more marked than the change from McKittrick towards Coalinga.

“*Temblor Basin.*”—Anderson brought out some very important relationships when he showed that the Kern River deposits on the edge of the Sierra Nevada and the deposits along the west side of the San Joaquin Valley about Coalinga and north are along the borders of what I consider the interior portion of the basin of deposition during Monterey time and what he calls

the Temblor basin. Along this eastern border region the rocks developed are chiefly terrigenous while the "Monterey" (by which of course he really means an upper diatomaceous member, although he evidently has in mind an ideal time interval) "is either absent, or is present in a reduced or disguised form"—"disguised form" is, I believe, a very appropriate expression.

"The explanation of this interesting fact is to be found no doubt in the diastrophic record of the times. The subsidence that inaugurated the occupation of this basin by Temblor sediments continued without interruption until middle Miocene time. It then paused, and on the eastern and northern borders of the basin the shore lines remained stationary throughout the epoch of the Monterey. In these parts, therefore, sedimentation was nil, while along the western borders subsidence went on without cessation, and sedimentation was therefore continuous."

"It is unnecessary to suppose that there was any elevation and denudation of the older Miocene during the Monterey epoch, either in the Kern River area or elsewhere, and no such disturbance seems probable. The facts appear to indicate merely an epoch of stability along the eastern and northern shore lines of the basin, along which, therefore, the conditions were unfavorable for the continued accumulation of any class of sediments" (pp. 110, 111). He also considered that the climates of the Temblor and Monterey epochs were different, the diatomaceae, foraminifera, gypsiferous strata and lack of terrigenous sediments, in the latter, indicating an arid climate (p. 111).

The writer inclines towards a simpler explanation than the one given by Anderson, which requires the interior edge of the basin to sink only during lower Miocene and to stop sinking in middle Miocene while the depression of the coastal portion continued. It looks very much like the result of simple progressive subsidence with minor oscillations. In the gradual transgression of the sea, terrigenous sediments (generally sandy or pebbly) were almost everywhere laid down and only with increasing depth and distance from the shore line do we get organic deposits. Naturally the edges of the basin when at its period of greatest areal extent must have been in the littoral zone and could have received only terrigenous or chiefly terrigenous de-

posits whatever part or portion of the whole Monterey time they represented. The arguments for marked change in climate do not appear to apply particularly, for unless the volume of silt-laden water discharged from the land had been comparatively small there could not have been such pure diatomaceous materials deposited at any portion of the period so close to shore as we know them to have been throughout the whole province, and this applies to the lower as well as the upper portions of the series. The evidence favors an arid climate throughout.

South End San Joaquin Valley, R. Anderson, 1912.—In the spring of the present year (1912) Robert Anderson published⁷⁷ a "Preliminary Report on the Geology and Possible Oil Resources of the South End of the San Joaquin Valley"—the region lying along the mountain flanks between the McKittrick-Sunset area and the Kern River region just discussed. He says "Although great differences in thickness and details of lithologic character occur, the similarity is sufficient to show that the major features of the Tertiary geologic history were alike on the two sides of the valley. . . ." "In the Temblor Range field the lower division corresponds to the Vaqueros sandstone (lower Miocene), the middle one to the Monterey shale, and the similar shale of the Santa Margarita (?) formation (middle Miocene)" (p. 115).

A most interesting relationship is brought out in the statement that "At the south end of the valley the formations of the Temblor Range continue into the San Emigdio region, with changes, however, that alter the section considerably, especially in the lower and middle divisions. . . . A significant change is the decrease in the exposed thickness of the organic shale from several thousand feet in the Temblor Range to about 1000 feet in the San Emigdio region, and its gradation into a less diatomaceous and more clayey and sandy type of shale. Whether this is due to the fact that a smaller volume of the organic sediment was deposited here, or to its having been partly eroded in this region, owing to its nearness to the zone of uplift represented by the granite mountains, or to its being hidden in part

⁷⁷ U. S. Geol. Surv. Bull., 471-A, pp. 102-132 (April, 1912).

by unconformably overlapping formations has not been determined. The character of the material composing the Miocene section gives some weight to the belief that the greater proximity of this area to the mountain belt caused a nearer approach to shore line conditions and the deposition here of coarser sediments in place of part of the purely organic deposits of the Temblor Range" (p. 116).

The deposits here described are on the north side of the mountainous area to the south of which the rocks of the Santa Clara region were deposited, and the great increase in terrigenous material on their approach from the south has already been described.⁷⁸

There seems no reason to doubt that much if not all of the earthy shale and sand of the San Emigdio region is contemporaneous with the biogenic shales to the north and west. Anderson's description supplements well the study on the south side of the mountains, connects the Sunset and Kern regions, and indicates the general position of the extreme shore line of the Monterey epicontinental sea.

Miocene Invertebrate Fossils, J. P. Smith, 1912.—Professor J. P. Smith has recently published a general statement⁷⁹ of the "Geologic Range of Miocene Invertebrate Fossils of California," in which he takes a stand on the Miocene faunas quite at variance with his former views and those of Anderson, Arnold and others, but much more in harmony with the stratigraphic conclusions of the present paper.

He says: "Later writers . . . have introduced a much more elaborate classification of the Neocene of California, and a large number of formation names. But these so-called formations, however useful they may be for areal mapping and for economic geology, do not always correspond to faunal divisions. Some of them are merely different facies of the same thing."

"Instead of the numerous subdivisions recognized by most stratigraphers, there are, in fact, only two major faunal units in the Miocene of California: a lower, including all the faunas up through the Monterey; and an upper, including the San Pablo,

⁷⁸ Part I of this paper, pp. 187 and 188.

⁷⁹ Cal. Acad. Sci. Proc., 4th Ser., vol. III, pp. 161-182, April, 1912.

Santa Margarita and Etchegoin faunas. The division line between them corresponds to the period of orogenic activity that came on at the end of the Monterey Epoch. . . . This brings us back almost to the standpoint of Lawson and Merriam, who have proposed to call all the lower Miocene 'Monterey' and all the upper Miocene 'San Pablo' (pp. 162-163). In his lower "major faunal division" Smith includes two subdivisions:

Lower	}	Monterey—Temblor faunas of the Contra Costa hills, Mt. Hamilton Range, Black Mountain, Santa Lucia Range, Coalinga region, Bakersfield region, Santa Ynez and Santa Monica mountains, and Santa Ana Range Vaqueros fauna, of the Santa Lucia Range, Black Mountain, the Santa Monica and Santa Ynez mountains.
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These two faunal subdivisions as judged from the faunal lists given correspond exactly to the faunal stages suggested by Merriam in 1904:

FAUNAL ZONES

	Merriam, 1904		Smith, 1912
Agasoma zone (Lower Miocene)	}	Lower Miocene	}
	Zone of <i>T. ocoyana</i> (and <i>T. variata</i>) Zone of <i>T. hoffmanni</i> (= <i>T. inezana</i>)		Monterey-Temblor faunas Vaqueros faunas

In regard to the Temblor, Smith says: "In the check-list the Temblor and Monterey faunas are entered separately as a matter of record, although they are certainly synchronous" (p. 169). As to the Vaqueros, "the lowest horizon of the Miocene has been called by Merriam the zone of *Turritella hoffmanni* (= *Turritella inezana*); it may eventually be found to be the inshore equivalent of the deep-water San Lorenzo Oligocene, with which it has a few species in common" (p. 165).

While Smith uses the well known terms Vaqueros and Monterey—and without any particular explanation of a changed definition—he does not use them in the sense in which anyone else has previously used them. It is quite probable that he is right in his division of the littoral fauna of the Monterey series into the two zones proposed, but he has applied to them two formation names—names for formations which do not really

exist as such. It would be impossible in any locality to draw the actual line in the field between the beds corresponding to one zone and those corresponding to the other, unless there were a wholly terrigenous series well supplied with zonally characteristic fossils. If a diatomaceous shale came in between two sandstones, one with forms of the lower zone and the other the forms of the upper zone, it would be impossible to tell to which zone the shale belonged.

It is a fact that the fossils given by Hamlin for his Vaqueros formation belong to the Vaqueros fauna of Smith. But in the "type" locality the distinction between "Vaqueros sandstone" and "Monterey shale" was admittedly on a lithologic basis, and who can say that the "Monterey shale" in part of that area does not represent the "Vaqueros fauna" life period, or that the "Vaqueros sandstone" of other parts of the area does not represent the "Monterey-Temblor fauna" life period?

As long as the Monterey series cannot be separated into two (or more) formations of any general validity, but only locally into lithologic types that vary rapidly in their thickness and the horizon of their gradation zones, it seems artificial, unnecessary and confusing to label the faunal subdivisions or stages with formational names. The only logical course is to give the faunas faunal names, as has been done by Merriam.

As soon as the sense in which Smith uses the terms Vaqueros and Monterey-Temblor is clear it is easy to see that in but few places where those terms have been applied will the division lines or correlations of other geologists agree with his subdivisions. Furthermore, in most of those fields no one could actually draw the lines representing his divisions.

The most noteworthy discrepancies are in the San Joaquin Valley region, where Arnold, F. M. Anderson and their associates have correlated the terrigenous sediments of the Monterey series (Temblor of Anderson) with the Vaqueros. As pointed out already, the indications are that they are in large part contemporaneous with certain "Monterey shale" of these authors—and as no higher fauna is found there than that of the *T. ocoyana* zone, and as the type "Vaqueros" was originally reported to contain fossils of the *T. hoffmanni* zone, Smith's reference of

these beds to the Monterey rather than to the Vaqueros is evident.

San Jose and Mt. Hamilton Quadrangles, Templeton, 1912.—At the April, 1912, meeting of the Cordilleran Section of the Geological Society of America E. C. Templeton presented a paper on “The General Geology of the San Jose and Mt. Hamilton Quadrangles,”⁸⁰ in an abstract of which he says: “The lowest Miocene sandstone belongs to the Temblor phase of the Monterey series and rests unconformably on the Franciscan. . . It has an abundant fauna, typically Temblor. Its thickness is about 1000 feet. Overlying it is the Monterey shale, hard, light-colored, and siliceous, with a thickness of about 1200 feet. . . . The Monterey shale is overlaid, apparently conformably, by a thickness of about 3500 feet of sandstone with a typical Temblor fauna.”

It is evident here that “Monterey shale” is used merely in the sense of a depositional facies, and “Temblor” is used in a faunal sense. The relative position of beds is instructive.

Kirker Pass, Clark, 1912.—The Monterey section of Kirker Pass, north of Mount Diablo, has recently been described by Bruce Clark.⁸¹ The fossils found in the upper part of the section are referred to the upper Monterey.

PART III

GENERAL CONCLUSIONS

GENERAL DESCRIPTION OF MONTEREY SERIES

MONTEREY SEDIMENTS

General Distribution.—The Monterey series (including such local divisions as have been called Vaqueros, Monterey shale, Modelo, Puente, Temblor, etc.) is a natural stratigraphic unit. It represents a cycle of sedimentation in the geologic history of the Pacific Coast, which has produced one of the most important and widespread series of deposits in the California region.⁸²

⁸⁰ To be published Geol. Soc. Am. Bull., vol. 24. Abstract.

⁸¹ Univ. Calif. Pub. Bull. Dept. Geol., vol. 7, no. 4, Oct. 10, 1912.

⁸² The Monterey province is not limited to California, although it has been more extensively studied there.

As reviewed in the preceding part of this paper, it occupies considerable areas in the territory commencing about Point Arena (Lat. 39° N.), embracing the Coast Range region from the ocean to the San Joaquin Valley southward to the Tehachapi Mountains and beyond in Ventura, Los Angeles, and Orange counties, and the channel islands (about Lat. 33° N.); and extending eastward across the Great Valley into the foothills of the Sierra Nevada from the Tehachapi region north to the vicinity of Deer Creek, a few miles south of Porterville.⁸³

Progress of Sedimentation.—The Monterey series represents an invasion of the sea from the west or southwest with a gradual and progressive subsidence, the advancing shore line being marked almost everywhere by sands, often gravels, generally well supplied with a characteristic littoral fauna.⁸⁴ With the progress of the subsidence and migration of the shore line inward, the character of sedimentation at any one point gradually changed—naturally in some places more rapidly than others, depending on the character of the shores and whether near larger or smaller stream mouths. It first became finer and assumed the form of terrigenous muds, then showed more and more admixture of organic material. The organic material was commonly at first preponderatingly calcareous (limestone and calcareous shale), but ultimately siliceous, and wherever any territory became far enough removed from the areas of terrigenous sedimentation the material became entirely organic (frequently more or less admixed with pyroclastic material) and in time produced those pure diatomaceous earths and shales for which the Monterey series is famous.

In some localities areas are found where the first sediments deposited on the older rocks were earthy shale or of organic origin. These may in part be explained as hills, mesas, ridges or other areas of higher ground, particularly if rather flat surfaced, which while the main shore line was migrating past them were comparatively small islands or peninsulas, and which later

⁸³ See Anderson's map.—Proc. Cal. Acad. Sci., 4th Ser., vol. III (1911), Plate III, opp. p. 126.

⁸⁴ Tabulated by Smith in Proc. Cal. Acad. Sci., 4th Ser., vol. III, pp. 161–182 (1912), as “Lower Miocene Fauna”—the fauna of Merriam's Agasoma zone.

subsidence quickly immersed in comparatively deep water—or at least far enough from the main shore to receive no earthy deposits.⁸⁵ Or certain elevated tracts might have been protected in places from direct wave action by lying behind some headland or within some embayment. In such inlets there may have been river-born detritus with deposits largely of very fine grain (later becoming shale). Or there may have been no main streams emptying into some of them, and only a meager supply of terrigenous detritus. Some areas may represent Dixon's lagoon type⁸⁶ of sedimentation. But whatever their origin, it should be noted that they are the exceptional type, and even some areas that have been so reported have proved on more careful examination to show at least a thin sandy base to the series.

Effect of Geographical Conditions.—Many phenomena of distribution and lithologic character indicate that the series was deposited over much of the province on an uneven topography, with many hills and mountainous ridges protruding above the water level and some of these remained above sea-level during the period of greatest depression (or greatest extent of water surface) and gave an archipelagic character to the epicontinental sea. These land masses did not in general carry large streams capable of contributing terrigenous sediments to a considerable area beyond the immediate shore line, and therefore the total thickness of the series and the relative proportions of terrigenous and non-terrigenous material varied rapidly in some localities from point to point.

The greatest thicknesses of siliceous earths are found near the central and seaward portion of the depositional areas outlined: in the Santa Maria-San Luis-Monterey region along the coast, where they are said to reach 6000–8000 feet in thickness, and from here directly toward the interior across the present ranges into the hills bordering the great valley on the west in the vicinity of McKittrick and the Temblor range. This forms an area that projects from the coast into the interior while

⁸⁵ Some of the areas which at first glance seem to have this relationship have been given this appearance by post-Monterey faulting, the siliceous shales being so displaced as to outcrop against the pre-Monterey formation.

⁸⁶ Quar. Jour. Geol. Soc., vol. 67, p. 511 et seq. (1911).

gradually narrowing—a gulf-like embayment representing in a general way the deepest and most detritus-free portions of the Monterey epicontinental sea during its period of maximum landward extension.⁸⁷

As we approach the ultimate shore line, in the San Joaquin Valley environs, and against the projecting mountain masses along the coast, the terrigenous sediments predominate, sometimes to the complete absence of the siliceous shales.

Depositional Oscillation.—The change from coarse to fine terrigenous sediments and then to non-terrigenous was not everywhere an unbroken progression. It is most simply developed in the Monterey-San Luis-Santa Barbara region along the present coastal area and in its immediate interior over towards the McKittrick and Temblor range region. Many localities show oscillations from sands or clays to siliceous ooze and back again to sands or clays. These areas are particularly those near permanent or long enduring land masses of Monterey time. They may indicate an oscillatory movement of subsidence, by which small retrogressive stages occurred at intervals during the general movement of depression—a type of action for which we have evidence at other times and places; or they may be the result of climatic changes, greater volumes of sediment being discharged

⁸⁷ Professor J. C. Branner at the recent meeting of the Cordilleran Section of the Geological Society of America put forward an ingenious theory to account for the great thicknesses of diatomaceous earths in the Monterey. He considered that the diatoms, naturally thriving in cold water, were floated along by the “marine currents that flowed southward from Alaska.”—“Once within the zone of islands” (of the Coast Range archipelago) “these floating materials were probably driven into the cul-de-sac at the lower or southern end of the present San Joaquin Valley. Materials carried at or near the surface of the water could not escape, if, as is assumed, the embayment was fairly well closed at the extreme southern end. It is exactly here, and around the southwestern corner of the San Joaquin Valley, that the deposits of diatom skeletons are thickest.” (To be published Bull. Geol. Soc. Amer., vol. 24.) It is quite probable that the marine currents had an influence on the life and distribution of the diatoms, but the distribution of thickest diatomaceous deposits as outlined by the writer in describing the California gulf of Monterey time seems to be entirely accounted for by its relations to the ultimate shore line and to the border of thick terrigenous sediments to its northeast, east, and southeast (the limits of Anderson’s Temblor basin). Furthermore, these thickest diatomaceous deposits extend to the coast of the open ocean in the San Luis-Santa Maria-Lompoc region, and even the thinner deposits to the north (and south as well) can likewise often be brought into definite relationship with recognizable shore features which determined depth of water and sediment supply.

during some stages than at others, and therefore spreading over larger areas; or both such agencies may have been active.

As examples of such areas may be mentioned the country to the north of Santa Clara Valley, the Los Angeles district, the southern end of the San Joaquin valley, the Vallecitos, the Mount Diablo region of Contra Costa County, and the Point Arena area, already discussed in parts one and two of this paper.

Chert.—Instead of diatomaceous earths or shales, the siliceous members of the Monterey often appear as cherts—chiefly opaline in character. They are generally yellowish, but sometimes brown to nearly black. The dark color is usually due to bituminous substances. Sometimes these cherts occur in thin beds one to several inches thick, interstratified with earthy or siliceous earthy shales, the alternation being repeated hundreds of times.⁸⁸

Relation to the Occurrences of Petroleum.—The siliceous and the earthy shales of the Monterey series are very commonly bituminous, and are looked upon by most of the geologists working in the California oil fields as the source of most of the commercially utilizable petroleum of the state. Seepages and brea deposits are often associated with them. As far as the supplies of oil for industries is concerned, it is commonly derived from the sands of the series (the basal sands, or higher sands intercalated in the shale series), sometimes from zones of brecciated chert, sometimes from the sands or other porous rocks of adjoining formation groups, stratigraphically either higher or lower—from Mesozoic to Pliocene.

VOLCANIC PRODUCTS IN THE MONTEREY SERIES

Tuffs.—Besides the terrigenous and biogenic deposits mentioned above, products of volcanic activity are frequently encountered within the Monterey Series. Over considerable areas ash beds are more or less common and at different horizons. Along the hills stretching from Lion Rock, near San Luis Obispo, to north of Santa Maria, about 30 miles, a layer of volcanic ash occurs, in part carrying coarse glass fragments, in part pumiceous, in part coarsely agglomeratic, which according to Fairbanks is rhyolitic and reaches a maximum thickness of 800 feet.

⁸⁸ Well shown in halftone, plate 11, opposite p. 365, Bull. Dept. Geol. Univ. Calif., vol. 2.

The writer has seen similar tuffs probably of the same horizon in the vicinity of the Santa Ynez River. Light colored tuffs (sometimes definitely stated to be rhyolite tuffs) have also been found along the coast about Point Sal, to the north of San Luis Obispo, and in the vicinity of Monterey, in Contra Costa County, the Mount Diablo region and Santa Catalina Island, and have been reported from the interior at various points as far east as the flanks of the Sierra Nevada in the Kern River region. Besides its occurrence in definite layers or beds, ashy material (mineral grains and glass fragments) is frequently found disseminated through the diatomaceous earths and shales.

Lavas.—Rhyolitic lavas have been reported from the San Luis region. Basic lavas are quite widespread, varied and in some places abundant. Fairbanks has described pyroxene-andesite, quartz-basalt, olivine diabase and augite-teschenite from the San Luis region. Other localities where basic volcanics, extrusive or intrusive, are known in this series, are about Point Sal, in the Santa Maria district, the Santa Monica mountains (a thick series of lavas and breccias and associated intrusives), Carmelo Bay, and the mountains bordering Carrizo plains (especially abundant in the southern portion, where large intrusive masses occur, some of which have produced considerable metamorphism in the shales). Mr. G. C. Gester⁸⁹ has observed abundant andesitic and basaltic volcanics associated with the Monterey series in the hills about the southwest extremity of the San Joaquin Valley. The volcanics of San Clemente and Santa Catalina islands may also belong to this series.

LIMITS OF THE SERIES

The upper limits of the Monterey Series are in all places so far studied marked by an unconformity—generally angular. The orogenic movements that took place at the end of the Monterey period of deposition were important and widespread, the next oldest succeeding formation being the San Pablo (and its supposed correlatives, the Santa Margarita, etc.), considered by some to correspond to the upper Miocene and by others to the Pliocene. The lower limits of the series are generally also dis-

⁸⁹ Personal communication, Aug., 1912.

tinently determined by an unconformity, the underlying formations ranging from crystalline terranes (Mesozoic or even Paleozoic) up to the Tejon (generally accepted as upper Eocene) and the Sespe (considered Eocene or Oligocene). In some areas, where no angular deformation took place, the separation from the Tejon appears to be difficult if the beds near the border are not fossiliferous. The general relations, however, and the contributory palaeontologic evidence indicates that there was a distinct discontinuity of conditions between the Tejon and the Monterey, and that there were orogenic movements and a general recession of the sea between those two periods of deposition.

The relation of the Monterey to the San Lorenzo (referred by Arnold to the Oligocene) is uncertain. These latter beds have not been definitely recognized outside of the Santa Cruz Mountains, where they are said⁹⁰ to lie "in general conformably below the Vaqueros sandstone" (p. 4, col. 1). And again, "In this body of water limestone of the Eocene age, the Butano sandstone (supposed Oligocene), the San Lorenzo shale (Oligocene), and the Vaqueros sandstone (lower Miocene) were deposited, all (except possibly the Eocene) in conformable⁹¹ sequence" (p. 10, col. 3). J. P. Smith has recently suggested⁹² that this "lowest horizon of the Miocene," the *Turritella hoffmanni* (or *inezana*) zone, "may eventually be found to be the inshore equivalent of the deep-water San Lorenzo Oligocene, with which it has a few species in common." In this case the Butano sandstone would probably be the base of the Monterey series for that region. It will require further investigation in the field to satisfactorily settle the question.

PALAEONTOLOGIC CHARACTERS

Fauna.—The fauna of the Monterey series is, at least for the inshore facies, quite distinctive, and with any reasonable development of fossils in the coarser terrigenous beds their proper assignment to the Monterey period is assured. Professor J. P.

⁹⁰ U. S. Geol. Surv. Santa Cruz Folio, California, no. 163 (1909).

⁹¹ Notwithstanding these definite statements in the text, in the columnar section and in the map legends of the folio cited, an unconformity is indicated between the San Lorenzo and the Vaqueros.

⁹² Proc. Cal. Acad. Sci., 4th Ser., vol. 3, p. 165 (1912).

Smith has recently published most convenient lists of the invertebrate fauna of the Monterey series in his "Geologic Range of Miocene Invertebrate Fossils of California" under the designation of "lower Miocene" faunas.⁹³ The reader interested in the palaeontologic data is referred to this useful paper, and no attempt will be made to present a faunal list here.

As for the offshore (shale) fauna, it is meager and apparently not so characteristic, and references of shale—especially siliceous shale—facies to the Monterey series have to be made with care, and either with regard to their association with characteristically fossiliferous sandstone, or to their inclusion within the limits of the sedimentary series of rather characteristic habit, between the unconformities already described.

Faunal Stages.—There appear to be at least two⁹⁴ widely recognizable faunal stages in the Monterey littoral faunas, the older of which is found only along the more immediate coast region of the present time. If we accept these as representing real stages and not merely distributional facies, they strengthen materially the idea suggested by stratigraphic considerations and geographic distribution of depositional types, that the invasion of the Monterey sea was a gradual process, that during the earlier part of the period (zone of *Turritella hoffmanni* or *inezana*) deposition was confined to the present coastal region, and that only during a later stage did it stretch over across the present coast range country and cover part of what is now the San Joaquin valley and Sierra Nevada foothills. And while coarse terrigenous deposits were gathering along the Cantua-Coalinga-Kern River-San Emigdio border region (the Temblor beds of F. M. Anderson, Vaqueros formation of Arnold, Robert Anderson, Johnson, etc.), very pure diatomaceous shales were forming over most of the coastal Monterey-San Luis-Santa Barbara region, and even over some of the interior—the McKittrick-Temblor region—(Monterey shale or Monterey formation of various authors).

⁹³ Proc. Cal. Acad. Sci., 4th Ser., vol. 3, pp. 161-182 (1912).

⁹⁴ Merriam recognizes an upper zone in the Contra Costa County region (see page 206 of this paper), but it is not discussed here, as it is either absent or at least has not yet been definitely recognized in the other Monterey areas.

SUMMARY STATEMENT OF VARIOUS OTHER CONCLUSIONS

No natural formations or groups of sediments exist which correspond to the littoral faunal stages recognized in the Monterey series. Any system of nomenclature which gives both faunal-temporal and formational significance to its terms (except for the series as a whole) is fallacious and pregnant of confusion and misconceptions.

Faunal zones and stages should have faunal names, as "Agasoma zone," stage of *T. ocoyana*, etc., and not formational names (Vaqueros fauna, etc., as recently proposed by J. P. Smith). Names primarily based on lithologic distinctions (depositional facies) have only very local significance as "formations." The term "Vaqueros sandstone" has only a facies value and not a formational one even in the Salinas valley region, where it was originally applied; Temblor as applied in the Kern River region seems quite surely equivalent to at least part of the "Monterey shale" on the west side of the valley. For economic purposes, or purposes of local mapping, and of structural geology it is often important to map local depositional facies—why not call them such? In the Salinas valley region in studying the water resources it may be important to separate the sands from the shales. Why not call them "Sandstone facies," "bituminous shale facies"?

Similarly in the oil fields the distinction is important. In the Santa Maria fields the petroleum bearing "basal sandstones" would be more expressive to geologists and oil men alike than "Vaqueros formation."

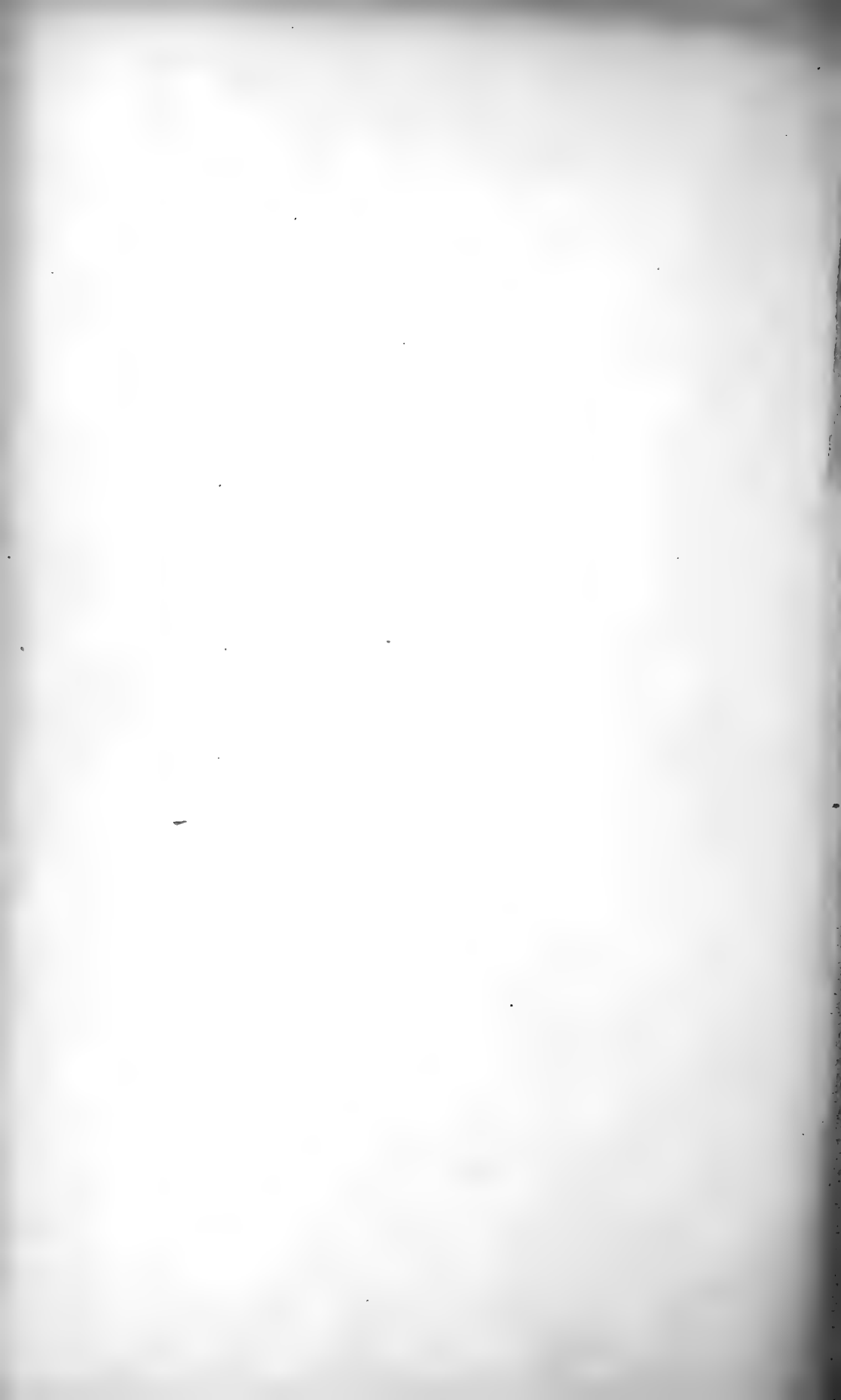
Locality names are not objectionable—though not always necessary—such as Modelo sandstone, Puente sandstone, Puente shale,—to apply to locally developed depositional divisions—provided they are presented in their true value.

Names like "Temblor beds" (in the sense of a supposed lower Miocene formation and faunal stage below the "Miocene shale" formation and zone), Vaqueros formation or sandstone (meaning the same), Monterey shale (in the sense of a supposed middle Miocene formation and faunal stage above the Vaqueros), Modelo formation (for the artificial group of Bull. 309, on the north side

of the Santa Clara Valley, or for the depositional facies south of the valley), Puente formation (in the sense of a local representative of the Monterey series) are either misleading or unnecessary and should be dropped.

Whether all or part of the faunal stages of the Monterey series be made equivalent to the Lower Miocene, the Oligocene or divided between them, in the vicissitudes of the history of long-distance faunal correlation, the series here studied represents a natural stratigraphic unit, with characteristic and related faunal elements, and clearness and simplicity demand that throughout this province of deposition it be designated by a single provincial name. The term Monterey in the form Monterey series has been established by priority and consistent usage and its use is urged as the general designation for deposits of this province and depositional cycle.

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FOSSIL SHARKS

BY

DAVID STARR JORDAN AND CARL HUGH BEAL

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SUPPLEMENTARY NOTES ON
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In the Bulletin of the Department of Geology, University of California publications for 1907, the senior writer published a memoir entitled "The Fossil Fishes of California." In this paper, with other matters, there is a record of the species of sharks known from the Miocene deposits of Kern County, California.

Stanford University has lately received from Mr. Charles Morrice of Bakersfield another large collection of shark's teeth. These were obtained from a hill on the west side of Kern River, about a mile distant from the stream and four miles from Oil City. These were preserved in a fine hard silt. The collection was made by Mr. Morrice at the suggestion or with the aid of Mr. F. M. Anderson of the California Academy of Sciences, Professor Harry A. Millis of Stanford University, Professor W. C. Mitchell of the University of California, and Mr. A. C. McLaughlin of Palo Alto.

Three other papers have dealt with the Miocene sharks of California. Two of these, by Louis Agassiz, preceded the paper of 1907. Professor Agassiz published in the American Journal of Science and Arts, pp. 272-275, a paper entitled "Notice of Fossil Fishes Found in California by W. P. Blake." This article with a few verbal changes and a page of engravings is reprinted in the appendix to Lieutenant Williamson's "Report on

Explorations in California," (U. S. Pac. R. R. Surv. for 1853, pp. 313-316, pl. 1). Since 1907 a review of these papers of Agassiz and of Jordan has been published by Maurice Leriche of Lille. It is entitled "Observations sur les Squales Néogènes de la Californie" and published in the *Annales de la Societe Géologique du Nord* (tome xxxvii, p. 302, December, 1908). This paper is based chiefly on the descriptions and figures published by the senior author in 1907. It consists mainly of a comparison of these California species with those of the same horizon in Europe. Leriche regards most of the species as identical with the European species. It may be freely admitted that in several cases no differences can be made out from the teeth alone. In several genera of sharks, the dentition is the same in all the several species. But to unite nominal species from opposite sides of the globe has also its difficulties. In most cases, the existing species of shark are largely localized, and it must have been so in the Miocene period. There are reasons of convenience for having a different set of specific names in each distinct faunal area. At the best, the substitution of Leriche's names for those of Agassiz in California is the exchange of one doubtful opinion for another. If we trust to teeth alone certain species will appear to have not only a cosmopolitan distribution but an abnormally wide range in geologic time. As the wide-ranging forms among the existing sharks have been studied more carefully, these have been split up into distinct species showing more or less definite localized differences. While no one can be sure that some of these sharks were not fully identical with European forms, we know that some of them are not so. We know also that the Miocene fauna of California is in general wholly different from that of Europe and also from that of the eastern portions of the United States. Where a California species has received a distinctive name we may provisionally allow that name to stand, even if no known characters separate the teeth in question from those of their European analogies.

Still later, several authors (Ameghino, Leriche, Woodward, Gaudry, Tournouer, Priem) have written on the Tertiary fishes of Patagonia, in which region occur a series of sharks, the teeth of which show a very strong resemblance to the species known

from California. Geographically these are nearer to California than the fauna of Europe. Many shark teeth of similar types also occur in the Tertiary of Kansas.

The new material examined in this paper is from the following localities:

1. The collection above mentioned from the lower Miocene, Temblor horizon, near Oil City, Kern County, California, the work of Mr. Charles Morrice and others.

2. One specimen from the collections of the University of California, taken from Chico (upper Cretaceous) sandstone.

3. A collection of fragments of broken teeth from the Eocene, Oligocene, and Miocene of various localities on the coast of Oregon has been presented by Mr. Harold Hannibal of Stanford University.

GEOLOGIC RANGE OF WESTERN AMERICAN SHARKS

Species	Triassic	Cret- aceous	Eocene	Miocene	Pliocene	Pleisto- cene	Recent
<i>Acrodus wempliae</i> Jordan,	x	..	..	..	..	..	..
<i>Myliobatis merriami</i> Jordan and Beal,	x	..	x	..
<i>Carcharhinus antiquus</i> Agassiz,	x	..	..	..
<i>Carcharias clavatus</i> Agassiz,	x	..	..	..
<i>Carcharias morricei</i> Jordan and Beal,	x	..	..	..
<i>Carcharodon arnoldi</i> Jordan,	x	x	..
<i>Carcharodon megalodon</i> Charl. (branneri Jordan),	x	..	..	..
<i>Carcharodon rectus</i> Agassiz,	x	..	..	..
<i>Carcharodon riversi</i> Jordan,	x	..	..	..
<i>Dalatias occidentalis</i> Agassiz,	x	x	..	..
<i>Galeocerdo productus</i> Agassiz,	x	..	..	..
<i>Galeorhinus hannibali</i> Jordan and Beal,	x	x	..	..
<i>Hemipristis chiconis</i> Jordan,	..	x	..	..	..	..	..
<i>Hemipristis hetero- pleurus</i> Agassiz,	x	..	..	..

GEOLOGICAL RANGE OF WESTERN AMERICAN SHARKS—(Continued)

Species	Triassic	Cret- aceous	Eocene	Miocene	Pliocene	Pleisto- cene	Recent
<i>Hepranchias andersoni</i> Jordan,	x	..	..	..
<i>Hybodus shastensis</i> Wemple,	x	..	..	..	..	..	..
<i>Isurus desori</i> Agassiz,	..	x	..	..	..	..	..
<i>Isurus hastalis</i> Agassiz (<i>I. smithii</i> Jordan),	x	x	..	..	..
<i>Lamna appendiculata</i> Agassiz,	..	x	x	..	..	..	..
<i>Rhinoptera smithii</i> Jordan and Beal,	x	x	..	..	..
<i>Squatina lerichei</i> Jordan and Beal,	x	..	..	..

The following is a list of the fossil sharks of California as now recognized:

Family HYBODONTIDAE

Genus HYBODUS Agassiz

1. *Hybodus shastensis* Wemple.

Upper Triassic at Bear Cove, Shasta County.

Genus ACRODUS Agassiz

2. *Acrodus wempliae* Jordan.

Upper Triassic of Bear Cove and North Fork, Shasta County.

Family HEXANCHIDAE

Genus HEPTRANCHIAS Rafinesque

3. *Hepranchias andersoni* Jordan.

Miocene at Barker's Ranch, Kern County.

This *M. Lerichei* identifies with *Notidanus primigenius* Agassiz of Europe. This may be correct, but the living species of *Hepranchias* of California, *H. maculatus* Ayres, is distinct from the European *H. cinereus*. (*Notidanus* is a later synonym of *Hexanchus*.)

Family GALEORHINIDAE

Family GALEOCERDO Muller and Heule

4. *Galeocerdo productus* Agassiz.

Leriche identifies this with *Galeocerdo aduncus* Agassiz of the Swiss Eocene. The four figures given by Jordan ("Fossil Fishes of California") in figure 13, page 114, represent this species. The smaller ones in figure 4 on page 102 referred doubtfully to *Galeocerdo* represent something else. Leriche suggests possibly a species of *Aprionodon*. Perhaps they are side teeth of *Odonaspis*; *e*, as well as *a*, in figure 4, belongs to *Galeorhinus*.

Genus GALEORHINUS Blainville

(*Galeus* Cuvier 1817, not of Rafinesque 1810)

5. *Galeorhinus hannibali* Jordan and Beal, new species.

Miocene of Barker's Ranch; Pliocene of Temescal Cañon.

The species indicated by Jordan (1907) under the name of "*Galeus (zyopterus* Jordan and Gilbert?)" can hardly be identical with the existing shark thus named.

The tooth from the Pliocene of Temescal Cañon, Santa Monica Mountains, is described as similar to the teeth of *Galeorhinus zyopterus*, but more nearly erect and less notched on the outer margin than are most of the teeth of that species. The tooth is small, narrowly triangular, turned moderately outward, the base with five small cusps on the inner margin, the cusp nearly entire. Tooth *e*, figure 4 (figs. *a*, *a'*, of the present paper), from the Miocene of Kern County, must, as indicated by Leriche, belong to this form. This tooth may be taken as type of the species.

The species is named for Mr. Harold Hannibal of Stanford University.

Under the ruling of the International Commission of Zoological Nomenclature, the name *Galeus* cannot be used for this genus, which becomes *Galeorhinus*.

Genus HEMIPRISTIS Agassiz

*(Dirrhizodon Klunzinger)*7. *Hemipristis heteropleurus* Agassiz.

Miocene, Ocoya Creek, Barker's Ranch, Oil City.

As indicated by Jordan and by Leriche these teeth are identical with those of *Hemipristis serra* of the European Miocene. The genus *Hemipristis* is no longer represented among the living fishes of America or Europe.

8. *Hemipristis chiconis* Jordan.

Chico deposits (upper Cretaceous) near Martinez.

Genus CARCHARHINUS Blainville

*(Carcharias Cuvier 1817, not of Carcharias Rafinesque 1810, which is Odontaspis Agassiz)*9. *Carcharhinus antiquus* (Agassiz).

Miocene of Ocoya Creek and Oil City.

We have no new material of this species.

The tooth indicated as No. 7 *Carcharias* sp. by Jordan, page 104 (fig. 5, upper figure) is perhaps a tooth of *Carcharodon rectus* from near the angle of the jaw. A better specimen is in the Morrice collection. We refer this with doubt to *Carcharodon*, probably to *C. rectus*.

Under the rules of the International Commission of Zoological Nomenclature the name *Carcharias* used originally for a single species, which later became the type of *Odontaspis*, must replace *Odontaspis*. The great genus of sharks called *Carcharias* by Cuvier must take the name *Carcharhinus*. This is a most inconvenient but apparently inevitable shifting of names.

Family CARCHARIIDAE

(*Odontaspididae*)

Genus CARCHARIAS Rafinesque

(*Odontaspis* Agassiz, not *Carcharias* Cuvier)10. *Carcharias clavatus* (Agassiz).(*Lamna clavata* Agassiz : Jordan)

Ocoya Creek, Miocene of Kern County.

This is not evidently different from *Odontaspis cuspidatus* (*Lamna cuspidata* Agassiz) of the Miocene and Oligocene of Europe as Agassiz has indicated and as Leriche again points out.

The teeth of *Lamna* and of *Carcharias* are very similar. Leriche observes (translated) "As I shall show in a later memoir ("Poissons Oligocènes de la Belgique") this species was provided with symphyseal teeth and should therefore be referred to the genus *Odontaspis*."

11. *Carcharias morricei* Jordan and Beal, new species.(Text fig. *c*)

To the genus *Carcharias* we refer with some doubt, four well preserved teeth differing in size and form but apparently belonging to the same species. They are from the Miocene of Kern County. They owe their dissimilarity probably to their being from different parts of the mouth. Two of the teeth are bent sharply back at the root and taper from an almost round cross-section to the point. The root is very thick and broad and is almost as wide as the tooth is high. On the sharply curved margin of the tooth, a large basal denticle protrudes from the root.

Another tooth, probably belonging to the same species, but from a different part of the mouth, is about one-half again as high as the preceding ones, the base is sub-triangular and does not bear as great a relative width to the height of the tooth as in the preceding case. The crown is rather convex in cross-section, is notched anteriorly and bears two sharp, rather large denticles on the posterior margin. This tooth may be taken as the type of the species which is named for Mr. Charles Morrice.

Family LAMNIDAE

Genus LAMNA Cuvier

12. *Lamna ornata* Agassiz.

Navy Point, Benicia.

We know nothing of this species.

13. *Lamna appendiculata* Agassiz.

Two teeth, from hard Chico sandstone, are rather long and flexuous. According to Dr. Jordan, "These belong to a species of *Lamna* apparently related to the one figured by Mr. Stewart as *Lamna appendiculata*, from the Cretaceous of Kansas." It is, however, doubtful whether this can be the same species, as there was no geographical connection between the California and Kansas seas during the Cretaceous time.

The large tooth is slender and tapering with sharp, knife-like edges, the altitude measuring about twice the width at the base of the root. The other standing next to it in the jaw is much smaller but similar. This specimen has no basal denticles, which are so characteristic of the larger tooth.

Mr. Harold Hannibal has collected from the Eocene Arago formation of Cape Gregory, Oregon, a tooth of this same genus but perhaps of a new species. It is a little higher compared to the width than the preceding species, sharper and more flexuous, and there are minute striations extending from near the point of the crown to the root of the tooth. This tooth has a basal denticle.

Genus ISURUS Rafinesque

(Oxyrhina Agassiz)14. *Isurus hastalis* (Agassiz).

(Oxyrhina plana Agassiz, loc. cit., p. 274. *Oxyrhina tumula* Agassiz, loc. cit., p. 275. *Isurus smithii* Jordan, loc. cit., p. 111.)

Miocene of Kern County, San Diego County, and Fresno County.

Teeth of a giant species of *Isurus* are excessively common in Miocene deposits of Kern County, far outnumbering all other

shark's teeth. There is no doubt that Leriche is quite right in referring all of these to one species, *plana* being the upper lateral teeth, *tumula* the lower, and *smithii* the long and flexuous front teeth. Similar differences are shown in the dentition of the existing species, *Isuropsis glauca*.

In this genus there are never serrations on the edge of the teeth and never denticles at base.

Some of these teeth are two and one-half inches in height, this indicating a shark of sixty feet more or less in length.

Leriche further identifies this species with *Isurus hastalis* (Agassiz) of Europe, which view is very likely correct. Dr. Priem refers similar teeth from the Miocene of Patagonia to *Isurus hastalis* and Woodward records the same species from Argentina.

Another tooth referable to *Isurus hastalis* was obtained from the lower Miocene at Stanford University, near the base of the intruding basalt columns. Another was found by Mr. Harold Hannibal in the Arago formation (Eocene) near Cape Gregory, Oregon. Still another was obtained by Mr. Hannibal from the Miocene of the east shore of Coos Bay, Oregon. This is quite typical of the lateral upper teeth of *Isurus hastalis*.

A large vertebra, nearly two inches in diameter, probably belonging to *Isurus hastalis* was also found by Mr. Hannibal.

15. *Isurus desori* (Agassiz).

Chico formation, upper Cretaceous.

A single tooth, doubtfully identified with this species of the European Cretaceous.

Genus CARCHARODON Smith

16. *Carcharodon megalodon* Charlesworth.

(*Carcharodon branneri* Jordan)

This giant shark's tooth named *Carcharodon branneri* is distinguished from the equally large *Carcharodon megalodon* of the Miocene of regions about the Atlantic Ocean, by the smaller number of serrations on the large teeth. Of these we count 80 to 100 on each side in the specimens from California called

Carcharodon branneri, while in *Carcharodon megalodon* Charlesworth from South Carolina we count 100 to 120. This distinction is of very doubtful value, and most likely Leriche is right in referring *C. branneri* to the synonym of *Carcharodon megalodon*, a species recorded from the Tertiary in various parts of the world, and undoubtedly the largest of all sharks. A large specimen of *C. branneri* in Mr. Morrice's collection agrees fully with *C. megalodon* from South Carolina.

17. *Carchorodon rectus*, Agassiz.

Miocene of Kern County.

This species, if different from *Carcharodon megalodon* is distinguished by the presence of a lateral denticle. It may be the young of one of the other species mentioned here, although none of these have a lateral denticle. The serrae are about fifty on each side. Probably the upper figure on page 103 of Jordan's memoir represents a lateral tooth of this species. If so, it may be known also by its very coarse serrae.

18. *Carcharodon arnoldi* Jordan.

Pliocene, Pescadero; Quaternary, Rustic Cañon, Santa Monica.

This species is identified by Leriche with the living species *Carcharodon carcharias* (L), (*Carcharodon rondeletii* Muller and Kurle). It has larger teeth than any yet found of the living species, and these are more closely serrated. It is therefore probably distinct.

19. *Carcharodon riversi* Jordan.

Santa Monica, Port Los Angeles, Quaternary; Miocene of Kern and Fresno Counties.

Leriche refers this species also to the living *Carcharodon carcharias*. This view seems improbable. It is perhaps not distinct from *C. arnoldi*, and *Carcharodon rectus* may not be different. In the living species, *C. carcharias*, the serrations on the teeth do not exceed 35 on each side, those of the middle of the side having most. *C. riversi* has about 40, *C. arnoldi* about 50, and *C. rectus* 50 to 60 on each side. *C. rectus*, as already

indicated, may be a lateral tooth and the others may represent different parts of the jaw. Possibly the name *Carcharodon rectus* should include *arnoldi* and *riversi*. But Leriche seems to regard *C. rectus* as the young of *C. megalodon* (= *C. branneri*). Any view of the case is at present a guess, one doubtful opinion being set off against another.

There are at least two fossil and one living species of *Carcharodon* represented in the California fauna. These are *C. megalodon*, *C. arnoldi* (including *C. riversi*?) and *C. carcharias*.

Family DALATIDAE

Genus DALATIAS Rafinesque

(*Scymnus* Cuvier)

20. *Dalatias occidentalis* (Agassiz).

Miocene, Ocoya Creek, Oil City; Pliocene, Temescal Cañon.

No new specimens of this species have been noted.

Family ECHINORHINIDAE

Genus ECHINORHINUS Blainville

21. *Echinorhinus blakei* Agassiz.

This species we have not seen.

Family SQUATINIDAE

Genus SQUATINA Duméril

22. *Squatina lerichei* Jordan and Beal, new species.

(Text fig. *b*)

This species was not named, but was noted and figured (p. 119, fig. 4*d*) by the senior author as perhaps belonging to the genus *Chiloscyllium*. Dr. Leriche suggests correctly that the tooth in question is that of a species of *Squatina*. Additional material is in the collection of Mr. Morrice.

There are five very small teeth, narrow, triangular and nearly erect, with the root very wide, its width nearly twice the height

of the tooth, and projecting backward so that the tooth rests on a triangular base double-notched posteriorly. The tooth will stand when set erect on the table. The enamel of the crown extends downward on the root in front to its base. All the species of *Squatina* are essentially alike in dentition, but as they are local in distribution the living Californian species (*Squatina californica*), being confined to this Coast we may indicate the California Miocene species by a separate distinction. It is named for Maurice Leriche of Lille.

Family MYLIOBATIDAE

Genus RHINOPTERA Kuhl

(*Zygobatis* Agassiz)

23. *Rhinoptera smithii* Jordan and Beal, new species.

(Text fig. *c*)

Under the name of "*Zygobatis* species" Agassiz* records a fragment of a tooth of this genus from Ocoya Creek. Several similar fragments have been obtained at different times from the Miocene of Kern County. The species seems to be abundant. Only single teeth more or less broken have been found. Most likely these belong to the genus *Rhinoptera* rather than to *Aëtobatus* (*Myliobatis*) to which Jordan doubtfully refers it (*loc. cit.*, p. 119). F. Priem (Bull. Soc. Geol. France, 1911, plate III, fig. 77, figures a tooth almost precisely similar from the Miocene of Argentina as "*Rhinoptera* sp."

The teeth from Barker's Ranch and Oil City are laterally much elongated, with serrated or comb-like edge. The breadth of the tooth and the size of the serrations vary considerably, but they must be of the same species. It is not possible to be certain as to the genus to which these fragments belong, but they may be recognized from the accompanying drawing.

Some imperfect, smaller specimens of this species were taken from the Eocene of Big Creek, Oregon, by Harold Hannibal.

The species is named for Dr. James Perrin Smith, palaeontologist of Stanford University.

* Agassiz, Am. Jour. Sci. Arts, 1856, p. 275; U. S. Pac. R. R. Surv., p. 316, pl. 1, figs. 31-35.

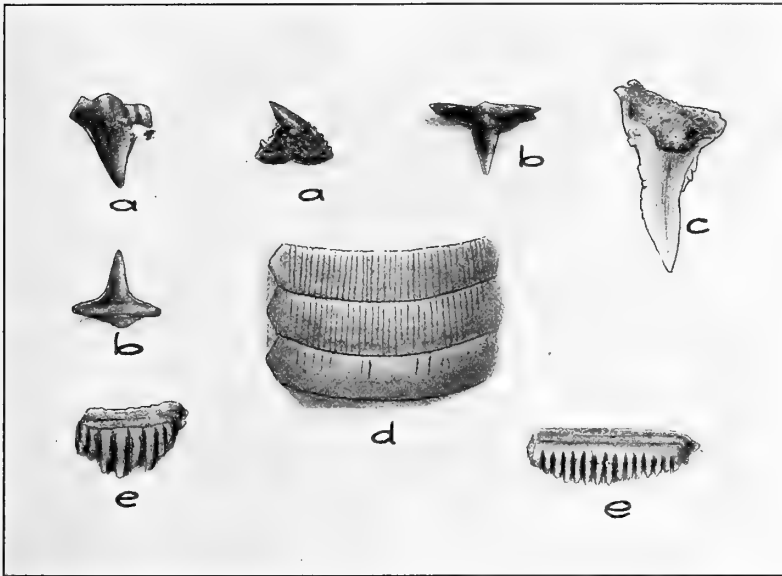


Fig. a. *Galeorhinus hannibali* Jordan and Beal. Pliocene of Temescal Cañon and Miocene of Kern County, California.

Fig. b. *Squatina lerichei* Jordan and Beal. Miocene of Kern County, California.

Fig. c. *Carcharias morricei* Jordan and Beal. Miocene of Kern County, California.

Fig. d. *Myliobatis merriami* Jordan and Beal. Miocene of Kern County, California.

Fig. e. *Rhinoptera smithii* Jordan and Beal. Miocene of Kern County, California.

Genus MYLIOBATIS Cuvier

24. *Myliobatis merriami* Jordan and Beal, new species.(Text fig. *d*)

In the collection of the University of California (no. 19714) is a fine large specimen composed of the three median teeth of a jaw of a species of this genus. These teeth are convex in surface, and curved in outline, the surface marked by longitudinal streaks of enamel which do not however roughen the surface. The teeth are one and one-quarter inches in breadth, each tooth five times as broad as long. The root surface is smooth, without the comb-like structures seen in *Rhinoptera*. The form of the edge of each tooth shows that it was flanked by smaller teeth as in living species of *Myliobatis*. In *Stoasodon* (*Aetobatis* of Müller and Henle) there are no lateral teeth.

The type is from the Miocene near Oil City. It is named for Dr. John C. Merriam, palaeontologist of the University of California. A few other specimens have been since received from Mr. Morrice.

As the generic name *Myliobatis* was first used about 1811 by Geoffroy St. Hilaire, it must have priority over *Aetobatus* proposed by Blainville in 1817.

As stated elsewhere (American Naturalist) the species described in Jordan's memoir ("Fossil Fishes of California," p. 131) as *Merriamella doryssa* proves to be a stickleback and should stand as *Gasterosteus doryssus*. It was later described by Dr. O. P. Hay, from the same Miocene deposits on the Truckee River, as *Gasterosteus, williamsoni leptosomus* (Proc. U. S. N. M., xxxii, 1907, p. 271).

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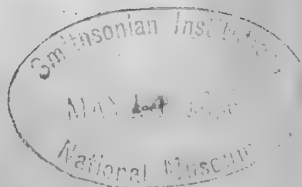
Issued April 29, 1913

FAUNA OF THE EOCENE AT MARYSVILLE
BUTTES, CALIFORNIA

BY

ROY E. DICKERSON

UNIVERSITY OF CALIFORNIA PRESS
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INTRODUCTION

The Eocene fauna obtained from outcrops at Marysville Buttes, California, has been known from the work of W. L. Watts and J. G. Cooper of the California State Mining Bureau, and Waldemar Lindgren and H. W. Turner of the U. S. Geological Survey.

In the course of a study of the Eocene fauna of California, small collections, the gifts of O. W. Jasper and W. L. Watts, representing the Eocene fauna from Marysville Buttes attracted the writer's attention by their wonderful preservation, and by the peculiar faunal phase represented. Most of the species in these collections had not been recognized in other Eocene localities. In order to determine the zonal relations of this fauna, the writer visited the Marysville Buttes in December, 1911, to collect for the Department of Palaeontology of the University of California. The writer is particularly indebted for many valuable suggestions to Professor J. C. Merriam, under whose supervision this work was undertaken.

REVIEW OF LITERATURE

The Eocene of Marysville Buttes was first described by W. L. Watts¹ who referred to it using the name "Cretaceous B," in the sense in which it had been used by Gabb.²

¹ Watts, W. L., The Gas and Petroleum Yielding Formations of the Central Valley of California. Bull. No. 3, California State Mining Bureau. Aug., 1894, pp. 9-10.

² Gabb, W. M., Geological Survey of California, Palaeontology, vol. 1, preface, p. 19, 1864.

In this note Watts referred to the sedimentary beds and recognized their geographic relation to the central igneous rocks. "In ascending the most southerly peak from the Moody ranch patches of light colored sand toward the base of the mountain mark the sedimentary formation and the coal measures. A few fragments of fossiliferous rock, showing Cretaceous fossils may be found on a portion of the slope. The best exposure of sedimentary rocks was seen at the base of the West Butte about a mile from the village of that name." He recognized an unconformity between the white sandy formation, dip about 15° S.W. and the underlying "Cretaceous" shales and clayey sandstone, dip 70° S.W. A partial list of fossils identified by Cooper was given. Most of these were recognized as occurring in "Cretaceous B" of Gabb. Through the courtesy of State Mineralogist Storms, the writer examined this collection and redetermined some of the species. The species which were redetermined are given in parenthesis after Cooper's determinations.

Leda gabbi Conrad	Ostrea idriaensis Gabb
Lunatia hornii Gabb	Corbula parilis var(?) Gabb
Olivella mathewsonii Gabb	Mysia polita Gabb
Nucula solitaria Gabb	Modiola cylindrica Gabb
(Nucula cooperi, n.sp.)	(Modiola cylindrica Gabb is probably an incorrect determination.)
Nassa cretacea Gabb	Cardita planicosta Lam.
Turritella uvasana Gabb	Area hornii Gabb
Turritella merriami, n.sp.)	Cardium translucidum Gabb
Turritella chicoensis Gabb	(Cardium dalli, n.sp.)
(Turritella merriami, n.sp.)	Dentalium, sp.
Meretrix hornii Gabb	Morio tuberculatus Gabb
Galerus excentricus Gabb	Architectonica hornii Gabb
Cardita veneriformis Gabb (probably the young of Cardita planicosta)	(Architectonica weaveri, n.sp.)
	Cucullaea, sp.

Dr. J. G. Cooper³ described the new species collected by Watts on the west side of West Butte, discussed the conditions of deposition and suggested that the strata were Eocene, although he used "Cretaceous B" as a synonym in some of the descriptions of new species. All of these descriptions are given at end of this paper and most of the species are refigured. Cooper wrote at a time when the debate concerning the age of the

³ Cooper, J. G., Catalogue of California Fossils, Bull. No. 4, California State Mining Bureau, Sept., 1894, pp. 36-45.

so-called "Cretaceous B" beds of Gabb was still undecided and on this account many points in his discussion are somewhat confused.

Lindgren and Turner⁴ in the Marysville Folio described the relations of the sedimentary beds to the central igneous core, divided the sedimentary beds into two formations, the Ione and the Tejon, recognized the age of the Tejon as Eocene, and the Ione as Miocene. This description is as follows:

"Between the exterior mud-flows and the massive core, and strongly contrasting with them, there often occur a series of smooth, rounded hills forming a frequently interrupted ring a mile or less in width. These hills are not volcanic but consist of a series of sandstones (usually soft), white or dark clays and gravelly beds. The beds are very much disturbed and dip at all angles and in all directions. As a rule, however, they dip away from the central core, and when near it stand at high angles, sometimes vertical. At the immediate contact with the massive volcanic rocks these sediments are usually hardened. No volcanic detritus of the same rocks of which the Buttes are made up is found in them, and it may be regarded as certain that they were laid down before the period of volcanic activity. The oldest of the formations belongs to the Tejon formation (Eocene); it has thus far been identified only in the sedimentary area northeast of the village of West Butte. It is here composed of greenish sandstone and shales, adjoining the volcanic masses and dipping at high angles east or west. A thickness of several hundred feet of sediments is exposed. Some of the beds contain abundant marine fossils, characteristic of the Tejon among which a small coral (*Trochosmia striata* Gabb) is most abundant. *Cardita planicosta*, a form eminently characteristic of the Tejon is also found. Overlying these beds are light-colored, soft sandstones and clays, dipping west at an angle of about 20°, which have been referred to the Ione formation. The other sedimentary areas consist largely, if not entirely, of these soft light-colored beds." Lindgren⁵ in a recent publication summarizes the dis-

⁴ Lindgren, W., and Turner, H. W., Marysville Folio, U. S. Geol. Surv. Folio 17, April, 1895.

⁵ Lindgren, W., The Tertiary Gravels of the Sierra Nevada of California, Professional Paper, U. S. Geol. Surv., No. 73, pp. 23-25; 1911.

cussion of the Ione and Tejon given in the Marysville Folio, and in addition gives a list of marine fossils found two miles east of South Buttes.

STRATIGRAPHIC RELATIONS AND LITHOLOGY OF MARYSVILLE BUTTES Eocene

According to the authors of the Marysville Folio, the buttes consist of a central core of coarse grained andesite which was forced up in the valley floor, a ring of sedimentary beds which were upturned when the lava was forced out, and a ring of andesitic muds which were thrown out from secondary craters on the edge of the sedimentary ring. In general, the sedimentary beds dip away from the central core. The only Eocene area which is mapped in the Marysville folio is a strip about a mile and a quarter long by a quarter mile wide on the west side of the buttes two miles east of the South Buttes. The Eocene in this area is overlain by the Ione formation which has a dip of 15° W., while the Eocene has in most places a dip of 35° to 40° W., strike N 90° W., although the dip is nearly vertical near West Butte peak. The Ione consists of gravels and sands, for the most part unconsolidated. Cross-bedding is very common and intricate. These sediments were probably deposited on the Eocene as an alluvial fan. The Ione in turn is overlain by andesitic mud flows—now firmly cemented—which dip to the west about 4° – 5° .

An east-west section through West Butte largely adapted from the Marysville Folio shows the following sequence on the west side:

- 100 feet of green-gray sandstone and shale with limestone concretions marking the upper limit of the Eocene.
- 300 feet of green-gray, glauconitic shale.
- 200 feet of massive, thin-bedded, buff sandstone.
- 100 feet of impure, gray limestone with thin strata of hard gray, medium-grained sandstone.
- 600 feet of massive, medium-grained, yellow, non-fossiliferous sandstone in contact with the andesitic core.

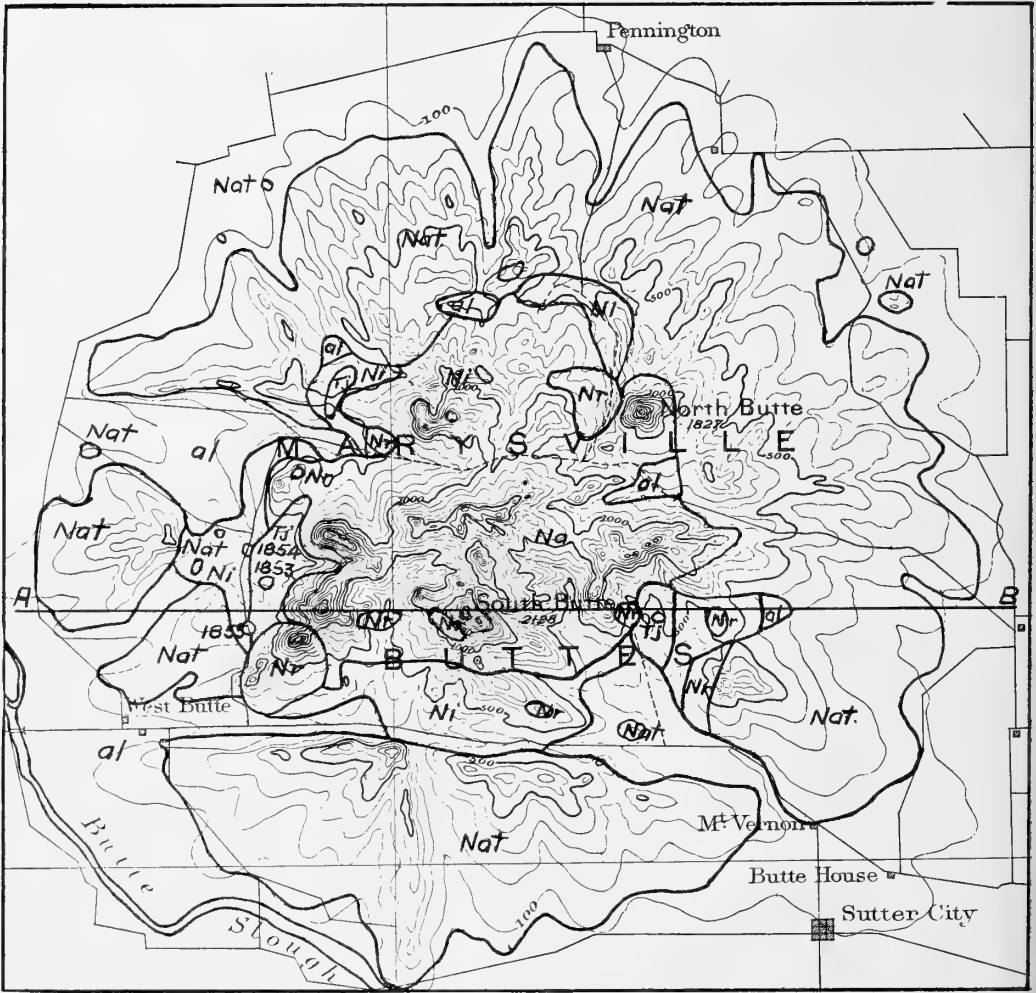
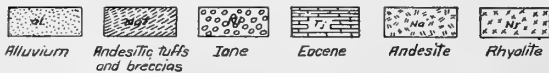


Fig. 1



Fig. 2

Figs. 1 and 2. Map of Marysville Buttes region with section showing sequence of geologic formations. *Al*, alluvium; *Nat*, andesitic tuffs; *Ni*, Ione; *Tj*, Tejon; *Na*, andesite; *Nr*, rhyolite. Scale, 1/2 inch = 1 mile. Fig. 1, areal relations of formations; fig. 2, east-west section along line *AB* as shown on fig. 1.



Resting upon the Eocene are 500–600 feet of Ione gravels and sands. The two uppermost Eocene members, which are very fossiliferous, can be easily recognized in the field by the bright red, clay soil formed through their decay. The limestone concretions, which are sometimes yellow, contain many small, dark green to black, rounded grains. When these are carefully examined with a hand lens they are found to be foraminiferal casts composed of glauconite. The green shales as well as the sandstone also contain glauconite and foraminifers. The strata are lithologically similar to certain horizons in the Martinez, but the character of the fauna here compels us to abandon the notion that green glauconitic sandstone and shale are absolutely indicative of the Martinez in the middle California region. Glauconitic sandstone also occurs in the Tejon of the Mt. Diablo region.

On the east side of South Butte the writer has mapped another Eocene area which has about the same sequence as the above. Thin strata of coal are reported by Watts⁶ and later by Lindgren⁷ and Turner, from the lower portion of this section.

According to H. Hannibal some of the area south of South Butte mapped as Ione is Cretaceous.

LIST OF THE FAUNA FROM THE UPPERMOST EOCENE OF MARYSVILLE BUTTES

The writer found most of the following species at the locality to which reference was made by Watts, and by Lindgren and Turner. The species starred (*) were reported by Cooper, but were not found by the writer. The single species marked by a dagger (†) was found at a locality two miles east of South Butte. The occurrence of each species is marked by an "x" in the columns representing separate localities.

⁶ Watts, W. L., The Gas and Petroleum Yielding Formations of the Central Valley of California. Bull. No. 3, California State Mining Bureau, p. 9, Aug., 1894.

⁷ Lindgren, W. and Turner, H. W., Marysville Folio, U. S. Geol. Surv. Folio 17, p. 2, April, 1895.

	Marysville Buttes	Mt. Diablo Region	Near Fort Tejon	Other localities
<i>Ancilla</i> (Oliverato) <i>californica</i> Cooper	x	x	..	x Oregon
<i>Astyris</i> , sp.	x	..	..	..
<i>Architectonica weaveri</i> , n.sp.	x	..	..	..
* <i>Bittium longissimum</i> Cooper	x	..	..	..
* <i>Cancellaria irelaniana</i> Cooper	x	..	..	x Coalinga
<i>Cancellaria stantoni</i> , n.sp.	x	..	x	..
<i>Caricella stormsiana</i> , n.sp.	x	..	..	..
<i>Cordiaera graecillima</i> Cooper	x	..	..	..
<i>Clavella tabulata</i> , n.sp.	x	..	..	..
<i>Cylichna costata</i> Gabb	x	x	x	..
<i>Calliostoma</i> (?) <i>arnoldi</i> , n.sp.	x	..	..	..
<i>Drillia ullreyana</i> Cooper	x	..	..	..
<i>Dentalium stramineum</i> Gabb	x	x	x	..
<i>rufinus</i> (<i>Priscofusus</i>) <i>lineatus</i> , n.sp.	x	..	..	..
<i>Ficopsis remondii</i> Gabb	x	x	x	..
<i>Galerus excentricus</i> Gabb	x	x	x	..
<i>Lunatia hornii</i> Gabb	x	x	x	..
<i>Lunatia nuciformis</i> Gabb	x	x	x	..
<i>Morio tuberculatus</i> Gabb	x	x	x	..
<i>Niso polito</i> Gabb	x	x	x	..
<i>Olivula marysvillensis</i> , n.sp.	x	..	..	..
<i>Olivella mathewsonii</i> Gabb	x	x	x	..
<i>Perissolax blakei</i> Gabb	x	..	..	..
<i>Phos</i> (?) <i>martini</i> , n.sp.	x	..	..	x Oregon
<i>Sureula crenatospira</i> Cooper	x	..	..	..
<i>Sureula holwayi</i> , n.sp.	x	..	..	..
<i>Sureula clarki</i> , n.sp.	x	..	..	..
<i>Sureula davisiana</i> (Cooper)	x	..	..	..
<i>Sureula</i> (<i>Sureulites</i>) <i>sinuata</i> Gabb	x	..	x	..
<i>Siphonalia sutterensis</i> , n.sp.	x	..	..	..
<i>Tritonium californicum</i> Gabb	x	x	x	x Coalinga
<i>Tritonium whitneyi</i> , Gabb	x	..	x	x San Diego
* <i>Terebra wattsiana</i> Cooper	x	..	..	..
<i>Turritella merriami</i> , n.sp.	x	x	..	x Oregon
<i>Turris andersoni</i> , n.sp.	x	..	..	..
<i>Turris perkinsiana</i> (Cooper)	x	..	..	..
<i>Turris inconstans</i> (Cooper)	x	..	..	..
<i>Turris monolifera</i> (Cooper)	x	x	..	..
<i>Turris suturalis</i> (Cooper)	x	..	..	..
<i>Voluta lawsoni</i> , n.sp.	x	..	..	..
<i>Acila</i> , cf. <i>truncata</i> Gabb	x	x	x	..
<i>Area</i> , cf. <i>hornii</i> Gabb	x	x	x	..
<i>Avicula pellucida</i> Gabb	x	x	x	..
<i>Cardium dalli</i> , n.sp.	x	..	..	..
<i>Corbula parilis</i> Gabb	x	x	x	..
<i>Corbula hornii</i> Gabb	x	..	x	..
<i>Cardita planicosta</i> Lamarek	x	x	x	..

	Marysville Buttes	Mt. Diablo Region	Near Fort Tejon	Other localities
<i>Dosinia elevata</i> Gabb	x	x	x	..
<i>Glycimeris cor</i> Gabb	x	x	..	..
<i>Glycimeris marysvillensis</i> , n.sp.	x	..	..	..
<i>Leda gabbi</i> Conrad	x	x	x	..
* <i>Mysia polita</i> Gabb	x	x	x	..
<i>Meretrix</i> (?), sp.	x	..	..	..
* <i>Meretrix hornii</i> Gabb	x	x	x	..
<i>Nucula cooperi</i> , n.sp.	x	..	..	..
<i>Ostrea idriaensis</i> Gabb	x	x	..	x New Idria, Coalinga
<i>Solen parallelus</i> Gabb	x	x	x	..
<i>Tapes conradiana</i> Gabb	x	x	x	..
† <i>Tellina sutterensis</i> , n.sp.	x	x	x	..
✓ <i>Schizaster lecontei</i> Merriam	x	x	x	..
<i>Trochoyathus striatus</i> Gabb	x	x	..	..
<i>Trochoyathus</i> (?) <i>perrini</i> , n.sp.	x	..	..	..
<i>Cancer</i> , sp.	x	..	..	..
<i>Nodosaria</i> , sp.	x	..	..	x Coalinga
<i>Synechodus</i> , sp.	x	..	..	..

BATHYMETRIC RELATIONS OF THE FAUNA

Dr. Cooper⁸ in discussing two collections of fossils made by Watts from the San Joaquin Coal Mine near Coalinga, Fresno County, and Marysville Buttes incidentally states his ideas concerning the bathymetric conditions under which this fauna was deposited as follows: "It is certain at least that the two localities from which Mr. W. L. Watts obtained the specimens described, furnished no Ammonitidae but this may be explained on the theory that they represent shallow water deposits close to a seashore or estuary, in which large quantities of vegetable matter from the land were accumulated. Both the probable habits of the species found at the coal mines near Huron, Fresno County (as compared with nearly related species), and the presence of coal in the rocks containing them, point to such a conclusion, and the occurrence of many of the same species, together with a thin bed of coal somewhat further away, indicate that the species from Marysville Buttes inhabited a similar but somewhat deeper sea."

⁸ Cooper, J. G., Catalogue of California Fossils, Bull. No. 4, California State Mining Bureau, p. 36. 1894.

Cooper, in placing the species referred to *Potamides*(?) *davisiana* under this genus, which is confined to brackish water or estuarine conditions, also leads one to infer that these strata are estuarine deposits. One of the specimens shows that his generic classification, due to a superficial resemblance to *Potamides diadema* Gabb is incorrect. The form referred to *Potamides* is a *Surcula*. The formation of glauconite by deposition in the tests of foraminifers, the occurrence of the genus *Trochocyathus*, and of certain genera of Gastropoda and Pelecypoda indicate that these beds are not in-shore deposits.

Thompson and Murray⁹ in discussing the bathymetric distribution of glauconite state that—"it appears to be most abundant about the lower limits of wave tidal and current action or in other words in the neighborhood of what we have termed the mud line surrounding continental shores. In the shallower depths beyond this line, that is to say, in depths of about 200 and 300 fathoms, the typical glauconitic grains are more abundant than in deeper water, but glauconitic casts may be met with in deposits in depths of over 2,000 fathoms. No typical glauconitic sands have, so far as we know, been recorded in process of formation in the littoral or sub-littoral zones."

Mosley¹⁰ gives the range of *Trochocyathus* found at present in the sea as from 100 fathoms to 750 fathoms.

Vaughan¹¹ in his monograph on corals considers them as peculiarly valuable indicators of bathymetric conditions of deposition.

Tryon¹² gives the following ranges for some of the genera of Gastropoda and Pelecypoda listed above. "The *Cancellariae* from low water to forty fathoms," *Turris*, low water to 100 fathoms; *Corbula*, lower laminarian zone to 80 fathoms; *Dosinia*, low water to 80 fathoms; *Cardium*, from sea shore to 140 fathoms; *Nucula*, 10-180 fathoms; *Leda*, 10 to 180 fathoms; *Turritella*, approximate range near 100 fathoms; *Tapes*, low water to 100 fathoms. The relatively small number of species of the genera

⁹ Challenger Report, Deep Sea Deposits, p. 378-391. 1891.

¹⁰ Challenger Report, Zoology, vol. ii, pt. vii, p. 132. 1881.

¹¹ Vaughan, T. W., U. S. Geological Survey, Monograph 43, The Eocene and Oligocene Corals of the United States, p. 23-33. 1900.

¹² Tryon, G. W., Structural and Systematic Conchology, vol. 1, 1882; vol. 2, 1883; vol. 3, 1884.

which range from low water to 100 fathoms was decidedly noticeable when the collection listed above was made. The lamellibranchs were, except *Nucula*, *Leda* and *Cardium*, very rare.

The evidence taken as a whole leads to the conclusion that the glauconitic sandstones and shales were laid down in water about 100 fathoms deep.

CLIMATIC CONDITIONS DURING ACCUMULATION OF MARYSVILLE BUTTES EOCENE

Another factor which must be considered in connection with this unique fauna is the climate at the time of the deposition of the sediment containing it. Dr. Cooper¹³ in describing *Turris monolifera* makes the following note: "The occurrence of seven new pleurotomidae without many other univalve shells, and especially the absence of many forms of genera allied to *Fusus* described by Gabb, is a condition of distribution indicating probably that a warmer sea existed where they are found than at most localities of similar age in California." Thorough collection does not sustain his view entirely. The number of Pleurotomidae is noteworthy, but they are associated with twenty-eight other univalve shells and seventeen lamellibranchs. Several of these gastropods are allied to *Fusus*. He was comparing a fauna which is not essentially littoral to species which are found in a portion of the Chico, the Martinez, and the Tejon. The writer is in thorough agreement with this suggestion of a warmer climate during the deposition of the Eocene of the Marysville Buttes, but the littoral or shallow water fauna of the typical Tejon *also* suggests a warmer climate than that of the present day. Several of the species, *Voluta lawsoni*, *Tapes conradiana*, *Oliverata californica*, *Surcula crenatospira* and *Cardium dalli*, still retain high coloring suggesting strongly the tropical forms of today. Several of these genera are according to Tryon confined to or characteristic of tropical and sub-tropical waters. Among these are *Voluta*, *Siphonalia*, *Turris*, *Surcula*, *Drillia*, *Terebra* and *Cancellaria*.

¹³ Cooper, Dr. J. G., California State Mining Bureau, Bull. No. 4, Catalogue of California Fossils, pp. 39-40. 1894.

It is not probable that the peculiarities of this fauna are due to climate, as the fauna of the type Tejon is also tropical or subtropical. The great variety of genera, and the great abundance of forms at most localities of the Tejon indicate life conditions such as are generally found in tropical or subtropical seas.

The widespread geographic distribution of certain species characteristic of the Tejon is especially noteworthy. *Cardita planicosta* is nearly world-wide, *Meretrix hornii*, *Tapes conradiana*, *Dentalium stramineum*, *Perissolax blakei*, and many others range from Washington to San Diego at least. C. E. Weaver's collections from the Eocene of Washington, the California Academy of Sciences' collection made by Martin in Oregon, and the Tejon collections show a great number of species common to all three localities and the writer infers from this that unusually uniform conditions of climate prevailed along the coast.

When the fauna from the Eocene of Eastern Oregon listed in the description of *Turritella merriami*, n.sp. (p. 287), is compared with that of the typical Tejon the difference is seen to be very slight. But few new species are found there, although the locality is several hundred miles distant. A Tejon fauna from San Diego collected by Mr. Wm. Kew does not show a great number of species different from those of Mt. Diablo region. Several species which were first known only from San Diego have since been recognized in the Tejon of the Mt. Diablo region. Geographic separation is thus seen to be insufficient to account for the great difference between the Tejon of Fort Tejon and the Marysville Buttes Eocene.

GEOGRAPHY OF THE TEJON SEA

Extensive Eocene deposits occur along the coast of Oregon and Washington as well as a considerable distance inland. Eocene deposits are found in Southern Oregon but no Eocene has been reported from the Klamath Mountains. That most of the Eocene of Oregon and Washington is Tejon can not be questioned if a careful study of the fauna is made. Form after form is seen to be identical beyond a doubt with those of the Tejon, although, as one might expect, there are many species which are new. Com-

ing down the coast, the next Eocene is reported by Gabb¹⁴ from Round Valley, Mendocino County. This is Tejon.

Tejon is reported from Lake County, which is west of the Marysville, although none is reported from along the coast of Sonoma or Marin Counties or the San Francisco Peninsula. The Tejon Sea probably once extended over the present site of Lake County, and reached nearly continuously through Napa County along the west side of the San Joaquin Valley to its southern end. Extensive lava flows in Napa county prevent a tracing of Tejon sediments to the Mt. Diablo region. Tejon is reported on the eastern side of the San Joaquin along the Merced River. The authors of the Santa Cruz folio¹⁵ do not report any Tejon, although the Butano formation may be of this age.

Fairbanks in the San Luis folio states that during Eocene times that region was a land area. Extensive Eocene deposits are found, however, in Santa Barbara County immediately to the south and at various other places along the coast to San Diego, and Lower California as far south as 29° 30', N. latitude.

In the discussion of bathymetric relations it was pointed out that the probable depth of the Eocene sea during the time of deposition of the green shales at Marysville Buttes was approximately 100 fathoms. As this is considerably deeper than the fauna of most Tejon localities indicates as prevailing during the deposition of their enclosing sediments, we may conclude that in the northern portion of the state some deposits were formed along the coast of an open ocean. This idea is also reënforced by the statements of Thompson and Murray¹⁶ in discussing the geographic distribution of glauconite. They conclude that "Where the detrital matters from rivers are exceedingly abundant, and where there is apparently a rapid accumulation, glauconite, though present, is relatively rare; on the other hand, along high and bold coasts where no rivers enter the sea, and where accumulation is apparently less rapid, glauconite appears in its typical form and greatest abundance."

¹⁴ Gabb, W. M., California Geological Survey, Palaeontology, vol. 2 (preface, p. 13), 1869.

¹⁵ Branner, J. C., Newsom, J. F., and Arnold, R., U. S. G. S., Folio 163, p. 3, 1909.

¹⁶ Challenger Report, Deep Sea Deposits (p. 382), 1891.

That these glauconitic sediments were deposited along an open ocean seems probable. Whether this is a unique condition in the Tejon is a question that arises immediately. The conditions of deposition during portions of Tejon time were evidently fairly uniform over California. White to dull red quartzose sandstones with cavernous weathering are typical of Tejon sections from San Diego to Lake County. Such a uniformity in lithology might be explained by deposition along a coast unbroken by large islands and peninsulas. The evidence indicates that no extensive or continuous land masses existed along the California coast west of the Sierras during Tejon time. Although sediments deposited in fresh or brackish waters are found, they appear to represent local oscillations of the strand line or estuarine deposits only. During most of Tejon time, a great embayment probably stretched from southern California to the region of Marysville Buttes, curving westward north of Mendocino County.

ZONAL POSITION OF THE MARYSVILLE BUTTES FAUNA

Of the species listed above from the Eocene at Marysville Buttes the following occur both in the Martinez and the Tejon:

<i>Cylichna costata</i>	<i>Perissolax blakei</i>
<i>Dentalium stramineum</i>	<i>Acila truncata</i>
<i>Galerus excentricus</i>	<i>Leda gabbi</i>
<i>Lunatia hornii</i>	<i>Schizaster lecontei</i>
<i>Niso polito</i>	

There are no distinctive Martinez species in the list, and the fauna has little or no suggestion of Martinez affinities. The following species are reported from Tejon localities:

<i>Cancellaria irelaniana</i>	<i>Cardita planicosta</i>
<i>Lunatia nuciformiis</i>	<i>Dosinia elevata</i>
<i>Morio tuberculatus</i>	<i>Glycimeris eor</i>
<i>Olivella mathewsoni</i>	<i>Meretrix hornii</i>
<i>Surcula (Surreulites) sinuata</i>	<i>Mysia polita</i>
<i>Surcula monolifera</i>	<i>Ostraea idriaensis</i>
<i>Tritonium californicum</i>	<i>Solen parallelus</i>
<i>Tritonium whitneyi</i>	<i>Tapes conradiana</i>
<i>Area hornii</i>	<i>Trochocyathus striatus</i>
<i>Avicula pellucida</i>	<i>Nodosaria, sp.</i>
<i>Corbula parilis</i>	

In the total list of sixty-five species a total of only thirty-one are reported from other Tejon localities. Nearly all of these forms, as the table shows, have a wide geographic range. The partial list of species collected by Bruce Martin from the Umpqua formation, given under the description of *Turritella merriami*, (p. 287), shows that many of them are found in the Eocene of Oregon. Many of these forms have also a great stratigraphic range. The exact range of some of these species is not known. *Cardium cooperi* is probably the progenitor of *Cardium dalli*. *Trochocyathus striatus* occurs in the San Francisco Bay region above the coal strata north of Mt. Diablo and in uppermost Tejon, south of Mt. Diablo where it is associated with *Cardium cooperi*. This suggests that the uppermost Eocene of the Marysville Buttes is younger than that of Mt. Diablo Region. Without doubt the beds at Marysville Buttes are Eocene but their fauna apparently represents a faunal zone which has not been recognized elsewhere. This faunal assemblage has over thirty species, which have not been found at other localities.

It has been shown that the peculiar aspect of the Marysville Buttes fauna is not due solely to local facies of climate, or of habitat along an open ocean. Life in relatively deep water no doubt influenced its development, but this factor does not explain the great difference between this fauna and that found in the uppermost Tejon of the Mt. Diablo region. As nearly as can be determined, the peculiarities of the Marysville Buttes fauna are due in some measure to its having lived in a division of Eocene time from which no adequate representation of the marine life of the Pacific Coast has been known up to the present time. Evidence that the Marysville Buttes collections represent a zone slightly different from the uppermost Tejon of the Mt. Diablo region is found in the fact that his assemblage differs much more from the Martinez fauna than does the fauna of any portion of the typical Tejon. This would indicate that the Marysville Buttes zone is removed from the Martinez by a longer period than is the typical Tejon. That the Marysville Buttes fauna is later than the Martinez and chiefly later than the typical Tejon is shown (1), by the absence of such genera as *Cucullaea*, *Anchura*, *Heteroterma*, *Urosyca*, and *Her-*

coglossa; (2), by the presence of such genera as *Bittium*, *Cordiera*, *Cancellaria*, and *Drillia*; (3), by the occurrence of such species as *Trochocyathus striatus*, *Tritonium californicum*, *Corbula parilis*, *Glycimeris cor*, *Tapes conradiana*, *Oliverato californica*, and *Cardium dalli*, n. sp.

Of the first mentioned genera *Cucullaea* and *Anchura* are characteristic of the Cretaceous and of the earliest Eocene on this coast. *Heteroterma* and *Urosyca* are wholly restricted to the Martinez. Since none of these genera are represented in the Marysville Buttes Eocene, the fauna is evidently not pre-Martinez. *Bittium*, *Cordiera*, *Cancellaria*, and *Drillia* are all represented in stages ranging from the late Eocene to the Recent. Since they occur in the Eocene strata of the Marysville Buttes, it is evident that this fauna is a phase of the later Eocene or Tejon, as they are certainly more characteristic of the later Eocene than they could be of any horizon inferior to the early Eocene of the Martinez stage. The species mentioned above all occur in the uppermost Tejon of the Mt. Diablo region except the last, whose precursor, *C. cooperi*, is found there. *Trochocyathus striatus* is restricted to the upper portion of the Tejon of this locality. *Cardium dalli*, n. sp., seems to the writer to have evolved from *C. cooperi* and hence to have lived at a later time. The unique character of the Marysville Buttes fauna appears to be due to its representing a period from which no adequate fauna had previously been obtained and not to depth of water, climate, or other causes. That it evolved from the typical Tejon there can be little doubt. We are led to the conclusion that the Marysville Buttes fauna is not only further removed from the Martinez than is the typical Tejon, but that the distance removing it from the Martinez is measured toward the Recent fauna. In other words the evidence indicates that the Marysville Buttes fauna represents a later zone or stage of the Eocene than the typical Tejon.

THE TEJON EAST OF SOUTH BUTTE

Two fossiliferous localities in the Ione formation are described in the Marysville folio, and these places were recently mentioned by Lindgren¹⁷ in the Tertiary Gravels of the Sierra Nevada of California as follows:

“Marine fossils were found about two miles east of South Butte and two and one-half miles north-northwest of South Butte. The fossils, while not abundant, point to a Miocene age. These beds are believed to be the exact equivalent of the Ione formation exposed along the foothills of the Sierra Nevada. Their aggregate thickness is very considerable, 1,000 feet being a fair minimum estimate. The following fossils were identified by Messrs. Stearns and Dall:”

<i>Crassatella collina</i> Conrad	<i>Macoma</i> , sp.
<i>Venericardia borealis</i> Conrad	<i>Tapes</i> (<i>Cuneus</i>), sp.
<i>Verticardia</i> (?), sp.	<i>Saxidomus</i> , sp.
<i>Acila castrensis</i> Hinds	<i>Cardium modestum</i> Conrad
<i>Liocardium apicinum</i> Carpenter	<i>Galerus</i> , sp.
<i>Fusus</i> (<i>Exilia</i>), sp.	

In another place Lindgren states: “These fossils are regarded by Messrs. Stearns and Dall as Miocene.”

The writer visited these localities recently and found the following fauna at the first locality, two miles east of South Butte:

UNIVERSITY OF CALIFORNIA LOCALITY 1856

<i>Ancilla</i> (<i>Oliverata</i>) <i>californica</i> Cooper	<i>Tritonium whitneyi</i> Gabb
<i>Galerus excentricus</i> Gabb	<i>Tritonium</i> , cf. <i>californicum</i> Gabb
<i>Voluta lawsoni</i> , n.sp.	<i>Cordia</i> <i>gracillima</i> Cooper
<i>Dentalium stramineum</i> Gabb	<i>Lunatia nuciformis</i> Gabb
<i>Trochocyathus striatus</i> (Gabb)	<i>Cardita planicosta</i> Lam.
<i>Turris monolifera</i> (Cooper)	<i>Cardium dalli</i> , n.sp.
<i>Turris suturalis</i> (Cooper)	<i>Tellina sutterensis</i> , n.sp.
	<i>Meretrix</i> , cf. <i>ovalis</i> Gabb

The fossils were found in limestone fragments which are exactly like those in the Eocene on the west side of the mountain. Essentially the same stratigraphic sequence is found on the east side as is seen on the west. The same bright red clay and glau-

¹⁷ Lindgren, W., The Tertiary Gravels of the Sierra Nevada of California, Professional Paper 73, U. S. Geol. Surv., pp. 57, and 120, 1911.

conitic shales and limestones occur here. There seems no room for doubt that these beds represent the same horizon in the Tejon as those on the west side of the Buttes.

The writer did not find fossils in the locality two and one-half miles north-northwest of South Butte, but the same bright red soil with concretionary limestone occurs here as a narrow strip bordered on the east and west by Ione conglomerates. It is lithologically the same as the Tejon area two miles south. Since these are the only localities which were described as furnishing marine Ione fossils it would seem that marine Tejon has been confused with Ione, and that there is no evidence to indicate the presence of an extension of the sea into this region in Miocene time.

SUMMARY

1. The Eocene of the Marysville Buttes is evidently of a relatively late stage.

2. Glauconitic beds, previously known only from the Martinez in the California Eocene, are present in the uppermost Eocene of the Marysville Buttes region.

3. There is no evidence of brackish water or of estuarine conditions in the region of Marysville Buttes while the uppermost glauconitic beds containing Tejon fossils were accumulating.

4. The fossil-bearing beds of the Marysville Buttes Eocene accumulated in water about 100 fathoms deep.

5. The faunal zone represented by these beds appears to be younger than the Tejon of the type localities.

6. The climatic conditions obtaining in the Marysville Buttes region during the deposition of the Eocene beds were tropical or subtropical.

7. The supposed marine Ione of Marysville Buttes is evidently Eocene.

DESCRIPTION OF SPECIES

SYNECHODUS, sp.,

Plate 14, figure 7

Tooth with sharply tapering cusps. Median cusp nearly straight, acute, margins sharp, inner side convex, the outer side is nearly flat with a slight concavity near the root. There are

two much smaller cusps on either side of the median one. They are both convex on the inner and outer sides.

University of California Locality 1853.

Dimensions: Greatest length of middle cusp, 9mm; greatest transverse diameter of base, 11mm.

TURRIS MONOLIFERA (Cooper)

Plate 11, figure 1

Surcula monolifera Cooper.—Cooper, J. G., Catalogue of California Fossils, Bull. 4, Cal. State Mining Bureau, p. 39, 1894.

“Fusiform; nuclear whorls three, smooth, conical; the next crossed by twelve or more strong, oblique riblets, which change on fourth or fifth into a row of beaded knobs, forming an angle along middle of whorls, increasing to thirty-five on ninth or body-whorl. Above this angle are nine or ten fine revolving riblets, and three or four below it, the two posterior being longest, and imperfectly beaded at the suture. On the anterior whorls the medial knobs are sometimes doubled, and on the body-whorl the revolving riblets are alternately large and small. Canal straight, equaling the sub-oval mouth in length. Sinus deep, situated at the angle. Length, 0.60 inch; breadth, 0.08; mouth and canal, 0.34 long.

Five specimens obtained, agreeing well in characters, at Marysville Buttes, by Mr. Watts. This is quite near to Gabb's “*Turris claytonensis*,” from near the Mt. Diablo coal mines, but a comparison with his description shows marked differences. Figures three times the natural size.

The occurrence of seven new Pleurotomidae without many other univalve shells, and especially the absence of the many forms of genera allied to *Fusus* described by Gabb, is a condition of distribution indicating probably that a warmer sea existed where they are found, than at most localities of similar age in California.”

Abundant at University of California Localities 1853 and 1856.

Dimensions: Length, 9mm; width of body whorl, 4mm.

TURRIS ANDERSONI, n.sp.

Plate 11, figure 2

Shell fusiform with rather short spire and a long body-whorl. Whorls, about seven (two upper whorls missing), rounded, nodose. The whorls are marked by eight rounded vertical nodes which extend from a well marked suture over the entire whorl. The lines of growth indicate a moderately deep sinus at the angle. Mouth, oval, narrowing abruptly at a point about two-fifths of the distance below the suture into a long narrow canal. Inner lip, smooth.

University of California Locality 1853. Named in honor of Mr. F. M. Anderson, Curator, Department of Palaeontology, California Academy of Sciences.

Dimensions: Length, 10.5mm; width of body whorl, 4.5mm.

TURRIS SUTURALIS (Cooper)

Plate 11, figures 6a, 6b

Mangilia suturalis Cooper.—Cooper, J. G., Catalogue of California Fossils, Bull. 4, Cal. State Mining Bureau, p. 41, 1894.

“Form lanceolate; nuclear whorls three, fourth with ten strong vertical riblets, continuing on next five whorls, but decreasing to six on body whorl; crossing entire whorl, but higher at middle, forming an obtuse angle, marked by a strong revolving riblet; one strong riblet parallel to this close to the suture, and one below angle. On the body they increase to over twenty of uniform size. Strong lines of growth cross these throughout, showing a deep sinus, mostly posterior to the angle. Canal slightly twisted. Length, 0.08; mouth 0.29 long, 0.06 wide. Two specimens found at Marysville Buttes by Mr. Watts.”

The canal of this species is entirely too long for a *Mangilia*. The mouth is longer than the spire. The nodes on the body-whorl do not decrease to six. Most of the whorls have eight or nine instead of ten, and the body-whorl is no exception.

Dimensions: Height, 40mm; width of Body-whorl, 13mm.

TURRIS INCONSTANS (Cooper)

Plate 11, figure 5

Surcula inconstans Cooper.—Cooper, J. G., Catalogue of California Fossils, Bull. 4, California State Mining Bureau, p. 40. 1894.

“Shell long, fusiform, whorls about ten, the first two turbinate, smooth; third to sixth with ten or twelve transverse close-set ribs, which, on the other four whorls, show only on the posterior half of each, being replaced by eight or ten revolving riblets, forming a cancellated sculpture near middle, and toward the canal appearing alone. Mouth narrow, sinus at angle, canal long. Dimensions, length, 1.10 inch; breadth, 0.25 inch, mouth, 0.50 inch.”

The figure is triple the natural size.

Rare at University of California Locality 1853.

Dimensions: Length, 12mm; width of body-whorl, 4mm.

TURRIS PERKINSIANA (Cooper)

Plate 11, figures 7a and 7b

Pleurotoma perkinsiana Cooper.—Cooper, J. G., Catalogue of California Fossils, California State Mining Bureau, p. 40. 1894.

“Very long and slender; whorls about ten, rounded, the first two turbinate, smooth; third with ten or twelve close-set vertical riblets, crossed by eight or ten revolving ones, the vertical gradually increasing to twenty-six on the body-whorl, forming a close beaded sculpture as far as the middle of body-whorl, while the revolving ribs continue alone on the body to canal. Varies also in relative strength of the two series of riblets, at different portions of spire. Sinus close to suture, canal straight, columella simple. Length, 0.60 inch; breadth, 0.15; mouth, about 0.25 long, 0.09 wide. This and the preceding (*Turris inconstans*) have many characters alike, and are both variable in similar directions, so that at first they seemed varieties of one species, but the position of the sinus and differences in size and form distinguish them. Two specimens were found at Marysville Buttes by Mr. Watts.”

This species was found at University of California localities 1853 and 1856. It is easily distinguished from *Turris inconstans* by the absence of nodes and by the rounded form of its whorls. Its sinus is not near the suture as Cooper states, but near the middle of each whorl. It resembles *Fusus diaboli* Gabb in general form but is slightly more slender, its longitudinal ribs are curved, and not straight like those of *F. diaboli* and its whorls are rounder.

Dimensions: Length 22mm; width of body-whorl, 5mm.

DRILLIA ULLREYANA Cooper

Plate 11, figure 8

Drilla ullreyana.—Cooper, J. G., Catalogue of California Fossils, Bull. 4, California State Mining Bureau, p. 41. 1894.

“General form oblong-rhombic; first three whorls smooth, conical; fourth with seven strong knobs crossing it, and continuing on the six following at regular intervals; crossed by about ten fine revolving riblets above the middle, and four stronger ones below, increasing to about thirty of uniform size on the body-whorl and canal. Mouth nearly half of whole length, acute posteriorly, with a slight angle on upper third. Canal tapering, straight, sinus deep behind angle. Length, about 0.66 inch; breadth, 0.30; mouth and canal, 0.35 long, 0.12 wide. Marysville Buttes, Mr. Watts; four similar specimens.

The canal is long for a *Drillia*, but not more so than in *D. rariocostata* Gabb, which this much resembles, differing in having the knobs more numerous, shorter, and broader.”

Several specimens were found at University of California Locality 1853.

Dimensions: Length, 16mm; width of body-whorl, 6.5mm.

SURCULA CLARKI, n.sp.

Plate 11, figure 3

Shell, fusiform with eight (?) whorls, the body-whorl being almost as long as spire. The whorls are marked by eight elongated rounded nodes crossed by revolving lines. Four or five revolving lines occur between the suture and the angle of the whorl. The angle of the whorl is marked by a strong revolving rib. Another strong rib occurs just below the angle and two weaker ribs are found on the space below. A moderately deep sinus is indicated by the lines of growth above the angle. Mouth, elongate, oval; canal, short.

University of California Locality 1853. Named in honor of Bruce L. Clark, Instructor in Palaeontology, University of California.

This species resembles *Pleurotoma guibersoni* Arnold, but it has more nodes on its whorls, the revolving lines are different and the lines of growth indicate without a doubt a sinus above the angle.

Dimensions: Length, 10mm; width, 4.5mm.

SURCULA CRENATOSPIRA Cooper

Plate 11, figure 4

Surcula crenatospira.—Cooper, J. G., Catalogue of California Fossils, Bull. 4, California State Mining Bureau, p. 39. 1894.

“Nuclear whorls three, smooth, large, the apical, immersed; other spiral whorls five, turreted, gradually enlarging, each with about nine rounded tubercles horizontally flattened, forming a chain around the middle, and connected by two strong revolving ribs, making a sharp angle. Above this are five or six fainter ribs, crossed by strong sinuated lines of growth, and below a similar sculpture, the whole surface being thus divided by strong reticulations, extending forward on body-whorl about half its length. Mouth simple, sinus moderate, above angle, canal long, straight, aperture as long as spire. Length, about 1.75 inch; breadth, 0.80; mouth and canal, 1 inch long, 0.40 wide.

Not very near any of Gabb's species of the family, except in the long canal, which seems to have been more common in the fossil than in living Pleurotomidae. The character of the sinus and sculpture ally this and

some of the following to the sub-genus *Clathurella*, though according to those who classify by the soft parts, such divisions are of little value. They must be taken for all they are worth in fossil species, as necessary divisions, in the absence of better ones.

Quite common at Marysville Buttes, where Mr. Watts and Mr. Ullrey obtained 35 specimens. A very similar species inhabits the West Coast of Mexico at present (*S. olivacea* Sby.)''

Dimensions: Length, 37mm; width of body-whorl, 12m.

SURCULA HOLWAYI, n.sp.

Plate 11, figure 9

Fusiform, with high spire; whorls number about eight (the three (?) upper whorls are missing). The fourth, fifth, sixth, seventh, and eighth whorls are marked by about twelve oblique nodes which extend from the angle to the suture below but do not appear on the space above the angle. These nodes are crossed by two prominent revolving lines. The whorls are angular with vertex of the angle about two-fifths of the distance above a sharply impressed suture. The space above the angle is marked by minute revolving lines and by sinuous lines indicating a deep sinus above the angle.

Only one specimen was found at University of California Locality 1853. Named in honor of Professor R. S. Holway, University of California.

Dimensions: Length of broken specimen, 18mm.

SURCULA DAVISIANA (Cooper)

Plate 12, figures 6a and 6b

Potamides davisiana Cooper.—Cooper, J. G., Catalogue of California Fossils, Bull. 4, California State Mining Bureau, p. 44. 1894.

“First three whorls convex, turbinate, smooth; the next six turreted, increasing rapidly by wide, flattened expansions of the upper surface of whorls, with a sharp raised carina half-way between the sutures, from which the surfaces above and below diverge at a right angle. Fourth whorl ornamented with about forty fine sharp riblets, strongly curved to the left, above the carina, and giving it a serrate edge, then passing down to the next suture. On the sixth whorl they are crossed by two revolving riblets below the carina, and on the seventh or body-whorl these increase to fifteen or more, with many intermediate smaller ones, which finally entirely efface the vertical lines. Mouth triangular, simple, inner edge of outer lip crenately notched, thin; (columella and canal lost). Length, 1.16 inch (or more); breadth, 0.70; mouth, 0.50

long, about 0.35 wide. The backward curve of the growth lines above the carina suggests a Pleurotomoid shell, which is partly confirmed by the curve forward of the posterior margin of outer lip remaining, but the general form is so similar to that of Gabb's *Potamides diadema*, that I have placed it in that genus until better known. (See Pal. of Cal., 1, p. 130, pl. 20). Resembles *Pleurotoma* (Perrona) *spirata* Lamk. Marysville Buttes, one specimen from Cret. B, Mr. Watts."

Dimensions: Length of smaller specimen figured 10mm; width of body-whorl 4mm.

Cooper's type specimen is much larger than the small one figured, but it does not show the canal or inner lip. The canal is long and straight and the inner lip is smooth. The body-whorl is marked by three prominent carinae in addition to the finer revolving lines.

In the type, an older specimen, the space between the first and second carinae on the body-whorl is sharply notched inward, the vertex of the notch being central. The smaller specimens vary much in the strength of the vertical ribbing. The small specimen figured was found at University of California Locality 1853.

CORDIERA GRACILLIMA Cooper

Plate 12, figure 3

Cordiera gracillima.—Cooper, J. G., Catalogue of California Fossils, Bull. 4, California State Mining Bureau, p. 41. 1894.

"Very slender, fusiform; first two whorls smooth, turbate; third with about twelve oblique subvertical riblets, which decrease to seven on sixth whorl, narrow, meeting at sutures, and with four revolving riblets crossing them, one along suture. A wide interval between this and the next anterior, forms an obtuse angle on whorls, continuing to the upper third of body-whorl, below which the vertical ribs disappear. On body-whorl about eight revolving riblets cross these, with three or four fine ones between each, and twelve to fifteen others below angle pass around the canal. (The shells being imbedded in rock the exact number of vertical ribs cannot be distinctly seen, whether seven or eight, and the outer lip is too much broken to see the form of the sinus, but it must be very shallow.) Mouth very narrow, sharp above, widest at angle of lip, below curving to the left, gradually forming the canal. Columella with four plaits at middle, the upper one, strongest. Length, 0.48 inch; breadth, 0.09; mouth, 0.14 long, 0.03 wide; canal, 0.10 long.

The figure is twice the natural size of the one specimen found at Marysville Buttes by Mr. Watts. This is a decidedly different shell from the two species figured and described by Mr. Gabb, both of which were also found in Santa Ana Mountains, Orange County, by Dr. Bowers, but in a very poor condition."

Cooper described this species from a single specimen imbedded in rock and hence a portion of the specimen was not visible. The "wide interval" between the revolving rib near the suture and the rib at angle is marked on the body whorl by five riblets which alternate in size, and two or three on the penultimate whorl. A persistent minor riblet can be seen between the other revolving ribs. On the body-whorl 12 or 13 revolving ribs alternating with minor riblets are found. The vertical ribs on the body-whorl extend nearly the length of this whorl excepting on the columella where they extend only a third to a half of the length. The columella is marked by six plaits which increase regularly in strength, the uppermost being the strongest. Columella slightly incrustated. Four or five nearly perfect specimens were found at University of California Locality 1853.

Dimensions: Length, 10mm; width of body-whorl, 3mm.

FUSINUS (PRISCOFUSUS) LINEATUS, n.sp.

Plate 11, figure 12

Shell, small, spindle shaped, eight whorls. The first three minute, rounded, smooth; the remaining whorls rounded and marked by equal, flattened ribs with interspaces half as wide as the ribs. The number of the ribs on fourth whorl is four, five on fifth and sixth and about fifteen on the body-whorl. The body-whorl is somewhat longer than the spire. Mouth, long, slightly widened posteriorly and narrowed anteriorly into a short canal. Inner lip slightly incrustated.

University of California Locality 1853.

Dimensions: Length 6mm; width of body-whorl, 2mm.

TEREBRA WATTSIANA Cooper

Plate 11, figure 10

Terebra wattiana Cooper.—Cooper, J. G., Catalogue of California Fossils, Bull. 4, California State Mining Bureau, p. 39. 1894.

"Whorls regularly tapering, about fourteen (upper three or four lost); flattened, slightly turreted by narrowing in front, the highest with about twenty-three narrow, close-set riblets crossing their whole width vertically, and increasing to about fifty on body-whorl. Base and columella smooth, mouth normal, canal much twisted, not deep. Length, about 1.75 inch; breadth, 0.45; mouth, 0.4; width, 0.10. More robust, larger, and fewer-whorled than *T. californica* Gabb, also of Div. B, but nearly allied to that species. A single specimen only was found at Marysville Buttes by Mr. W. L. Watts."

CANCELLARIA STANTONI, n.sp.

Plate 12, figures 2a and 2b

Shell, small, with five whorls, the first two, turbinate, smooth; the third whorl is cancellated by ten or twelve ribs. About every fourth rib is enlarged. These heavy ribs are well rounded on the fourth and fifth whorls and are more oblique than those on the third. They extend from an indistinct, irregular suture over the entire whorl. Strong revolving ribs with finer riblets also decorate this beautiful little shell. Mouth, sub-oval; outer lip thickened, rounded, and crenulated on interior. Columella marked by three strong plaits, the posterior one being the strongest. Canal short and very slightly notched.

Three specimens were found at University of California Locality 1853. Another specimen was found in the University of California Collection from near Fort Tejon.

Named for Dr. T. W. Stanton, Chief Palaeontologist, United States Geological Survey.

Dimensions: Length, 12mm; width of body-whorl, 6mm.

CANCELLARIA IRELANIANA Cooper

Plate 12, figure 8

Cancellaria irelaniana.—Cooper, J. G., Catalogue of California Fossils, Bull. 4, California State Mining Bureau, p. 42. 1894.

“Shell oblong fusiform; spire of eight whorls, the first three nuclear, smooth, conical; fourth with nine prominent vertical ribs abruptly truncate at sutures, and continuing thus on next three whorls, but on eighth whorl becoming conical tubercles at posterior margins, more distinct on body-whorl, the ribs disappearing. The three anterior whorls show strong vertical lines of growth, or irregular sculpture, which above the tubercles is crossed by three or four revolving raised lines. (Outer lip broken off for about half an inch.) Columella with four very strong and three fainter oblique folds (or ribs). Length, about 1.75 inch; breadth, 0.75; mouth, 0.87; width, (?).

“Only one specimen found at Marysville Buttes by Mr. Watts. This shell is nearer to the sub-genus *Narona* than to any of the allied forms, and in its spire much resembles the species living on our coast, *C. (N.) cooperi* Gabb. Though Mr. Gabb described a Tertiary species as *C. vetusta*, thus suggesting its absence from the Cretaceous strata, we have here a proof of its presence in the Eocene or Cret. B. strata.”

Arnold reports this form from the Eocene of the Coalinga District.

Dimensions: Length, 43mm; width of body-whorl, 20 mm.

SIPHONALIA SUTTERENSIS, n.sp.

Plate 12, figure 1

Fusiform; whorls, nine or nine and a half. The first three nuclear whorls are smooth while the rest are marked by ten or eleven sharply pointed nodes. On the fourth to the ninth whorl these nodes are crossed below the angle by three revolving ribs, the one at the obtuse angle of whorl being the strongest. Two or three riblets occur between the ribs. The portion of the whorl above the shoulder is marked by riblets which alternate in size and vary in number from eight or ten on upper whorls to fifteen to twenty on the body-whorl. This portion is concave and on the body whorl is channeled as well. The concavity and channeling are variable in amount. The canal is decidedly bent laterally. Inner lip smooth and bent; outer lip crenulated on interior; umbilicus small, ovate.

University of California Locality 1853. Named for its occurrence in Sutter County, California.

Dimensions: Length, 24mm; width of body-whorl, 11mm.

ASTYRIS, sp.

Plate 12, figure 4

Shell spindle-shaped with eight whorls. The first two whorls turbinate, smooth. The third, fourth, fifth, sixth, and seventh whorls smooth or marked with microscopic revolving lines; flat sided; the body-whorl rounded and marked by fine revolving riblets. Outer lip broken, inner lip smooth. Canal, long for this genus.

University of California Locality 1853. Only two small specimens were found.

Dimensions: Length, 7mm; width of body-whorl, 3mm.

CLAVELLA TABULATA, n.sp.

Plate 12, figure 7

Shell robust, fusiform with at least nine whorls. The whorls are flattened parallel with the axis of the shell, tabulate above a very marked shoulder, a few rather fine revolving lines occur on some of the whorls just beneath the angle. Suture impressed.

The body-whorl with canal is nearly one and a half times as long as the spire. It is suddenly contracted into a long, narrow canal about two-fifths of the distance below the angle.

Only one large specimen was found at University of California Locality 1853.

Dimensions: Length, 73 mm; width of body-whorl, 28 mm.

VOLUTA LAWSONI, n.sp.

Plate 12, figures 5a, 5b, and 5c

Shell conical with short spire; eight whorls, the first and second smooth and turbinate; the third, fourth and fifth decorated by about ten vertical ribs, which end at the angle of the whorl in spiny nodes. The angle of the whorls is nearly 90°. The space above the shoulder is flattened and on the body-whorl is channeled. Suture, linear, distinct. Outer lip, straight and simple. Columella faintly incrustated. Inner lip marked by three faint plaits. The body-whorl is decorated by fine revolving lines which increase in size on the lower part of the whorl.

Named in honor of Professor A. C. Lawson, University of California.

The type specimen was found at University of California Locality 1853. Three other specimens were found at Locality 1856.

Dimensions: Length, 21mm; width of body-whorl, 10mm.

TURRITELLA MERRIAMI, n.sp.

Plate 13, figures 6a, 6b, and 6c

Shell moderate in size, elongate; whorls number about fifteen or sixteen; the first four whorls are rounded and marked by three strong revolving ribs with a single riblet between each pair. The fifth, sixth, seventh and eighth whorls are also convex, but the center of the convexity is below the middle of the whorl; these whorls are marked by five nearly equal revolving ribs, equally spaced. The rest of the whorls are markedly different from the upper eight whorls. The first revolving rib below the suture is much larger than the rest, and the space between it and the impressed suture is flattened horizontally making a tabulate shoulder. The next three ribs are equal and equally spaced. The

fifth rib is stronger than the three above and a persistent riblet is found between it and the fourth rib; the space between it and the suture is twice as great as the space between the ribs above. The lower whorls are flattened between the first rib and the suture.

University of California Localities 1853 and 1855. Named in honor of Professor J. C. Merriam, University of California.

The upper whorls resemble *T. uvasana* somewhat in apical angle and ribbing, but their shape is slightly different. The lower whorls bear a superficial resemblance to *T. chicoensis* in that the suture is impressed and is bordered by a rim on the whorl below and sometimes by one above. The rib below the suture is much more developed in *T. merriami* than *T. chicoensis*. The number of ribs in *T. chicoensis* is only three with four or five minute revolving lines between, while there is only the one mentioned above between the fourth and fifth rib in *T. merriami*.

This species also occurs in the Eocene of Oregon.

Mr. Bruce Martin collected the following "under bridge at mouth of Little River, North Fork of Umpqua River, 18 miles northeast of Roseburg, Umpqua Formation," California Academy of Sciences Locality:

Oliverato californica Cooper	Rimella canalifera Gabb
Cylichna costata Gabb	Cerithium carbonicola Cooper
Morio tuberculatus Gabb	Tapes conradiana Gabb
Loxetrema turrata Gabb	Glycimeris cf. sagittata Gabb
Fusus mathewsonii Gabb	Cardita planicosta Lamarck
Turritella uvasana Conrad	Cardium breweri Gabb
Amauropsis alveata Conrad	Crassatellites grandis Gabb
Turritella merriami, n.sp.	Modiolus ornatus (Gabb)
Pseudoliva volutaeformis Gabb	Corbula parilis Gabb
Phos(?) martini, n.sp.	Lucina cumulata Gabb

Turritella merriami is in a collection made by Mr. Vance Osmont at the Tesla coal mines.

Dimensions: Length of broken specimen (see figure 6*b*, plate 13), 30mm.

OLIVULA MARYSVILLENSIS, n.sp.

Plate 13, figures 1a and 1b

Whorls number six, the body-whorl being four times as long as the spire. The body-whorl is decorated by distinct, close longitudinal and revolving striae, and four prominent slightly oblique revolving ribs on the lowermost third; spire covered by a longitudinally striate deposit, angulated at suture of body-whorl forming a raised band just below the suture. Aperture, channeled posteriorly. Posterior portion of inner lip covered by a callus which extends to top of spire. The lower portion of the columella is marked by five small but prominent very oblique plaits. Outer lip, thin and straight.

Only one small specimen was found at University of California Locality 1853. The only noteworthy difference between this species and *Olivula staminea* Conrad of the Alabama Claiborne is that the revolving ribs on the body-whorl are less oblique than those of *O. staminea*.

Dimensions: Length, 10mm; width of body whorl, 4mm.

OLIVERATO CALIFORNICA Cooper

Plate 13, figures 4a and 4b

Oliverato californica.—Cooper, J. G., Catalogue of California Fossils, Bull. 4, California State Mining Bureau, p. 43. 1894.

“About half of spire (the nuclear whorls) invisible in adult; mouth with lips nearly parallel at middle; narrower at ends in the young, with about ten faint ridges along columella, not passing inside; no umbilicus. Dorsal surface marked by ridges from irregular thickness of the callus, and a deep oblique furrow running from the anterior notch toward the left, as in *Pseudoliva*, etc. Parallel to this, about six light ridges remain permanent behind it, thickened but not obscured by callus. General form becoming more ovate with age, but always narrower in front. Length, about 1.50 inch; breadth, about 0.85; mouth, 1.12 inch long, 0.50 wide. Eight specimens examined.

“Four of the specimens are polished and colored a fine brown, just as in the living *Erato vitellina*. This color is confined to a thin outer layer of the callus, as shown in the dorsal figures.”

Dimensions: Length, 38mm; width of body-whorl, 23mm.

This form occurs at nearly all the Eocene localities in the Marysville Buttes. It is also found on the Umpqua River in Oregon and at University of California Locality 195, “Concord

sheet 2½ miles N.W. of Grayson Creek on main road from Martinez to Walnut Creek, north side of road." It is associated with *Conus hornii*, *Turritella uvasana*, *Rimella canalifera*, *Cylichna costata*, *Dentalium cooperi*, *Cardium breweri*, *Modiola ornata*, *Meretrix hornii*, *Cardita*, sp., *Tapes conradiana*, and *Trochocyathus striatus* (?). Cooper figures a "young" form of *Oliverato* which proves to be a new species, *Caricella stormsiana*.

ARCHITECTONICA WEAVERI, n.sp.

Plate 13, figures 2a and 2b

Whorls five or six, low, conical. The last two whorls are decidedly concave and are marked by two nodose carinae, one immediately above a sharp linear suture and the other just below. The nodes on the upper carina are much closer together than those on the lower. The upper nodes have a beaded appearance while the lower nodes are distinctly elongated and extend nearly to a revolving line in the middle of the smooth concave portion of the whorl.

A single specimen was found at University of California Locality 1853.

This form is readily distinguished from *A. cognata* and *A. hornii* by its concave whorls and distinctive decoration. Named in honor of Professor C. E. Weaver, University of Washington.

Dimensions: Height, 7mm; radius, 10mm.

CARICELLA STORMSIANA, n.sp.

Plate 13, figures 3a and 3b

Shell pyriform, thin, smooth, spire low; whorls number six. The first three nuclear whorls smooth and more convex than the fourth and fifth whorls. Body-whorl twice as long as spire; upper part swollen and smooth while lower part is marked by eight or nine revolving transverse riblets. Outer lip, simple. Canal short and slightly twisted. At least two strong plaits appear on the lower part of the columella.

Cooper described this as a young form of *Ancilla (Oliverato) californica*, but the plaits on the columella throw it entirely out of this subgenus.

University of California Locality 1853. Named in honor of Mr. Storms, State Mineralogist, California State Mining Bureau, who very kindly loaned us several of Dr. Cooper's type specimens. This species resembles *Caricella pyruloides* Conrad of the Alabama Claiborne very closely.

Dimensions: Length, 15mm; width of body-whorl, 6mm.

PHOS(?) MARTINI, n.sp.

Plate 13, figure 5

Shell, bucciniform with very sharp spire, whorls seven and a half; the first three smooth, minute; fourth, fifth, and sixth marked by vertical ribs crossed by three revolving riblets which form a beaded structure at intersection. The vertical ribs number twelve on the fourth, fifteen to sixteen on the fifth, and eighteen or twenty on the sixth whorl. The revolving and vertical ribs are the same in strength on the body-whorl. The inner lip, crenulated; columella smooth. Canal unknown, but is probably short and narrow.

University of California Locality 1853. Named in honor of Mr. Bruce Martin, Assistant Curator, California Academy of Sciences.

Dimensions: Length, 11mm; width of body whorl, 7mm.

CALLIOSTOMA(?) ARNOLDI, n.sp.

Plate 14, figures 5a, 5b, and 5c

Shell conical, with moderately angulated base. Whorls, number six the first two, turbinate. The second, third, fourth and fifth whorls are marked by three nodose revolving lines while the body-whorl has six, five of which are continuous on the base. A part of the body-whorl is broken, making an accurate description of its base impossible. The body-whorl is about one and one-half times the penultimate whorl. Aperture, subquadrate. The apical angle of this species is very small in comparison with many species of this genus.

University of California Locality 1853. Named for Dr. Ralph Arnold.

Dimensions: Length, 6mm; width of body-whorl, 3mm.

BITTIUM LONGISSIMUM Cooper

Bittium longissimum.—Cooper, J. G., Catalogue of California Fossils, Bull. 4, California State Mining Bureau, p. 43. 1894.

“Exceedingly long compared to its diameter; first three or four whorls regularly convex, smooth; the remaining thirteen with ten to fourteen vertical riblets crossed by three revolving ones, which cancellate the surface uniformly; the anterior riblet largest, thus giving the whorl a turreted form; mouth quadrilateral, simple (the basal surface cannot be seen). Length, 0.55 inch; breadth, 0.06; mouth, 0.03. The shell had at least sixteen whorls, and the smoothness of the upper ones may be due to erosion. It much resembles the living *B. asperum* Gabb (stouter with thirteen whorls), a variety of which is also turreted. (See Pal. of California, 11, p. 12, pl. 2, f. 20). Marysville Buttes, only found by Mr. Watts.”

CARDIUM DALLI, n.sp.

. Plate 14, figures 4a, 4b, and 4c

Shell, thin, broad, cordate, equilateral, beaks central, prominent, approximate; hinge-line, nearly straight. Anterior and basal margins form a regular curve; the posterior margin is straight. The surface is marked by minute rounded, radiating ribs excepting on the posterior face of the shell which is covered by about 25 larger ribs rounded on their posterior sides and granulated on their anterior sides. These larger ribs are set off from the finer ribs by a sharp angle which extends from the beak to a point on the basal margin a fifth of the distance from the posterior margin. The posterior face is decidedly concave. The immature forms are frequently bluish on the beaks. The concentric lines of growth are as prominent as the ribs. This gives the shell surface a beautiful reticulated appearance.

University of California Localities 1853 and 1856.

Named in honor of Dr. W. H. Dall, Palaeontologist, Smithsonian Institution.

This species differs from *Cardium cooperi* Gabb in having larger granular ribs on the posterior face distinctly set off from the finer ribs on rest of the shell. Its ornamentation is entirely different from that of *Cardium breweri* Gabb but the shape is somewhat similar. The posterior margin is straight in *C. dalli*, n.sp., while that of *C. cooperi* is rounded.

Dimensions: Height, 18mm; length 17mm.

GLYCIMERIS MARYSVILLENSIS, n.sp.

Plate 14, figures 1a and 1b

Shell, small, subglobose, almost equilateral; beak small, incurved and central. Cardinal margin, straight; the anterior and posterior margins, regularly rounded. Surface marked by prominent concentric ribs. Hinge marked by eleven teeth. Area trigonal, small.

University of California Locality 1853. Named for the occurrence at Marysville Buttes in which the type specimen was found.

Dimensions: Height, 5mm; length 5mm.

NUCULA COOPERI, n.sp.

Plate 14, figures 2a and 2b

Shell, small, rounded triangular; small rather prominent beaks located about a third of the length from the anterior end and inclined forward. Cardinal margin nearly straight, sloping rapidly to the posterior margin; anterior end truncated, excavated under the beaks, slightly concave and united with the basal margin by a sharp angle; basal margin evenly rounded; posterior end narrowly rounded. Surface marked by many minute lines of growth and by small radiating ribs. Hinge robust, pit, very small. This species resembles *Nucula solitaria* Gabb of the Chico group closely, but the radiating ribs of this form readily distinguish it.

University of California Locality 1853. Named in honor of Dr. J. G. Cooper, who first described species from this locality.

Dimensions: Height, 6mm; length, 8mm.

TELLINA SUTTERENSIS, n.sp.

Plate 14, figures 3a and 3b

Shell, oblong, compressed, thin. Beaks prominent, being located about one-third of distance from the anterior end. Anterior and posterior extremities rounded; the anterior dorsal margin slopes from the beaks more steeply than the posterior dorsal margin. Surface marked by minute lines of growth.

University of California Localities 1853 and 1856. Named for the occurrence in Sutter County, California.

Dimensions: Height, 6mm; length, 8mm.

TROCHOCYATHUS(?) PERRINI, n.sp.

Plate 14, figures 6a, 6b, and 6c

Form short, trochiform. Cross-section, elliptical. Base attached by a small short pedicel which is now broken from the type. Costae distinct, granular or even nodose, and corresponding to all cycles of septa. Septa in four cycles. Pali appeared to be present, but not clearly shown. Columella, fascicular (?) indistinct. Calice, shallow.

Only one specimen was found at University of California Locality 1853.

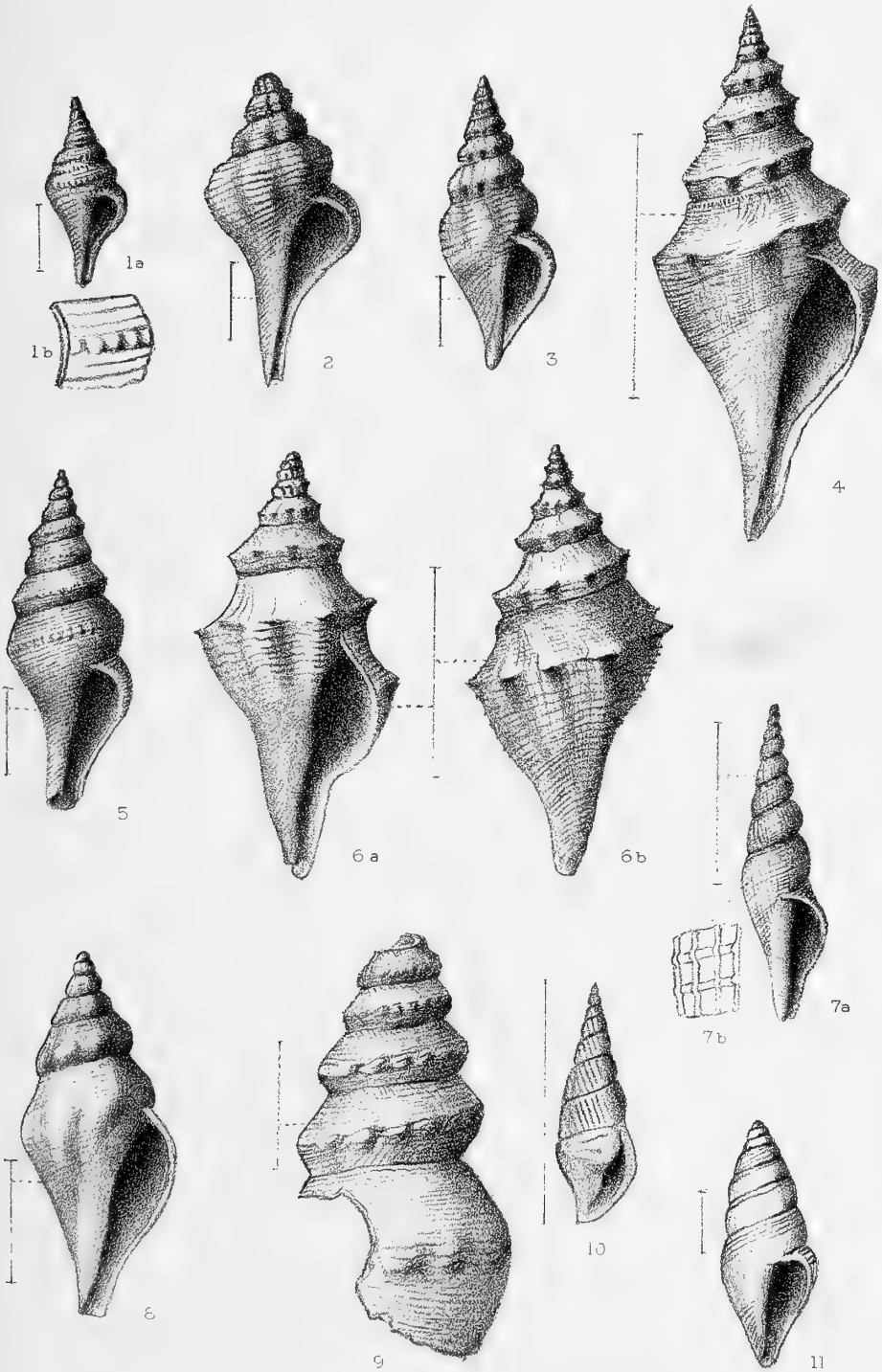
Named in honor of Professor James Perrin Smith of Stanford University.

Dimensions: Height, 6mm; width, 6mm.

EXPLANATION OF PLATE 11

Eocene of Marysville Buttes

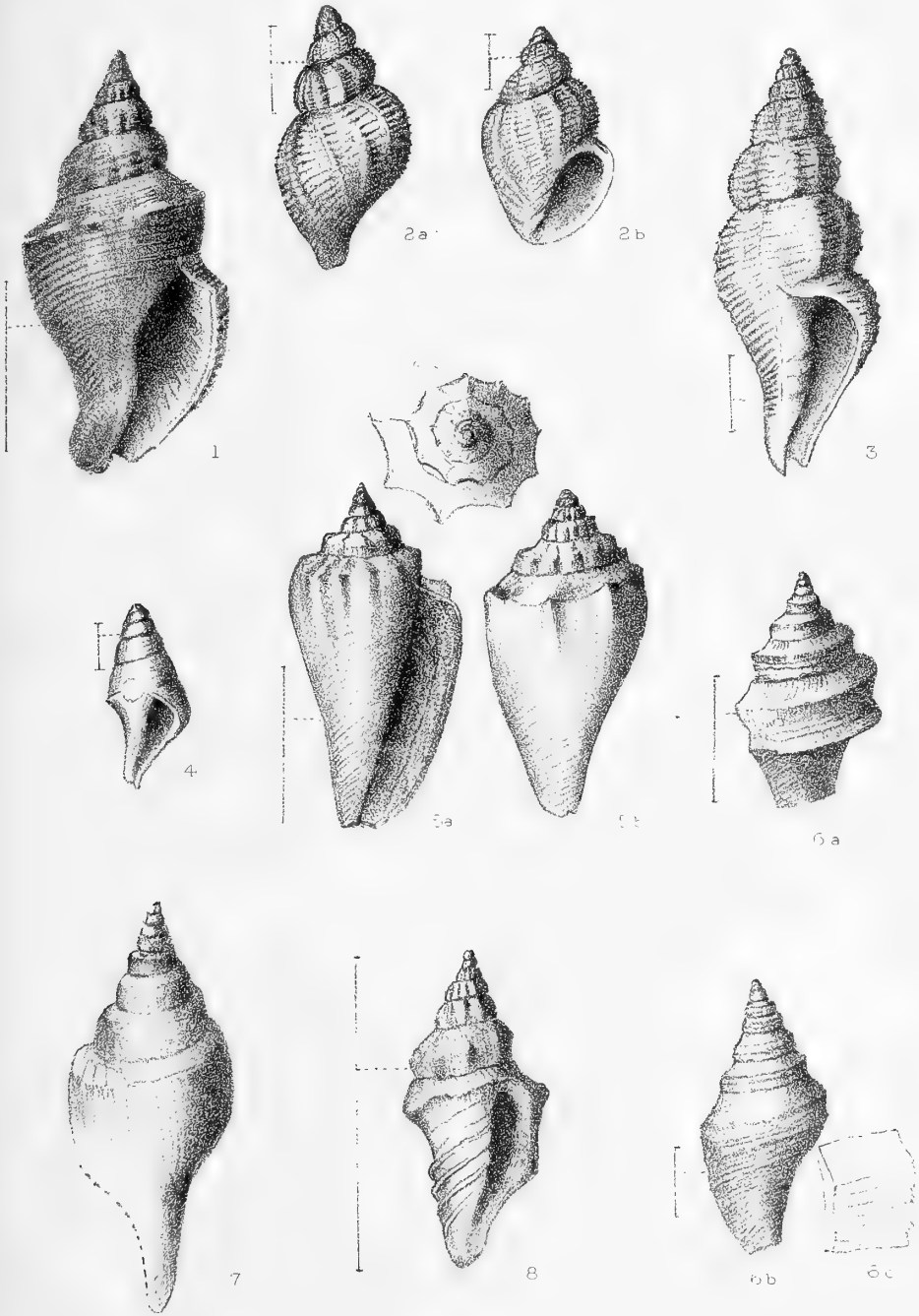
- Fig. 1*a*. *Turris monolifera* (Cooper). $\times 3$.
Fig. 1*b*. *Turris monolifera* (Cooper). $\times 3$.
Fig. 2. *Turris andersoni*, n.sp. $\times 4$.
Fig. 3. *Surcula clarki*, n.sp. $\times 4$.
Fig. 4. *Surcula crenatospira* Cooper. $\times 2$.
Fig. 5. *Turris inconstans* (Cooper). $\times 4$.
Fig. 6*a*. *Turris suturalis* (Cooper). $\times 2$.
Fig. 6*b*. *Turris suturalis* (Cooper). $\times 2$.
Fig. 7*a*. *Turris perkinsiana* (Cooper). $\times 2$.
Fig. 7*b*. Detail of decoration of figure 7*a*.
Fig. 8. *Drillia ullreyana* Cooper. $\times 3$.
Fig. 9. *Surcula holwayi*, n.sp. $\times 4$.
Fig. 10. *Terebra wattiana* Cooper. $\times \frac{4}{5}$.
Fig. 11. *Fusinus lineatus*, n.sp. $\times 4$.



EXPLANATION OF PLATE 12

Eocene of Marysville Buttes

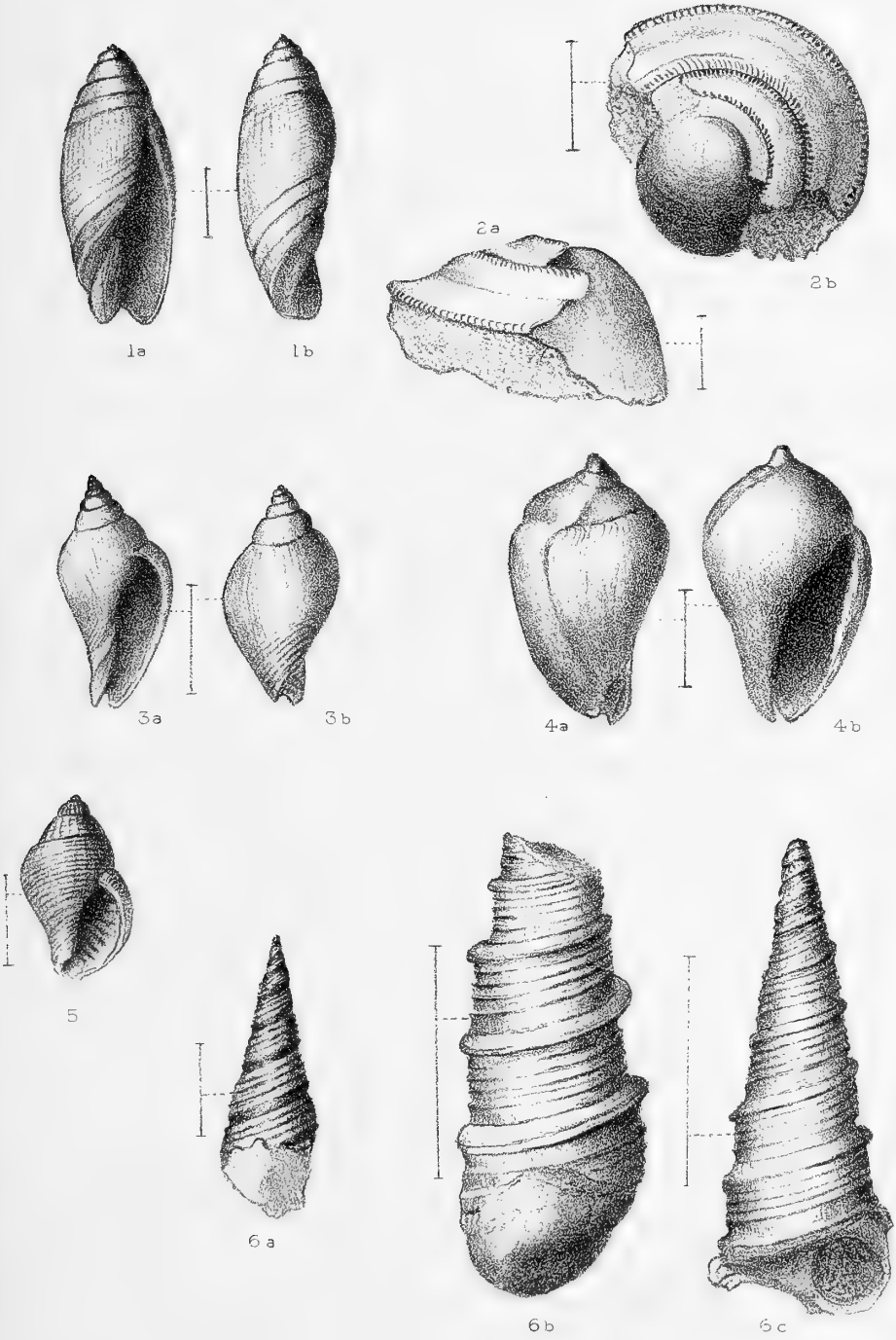
- Fig. 1. *Siphonalia sutterensis*, n.sp. $\times 2$.
Fig. 2a. *Cancellaria stantoni*, n.sp. back view. $\times 3$.
Fig. 2b. *Cancellaria stantoni*, n.sp. mouth view of smaller specimen. $\times 4$.
Fig. 3. *Cordiera gracillima* Cooper. $\times 5$.
Fig. 4. *Astyris*, sp. $\times 4$.
Fig. 5a. *Voluta lawsoni*, n.sp., mouth view. $\times 2$.
Fig. 5b. *Voluta lawsoni*, n.sp., back view. $\times 2$.
Fig. 5c. *Voluta lawsoni*, n.sp., top view. $\times 2$.
Fig. 6a. *Surcula davisiana* (Cooper) type specimen. $\times 2$.
Fig. 6b. *Surcula davisiana* (Cooper) smaller specimen showing body whorl. $\times 4$.
Fig. 6c. Detail of body whorl of Fig. 6b.
Fig. 7. *Clavella tabulata*, n.sp. $\times \frac{2}{3}$.
Fig. 8. *Cancellaria irelaniana* Cooper, type specimen, natural size.



EXPLANATION OF PLATE 13

Eocene of Marysville Buttes

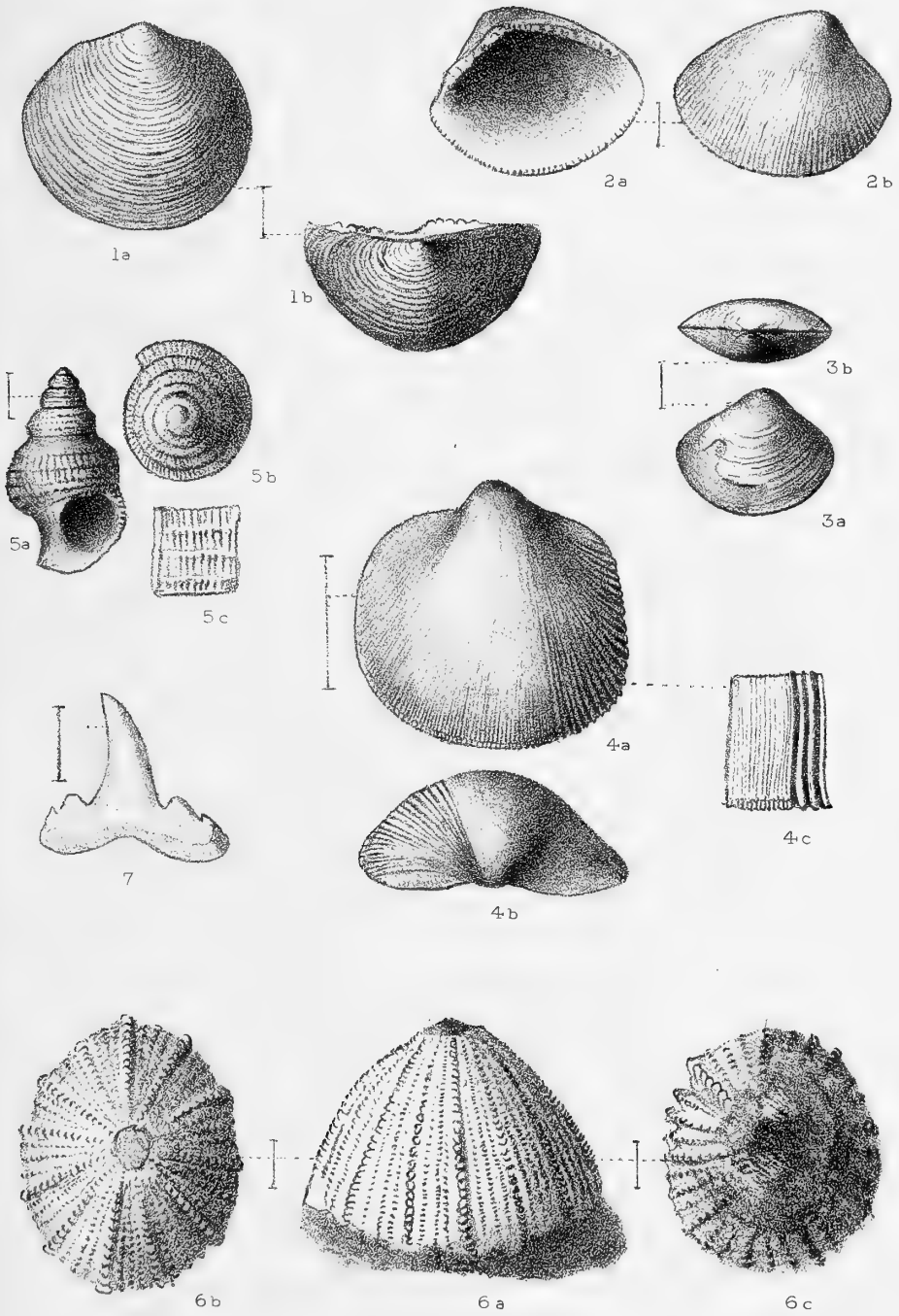
- Fig. 1*a*. *Olivula marysvillensis*, n.sp. $\times 4$.
Fig. 1*b*. *Olivula marysvillensis*, n.sp. $\times 4$.
Fig. 2*a*. *Architectonica weaveri*, n.sp., top view. $\times 2\frac{1}{2}$.
Fig. 2*b*. *Architectonica weaveri*, n.sp., side view. $\times 2$.
Fig. 3*a*. *Caricella stormsiana*, n.sp., mouth view. $\times 2$.
Fig. 3*b*. *Caricella stormsiana*, n.sp., back view. $\times 2$.
Fig. 4*a*. *Oliverato californica* Cooper, back view. $\times 3$.
Fig. 4*b*. *Oliverato californica* Cooper, mouth view. $\times 3$.
Fig. 5. *Phos(?) martini*, n.sp. $\times 2$.
Fig. 6*a*. *Turritella merriami*, n.sp., spire of young specimen. $\times 3$.
Fig. 6*b*. *Turritella merriami*, n.sp., back view of lower whorls. $\times 2$.
Fig. 6*c*. *Turritella merriami*, n.sp. $\times 2$.



EXPLANATION OF PLATE 14

Eocene of Marysville Buttes

- Fig. 1a. *Glycimeris marysvillensis*, n.sp. $\times 4$.
Fig. 1b. *Glycimeris marysvillensis*, n.sp., looking down upon the umbones. $\times 4$.
Fig. 2a. *Nucula cooperi*, n.sp., view showing hinge. $\times 4$.
Fig. 2b. *Nucula cooperi*, n.sp., back view. $\times 4$.
Fig. 3a. *Tellina sutterensis*, n.sp. $\times 3$.
Fig. 3b. View showing umbones of Fig. 3a. $\times 3$.
Fig. 4a. *Cardium dalli*, n.sp. $\times 2$.
Fig. 4b. *Cardium dalli*, n.sp., view showing umbone. $\times 2$.
Fig. 4c. Detail of Fig. 4a showing the two kinds of decoration.
Fig. 5a. *Calliostoma(?) arnoldi*, n.sp. $\times 4$.
Fig. 5b. Top view of Fig. 5a. $\times 4$.
Fig. 5c. Detail of decoration of Fig. 3a.
Fig. 6a. *Trochocyathus(?) perrini*, n.sp., side view. $\times 4$.
Fig. 6b. *Trochocyathus(?) perrini*, n.sp., base view. $\times 4$.
Fig. 6c. *Trochocyathus(?) perrini*, n.sp., top view. $\times 4$.
Fig. 7. *Synechodus*, sp. $\times 2$.



UNIVERSITY OF CALIFORNIA PUBLICATIONS

BULLETIN OF THE DEPARTMENT OF

GEOLOGY

Vol. 7, No. 13, pp. 299-304, pl. 15

Issued June 12, 1913

NOTES ON SCUTELLA NORRISI AND
SCUTASTER ANDERSONI

BY

ROBERT W. PACK

Notes on Scutella norrisi and Scutaster andersoni

UNIVERSITY OF CALIFORNIA PRESS

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NOTES ON SCUTELLA NORRISI AND
SCUTASTER ANDERSONI

BY

ROBERT W. PACK¹

In 1909 the writer published a few notes on the Tertiary Echinoids of California, describing several new species and the new genus *Scutaster*.² Since this paper was written more nearly perfect specimens of *Scutella norrisi* and *Scutaster andersoni* have been obtained. The writer therefore takes pleasure in furnishing more complete figures of these species than it was possible to give at the time the type descriptions were written, together with a few notes to supplement the original descriptions.

SCUTELLA NORRISI Pack

Plate 15, figure 1

Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 277, pl. 23, fig. 3, 1909.

The original description is as follows:

Test sub-circular in general outline, with deep, broad, marginal notches in the edges of the ambulacral areas. The two posterior notches are much deeper than are the anterior ones, and truncate the posterior interambulacral space on either side of the median line, shaping the posterior end of the test into a prominent process. The test when viewed from above has a leaf-like appearance. Test much depressed, edges markedly thin, abactinal surface very slightly arched, apex central; actinal surface flat or gently concave. Mouth central, slightly sunken; ambulacral furrows poorly shown in the specimens examined, but evidently branch but little,

¹ Published by permission of the Director of the United States Geological Survey.

² Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, pp. 275-283, 1909.

if at all. Main ambulacral grooves continue from the mouth to the margin, entering the marginal notches. Anal pore small, inframarginal. Ambulacral star central. Petals extend about three-fourths the distance to the margin and not entirely closed at the ends.

Examination of the new material has brought out the following points: The test is sub-circular to sub-pentagonal in outline, resembling somewhat a maple leaf. The outline is rendered undulatory both by the deep notches in the extremities of the ambulacrae and by shallow indentations of the margin near the junction of the ambulacral and interambulacral areas. The abactinal surface is very slightly arched, and the slope from the margin to the apex is regular. The petals extend about two-thirds the distance from the center to the margin, and show only a slight tendency to close. The apical system is central. The size and peculiar outline of this species are sufficient to differentiate it from other west coast forms. *Scutella merriami* Anderson shows shallow marginal notches in the extremities of the posterior ambulacrae, and in rare cases the notches become deep enough to shape the test into an outline similar to that of *S. norrisi*. The greater size of the latter species is, however, sufficient to differentiate it.

Occurrence: Eastern Monterey County near the Stone Canyon mine; San Luis Obispo County, at Panza, on the San Juan River, and in the mountains between the San Juan River and the Carrizo Plains; Orange County, in the San Joaquin Hills south of Santa Ana.

This species is characteristic of the Lower Miocene.

Dimensions: Diameter through the anterior petal about 75 mm. Height 6 to 7 mm.

Genus SCUTASTER Pack

Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 270, 1909.

The original generic description is as follows:

Test circular, depressed, ambulacral star small. Lunules in the prolongation of the petals of the trivium; and either lacking in the bivium and posterior interambulacral space, or not placed in the same relative positions as on the anterior portion of the test.

The new material shows that lunules and narrow marginal notches are lacking in the prolongation of the posterior petals and in the posterior interambulacral area, as was suggested in the original description.

SCUTASTER ANDERSONI Pack

Plate 15, figures 2a and 2b

Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, pp. 278-279, pl. 23, 1909.

The original description is as follows:

Test sub-circular in outline, edges markedly thin. Upper surface regularly arched from the margin; apex anterior to the center. Apical system small and apparently central. Ambulacral star small; petals extending slightly less than half way to the margin of the test, closed at the ends. Lateral petals broader than the posterior ones, but of almost the same length. Poriferous zones broad, and continuing full width almost to the ends of the petals. In the posterior petals the interporiferous area forms about one-third the width of the petal. Poriferous zones of the lateral petals equal in width to those of the posterior petals, but enclosed area broader. In the extension of the three anterior petals are broad lunules, over half as long as the petals; shallow grooves extend from the lunules to the margin. Anterior lunule slightly farther from the apical system than are the lateral ones. From the ends of the posterior petals the plates enlarge, and the area broadens rapidly. No lunules were seen here, nor in the posterior interambulacral space. They may be represented by marginal notches, as the posterior edge of the specimen is lacking.

The new material shows that the test is sub-circular to oval in outline. The apical system is slightly posterior to the middle of the test, the ratio of the distance from the apical system to the posterior and anterior margins in the figured specimen is as 23:30. The middle of the arch of the abactinal surface is slightly anterior to the middle of the test, being located approximately in the middle of the anterior petal. In the figured specimen the distance from the middle of the arch to the anterior margin is 21 mm., to the posterior margin 32 mm. The posterior ambulacrae terminate rather abruptly, the edge of the test forming broad, shallow notches which fashion the posterior interambulacral area into a process somewhat similar to that of *Scutella norrisi*. The test is much compressed. In some cases there is a

slight tendency for the arch of the abactinal surface to flatten near the lateral margins, but in most cases the profile of the upper surface is regular between these margins. The slope of the abactinal surface from the apex to the anterior margin is rounded and rather abrupt, to the posterior margin flat and gentle. There are neither lunules nor narrow marginal notches in the posterior half of the test. The petals are almost closed, the outer row of pores swinging in abruptly toward the inner row. The posterior petals are slightly shorter as well as slightly narrower than the lateral ones. Isolated pores are visible for only one or two plates beyond the outer end of the petals. The greatest width of the test is posterior to the center, and approximately through the apical system.

Occurrence: Near Muir, Contra Costa County, California; in Kern County, California, on the north slope of the San Emigdio Mountains at the southern end of the San Joaquin Valley. At the first locality only a single specimen has been found; at the second the tests occur in great abundance.

Known only in the lower half of the Miocene.

Dimensions: Diameter through the anterior petal 53 mm.; diameter between the lateral margins 62 mm.; height 5 to 6 mm.

Transmitted January 15, 1913.

EXPLANATION OF PLATE 15

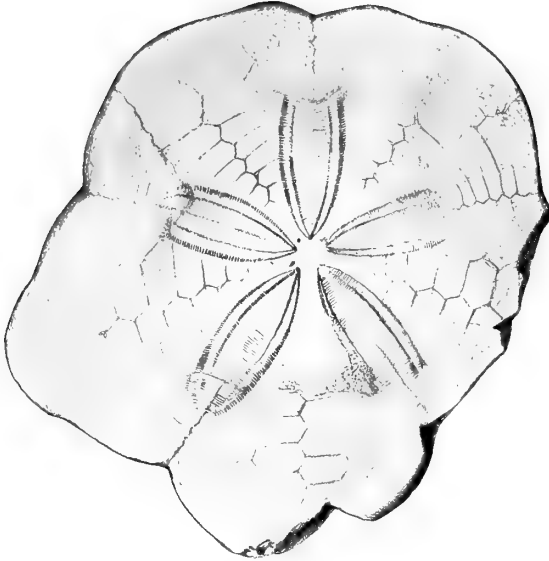
Fig. 1.—*Scutella norrisi* Pack. View of abactinal surface. Natural size.

Diameter through anterior petal, about 75 mm. Occurrence, near the mouth of the Alizo Canyon, in the southern end of the San Joaquin Hills, south of Santa Ana, Orange County, California. University of California locality 1157.

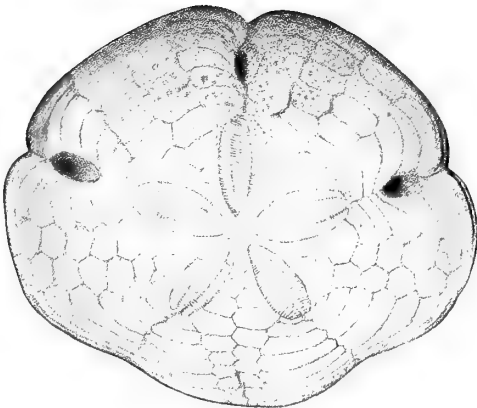
Figs. 2*a* and 2*b*.—*Scutaster andersoni* Pack. Natural size.

Fig. 2*a*. View of abactinal surface. Diameter through anterior petal, 53 mm. Occurrence, in the Mount Pinos Quadrangle, California, at the southern end of the San Joaquin Valley, about three and three-quarters miles northeast of Antimony Peak.

Fig. 2*b*. Anteroposterior section.



1



2a



2b



UNIVERSITY OF CALIFORNIA PUBLICATIONS
BULLETIN OF THE DEPARTMENT OF
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Vol. 7, No. 14, pp. 305-323

Issued May 24, 1913

THE SKULL AND DENTITION OF A CAMEL
FROM THE PLEISTOCENE OF
RANCHO LA BREA

BY

JOHN C. MERRIAM

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INTRODUCTION

Although remains of camels are fairly common in the Pleistocene of North America, and are widely distributed over the continent, up to the present time the material obtained has been very fragmentary, and the available information correspondingly unsatisfactory. So far as known to the writer, the best specimens described consist of small parts of the skeleton, the skull being represented by jaws and very incomplete cranial material.

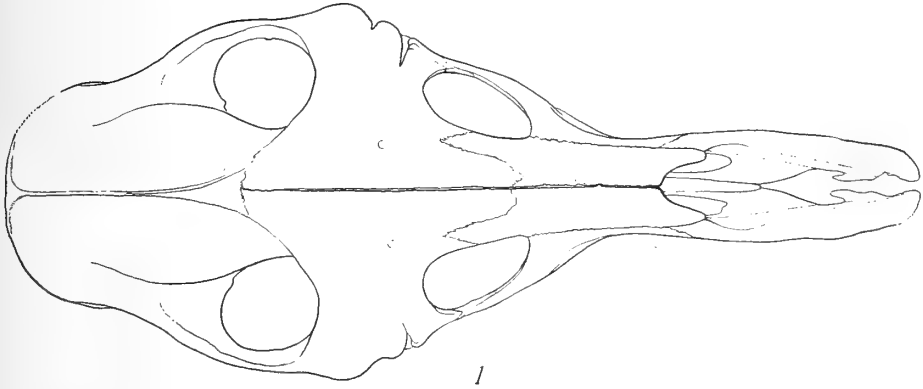
Owing to the nature of the material available, the North American Pleistocene Camelidae have almost necessarily been

described under numerous generic and specific names, as the fragmentary specimens representing different parts of the skeleton cannot be correlated satisfactorily. Not less than six genera are listed. It is probable that three of the generic groups have a valid basis in American material. The others are of doubtful value. The forms referred to *Eschatius* and *Camelus* represent two of the generic groups. The relationships of the species referred to *Camelops*, *Megalomeryx*, *Auchenia* and *Holomeniscus*, present one of the problems in the study of this group, recent writers generally considering the four as representing a single genus.

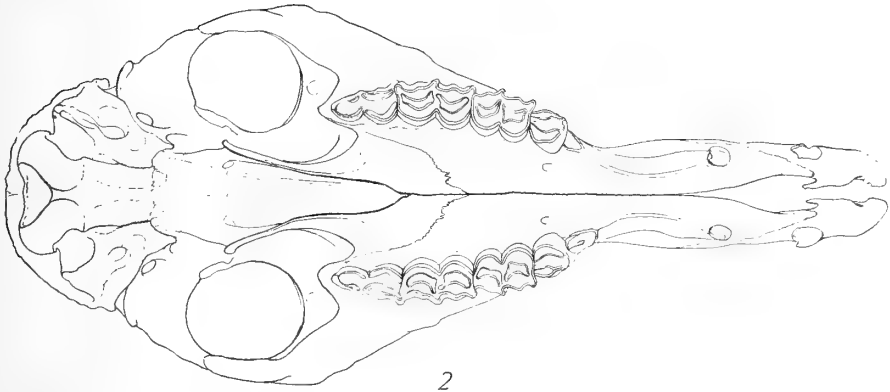
Wortman¹ in his revision of the extinct Camelidae of North America called attention to the very fragmentary nature of the material upon which all of the North American Pleistocene species rest, and considered that no evidence had been presented showing that valid characters separated the genera *Megalomeryx* and *Holomeniscus* from *Camelops*, the first genus described. The North American forms referred to *Auchenia* he showed to be distinct from the Recent *Auchenia*, and not clearly separable from *Camelops*. *Megalomeryx* was described from Nebraska later than *Camelops* from Kansas, and may be of Tertiary age. It was based upon two molar teeth, while the type of *Camelops* consisted of an anterior end of the rostral region without cheek teeth. *Holomeniscus* was characterized by Cope as possessing a single superior premolar, P¹. Wortman stated that, so far as he had been able to obtain information, in the only specimen in which the superior premolar formula can be determined, both P³ and P⁴ are present. So far as determined by Wortman, no characters were presented which might reasonably be considered as distinguishing *Holomeniscus* from *Camelops*.

In the excavation work done at Rancho La Brea during the past six years camel material has been found occasionally, but not until recently has it been possible to obtain a complete skull. In the excavations of the last few months, the University of California has been so fortunate as to find several nearly perfect skulls, and associated with them is a quantity of skeletal material representing the greater part of the animal. Three skulls now

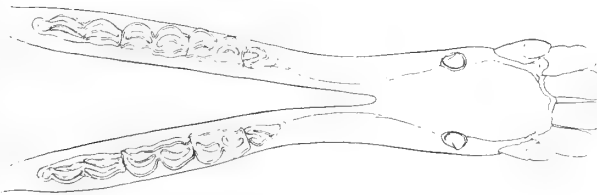
¹ Wortman, J. L., Bull. Am. Mus., vol. 10, p. 128, 1898.



1



2



3

Fig. 1. *Camelops hesternus* (Leidy). Skull, superior view. No. 20040, $\times \frac{1}{2}$. Rancho La Brea Beds.

Fig. 2. *Camelops hesternus* (Leidy). Skull, inferior view. No. 20040, $\times \frac{1}{2}$. Rancho La Brea Beds.

Fig. 3. *Camelops hesternus* (Leidy). Superior view of anterior portion of the mandible with dentition. No. 20040, $\times \frac{1}{2}$. Rancho La Brea Beds.

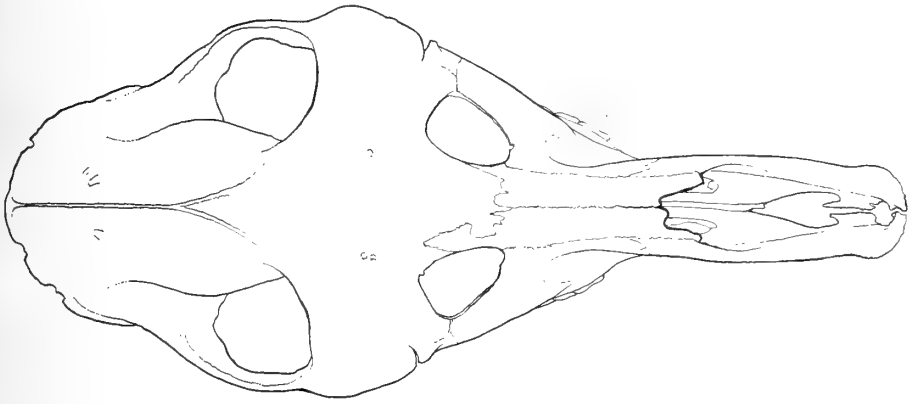
available in the palaeontologic laboratory furnish for the first time a satisfactory basis for comparative study of the skull and dentition of our American Pleistocene camels. In advance of an investigation of the entire representation of the skeleton the following descriptions are presented. A discussion of the skeleton will be furnished after completion of the excavation work, when all materials of this group can be brought together for more satisfactory study.

SKULL

The skull in specimens 20040, 20028, and 20049 approximates the size in that of the Bactrian camel. The general outlines resemble *Auchenia* more nearly than *Camelus*. In superior view (figs. 1 and 4), the slender rostral region tapers more gradually toward the anterior end than in *Camelus*, and in this respect resembles *Auchenia*. The frontal region is quite distinctly convex transversely, with no median depression, and in this character differs from the specimens of both *Auchenia* and *Camelus* available for comparison. The orbits are situated relatively far back, the anterior border being situated above the last superior molar. The basicranial and basifacial axes are nearly parallel, as in *Camelus*.

The nasal elements are long and narrow, the posterior ends are separated by a wedge of the frontals, but the outer borders do not spread widely as in *Auchenia* and *Camelus*. The anterior ends of the nasals are in broad contact with the premaxillaries, as in *Auchenia*. The nasals are relatively longer and narrower than in *Auchenia*, and the notch for the posterior border of the anterior nasal opening is not behind the posterior end of the premaxillaries. In *Auchenia* the posterior ends of the premaxillaries do not extend as far back as the posterior border of the anterior nasal opening. The ends of the nasals project anteriorly beyond the superior border of the premaxillaries.

A characteristic feature of the Rancho La Brea specimens is the presence of a large, deep fossa near the upper margin of each maxillary above the fourth premolar (fig. 5). The inferior region of this fossa is not sharply marked. The upper wall of



4



6

Fig. 4. *Camelops* near *hesternus* (Leidy). Skull, superior view. No. 20028, $\times \frac{1}{2}$. Rancho La Brea Beds.

Figs. 5 and 6. *Camelops* near *hesternus* (Leidy). Skull. No. 20028, $\times \frac{1}{2}$. Rancho La Brea Beds. Fig. 5, cranium, lateral view; fig. 6, mandible, lateral view.

the cavity is abrupt in no. 20040 and is bordered by a sharp overhanging ridge in nos. 20028 and 20049. This fossa is clearly shown in *Plianchenia* (*Megatylopus*) *gigas* described by Matthew and Cook² and is strongly marked in *Alticamelus*.³ There is no suggestion of it in *Auchenia* or in *Camelus*.

The lachrymal vacuities are very large and have an approximately triangular outline. In specimen 20028 the lachrymals are separated externally from the lachrymal vacuities on one side by the union of the maxillaries and frontals. In no. 20040 they barely touch the vacuities.

The heavy anterior end of the zygomatic process of the squamosal extends forward well beneath the posterior border of the orbit somewhat as in *Auchenia*, but in contrast to the form in *Camelus*. The jugal is much thicker vertically below the orbit than in *Camelus*, and exhibits a marked inferior crest or ridge as described in *Megatylopus gigas* by Matthew and Cook.⁴

The palate is narrow (figs. 2 and 9), the long, narrow, V-shaped posterior nasal opening extending forward to a point slightly in advance of a line connecting the middle region of the third upper molars in nos. 20028 and 20049, and to the posterior end of M² in no. 20040.

The basiphenaoid and presphenoid form a deep narrow ridge quite different from the inferior surface of this element in *Camelus* and in *Auchenia*. The inferior processes of the alisphenoid seem smaller, are less divergent, and do not project as far inferiorly as in *Camelus*.

The glenoid fossa is relatively narrower posteriorly than in *Camelus*, and as in *Auchenia*, the outer margin of this fossa is not bordered by a distinctly elevated wall or process that is seen in *Camelus*. The postglenoid process is somewhat larger than in *Auchenia*.

In specimen 20028 the transverse palato-maxillary suture truncates the anterior ends of the palatines rather broadly, as in *Camelus dromedarius*. In no. 20049 the suture is more strongly

² Matthew, W. D., and Cook, H. H., Bull. Am. Mus. Nat. Hist., vol. 26, p. 397, 1909.

³ *Ibid.*, p. 403.

⁴ *Ibid.*, p. 398.

convex anteriorly. In no. 20040 it is still more acute anteriorly. In *Auchenia lama* the anterior ends of the palatines extend forward as an acute wedge between the maxillaries.

The paroccipital process is rather slender, and bends forward with a marked inferior hook. In *Auchenia* this process is wider distally. The mastoid region forms a deep and rather narrow plate anteriorly. The mastoid and paroccipital plates are brought nearer together than in either *Auchenia* or *Camelus*. In nos. 20040 and 20028 the posterior inferior border of the mastoid plate slopes forward quite sharply in contrast to the form seen in *Auchenia*.

The occipital region (fig. 7) shows rather more similarity to *Camelus* than to *Auchenia*. In *Auchenia* the occiput consists of



Fig. 7. *Camelops near hesternus* (Leidy). Occipital region of the skull. No. 20028, $\times \frac{1}{5}$. Rancho La Brea Beds.

two lateral planes which meet in a strong median crest. At the outer borders of these planes are the lateral foramina of the occiput. In the Rancho La Brea specimens there is a short low median crest at the upper end of the occiput in nos. 20028 and 20040; in no. 20049 it is scarcely visible. On each side of the crest is a deep fossa for the rectus capitis posticus. At either side of the occiput the large lateral foramina lie at the bottom of large, deep fossae, and these foramina deeply notch the margins of the occipital bone. Between the lateral foramina and the fossae for the muscles below the inion the occipital bone rises on each side as a prominent rounded buttress or ridge extending from near the upper border of the foramen magnum

to the lamboidal crest. The region of the occiput immediately above the foramen magnum is moderately convex, approaching flatness, as in *Camelus*, instead of strongly convex nearing angularity, as in *Auchenia*.

The frontal foramina are a little farther apart than in *Camelus*. In *Auchenia* these foramina are relatively larger and there are distinct channels leading forward from them such as are not seen in the Rancho La Brea specimens. The infraorbital foramen and the foramen piercing the root of the zygomatic arch are situated much as in *Auchenia*. The infraorbital foramina consists of a single opening on each side in no. 20028; the opening is separated into two parts by a bridge of bone in 20040; and is divided on one side by a slender bridge in 20049. The infraorbital foramina are situated approximately over the posterior border of P⁴ in nos. 20028 and 20040, and over the middle region of M¹ in no. 20049. The anterior palatine foramina are long and narrow, and extend back to the canines. The anterior ends of the maxillaries extending around the borders of these foramina reach to the anterior side of the openings, as in the type of *Camelops*. In *Auchenia lama* they do not reach as far forward. The posterior palatine foramina are situated well forward near P³ in specimen 20028, and opposite P⁴ in nos. 20040 and 20049.

The postglenoid foramen is very small, in contrast to the large size of the opening in *Camelus*. A small foramen present on the outer base of the postglenoid process is not found in *Camelus* and is absent or very minute in *Auchenia*. The lateral foramina of the occiput are very large and open externally into the deep lateral fossae of the occipital region. The anterior mental foramen of the mandible is immediately below or slightly behind the canine, as in *Auchenia*. It is situated farther back on the horizontal ramus in *Camelus*.

In the mandible (figs. 3, 6, and 8), the symphyseal region is relatively short anteroposteriorly, as in *Auchenia*. The symphyseal union in *Camelus* is much longer anteroposteriorly than in *Auchenia* or in the Rancho La Brea specimens. The horizontal ramus is somewhat higher than in *Camelus*, and slightly higher than in *Auchenia*. It tapers very gradually

toward the anterior end. Below the diastema the lower margin is barely concave, in contrast with *Auchenia*, in which it is distinctly concave. In *Camelus* the inferior border may show a distinct concavity between a point below M_3 and the symphysis. The high coronoid process shows a nearly even width or antero-posterior diameter for the greater part of its height.

MEASUREMENTS OF SKULL

	No. 20028	No. 20040
Length, anterior end of premaxillaries to posterior end of occipital condyles	571. mm.	573.
Length, anterior end of premaxillaries to anterior end of inferior nasal opening	316.4	318.
Length along median line, anterior end of premaxillaries to posterior end of superior molar series....	341.	362.
Length along median line from anterior border of premaxillaries to plane connecting anterior borders of orbits	324.5	322.
Greatest width at posterior region of orbits	245.	251.
Greatest height of orbits	63.3	61.
Least width of brain-case immediately behind orbits	77.	83.
Least width of rostral region between superior canine and cheek-tooth series	62.9	.....
Greatest anteroposterior diameter of right ramus of the mandible	452.	469.
Greatest height of mandible below posterior border of M_3	109.	103.
Height of mandible below anterior border of P_4	60.	61.
Length of diastema between inferior canine and P_4	100.	112.

DENTITION

Dental formula, I_3^1 , C_1^1 , P_1^2 , M_3^3

The dentition in general shows more resemblance to that of *Auchenia* than to any other form.

I^3 is a little larger than the superior canine. It is a laterally compressed, recurved, lanceolate tooth quite similar to I^3 of *Auchenia*. The lower incisor dentition was of much the same type as in *Auchenia*. I_3 was at least as large compared with I_1 and I_2 as in *Auchenia*; it seems distinctly larger than in *Holomeniscus hesternus* from Texas figured by Cope.⁵

⁵ Cope, E. D., Geol. Surv. Texas, 3rd, Ann. Rep. for 1891; pl. 21, fig. 4.

The small superior canines have much the same form as in *Auchenia*, but are relatively thicker transversely.

As in *Auchenia*, small papillae which may be present behind the canines indicate the existence of rudiments of the anterior premolars.

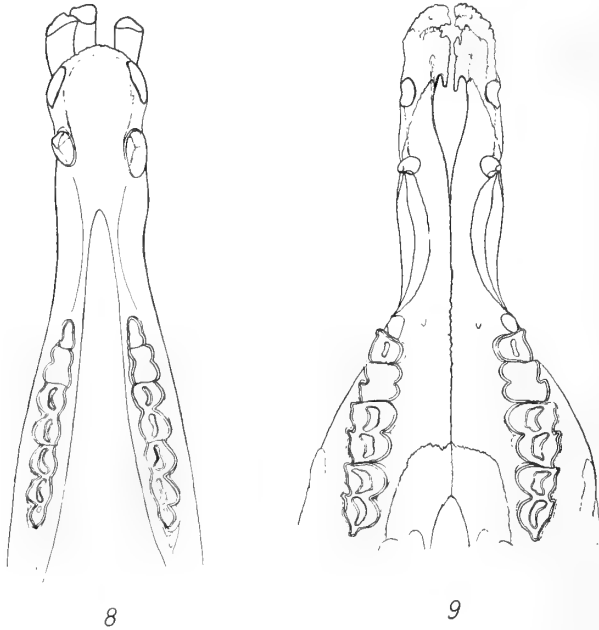


Fig. 8. *Camelops* near *hesternus* (Leidy). Superior view of anterior portion of the mandible with dentition. No. 20028, $\times \frac{1}{5}$. Rancho La Brea Beds.

Fig. 9. *Camelops* near *hesternus* (Leidy). Inferior view of anterior portion of the skull with dentition. No. 20028, $\times \frac{1}{5}$. Rancho La Brea Beds.

See also for dentition, figs. 2 and 3, p. 307.

P^3 as shown in no. 20040 (fig. 2) has a narrow, almost blade-like crown with a very small cusp, or a prominent ridge of the cingulum high up on the postero-internal wall. It shows approximately the same size compared with P^4 that is noted in *Auchenia*.

P^4 has a relatively greater transverse diameter than in *Auchenia* and a more distinctly quadrate form. In this respect, it more closely approaches the form seen in *Camelus*.

Lower premolar four has approximately the same relation to M_1 in dimensions as in *Auchenia*. It has a wedge-shaped cross-section and approximates the form in *Auchenia*. There is a deep enamel fold on the posterior side of the crown, as in *Auchenia*, but the inner or medial side is an almost even vertical wall without the folds seen in *Auchenia*. P_4 shows some evidence of division of the root into two parts, and a faint groove on one side may mark the line of separation.

The upper molars all differ somewhat from those of *Auchenia* in the less marked development of the external styles and of the median ribs on the outer side of the paraconid and metaconid. In M^2 the anterior lobe has a noticeably greater transverse diameter than the posterior lobe. On the somewhat worn M^3 of no. 20028 the metastyle is drawn out posteriorly as a wing not shown in *Auchenia*. This wing does not appear in the unworn M^3 of no. 20040.

In M_1 and M_2 the inner walls of the protoconid and hypoconid lobes tend to be a little more distinctly separated by a median longitudinal groove than in *Camelus*. The styles and inner ribs of the lower molars are less strongly developed than in *Auchenia*. M_2 and M_3 differ markedly from the corresponding teeth of *Auchenia* in the absence of the anteroexternal buttresses so characteristic of that genus. It is upon this character that Wortman⁶ separates *Camelops* from *Auchenia*. M_3 is distinguished from that of *Camelus* by the position of the posterior or third lobe. In the Rancho La Brea specimens this lobe extends nearly straight back, and its inner wall is nearly even with that of the anterior lobes of this tooth. In *Camelus* the inner wall of the posterior lobe turns sharply out and away from the nearly even plane formed by the inner walls of the first and second lobes. In *Auchenia* the posterior lobe of M_3 rises from approximately the middle of the posterior end of the second lobe, and is separated from the inner and outer walls of the second lobe by a deep longitudinal groove on each side.

⁶ Wortman, J. L., Bull. Am. Mus. Nat. Hist., vol. 10, pp. 129-130, 1898.

MEASUREMENTS OF DENTITION

	No. 20028	No. 20040
Length, anterior side of I ¹ to posterior side of M ³ , measured along outer border of dental series	301. mm.	327.
Length, anterior side of P ₄ to posterior side of M ₃	141.9	
Length, anterior side of inferior canine to posterior side of M ₃	250.	290.
Greatest width of palate between outer borders of superior cheek-tooth series (measured between outer borders of third molars)	141.9	148.
Least transverse diameter of palate between superior cheek-tooth series (measured between inner borders of fourth premolars)	66.	56.
Length, anterior side of P ³ to posterior side of M ²	142.7	156.4
Length, anterior side of M ¹ to posterior side of M ³	124.	132.
I ¹ , anteroposterior diameter		17.8
I ³ , greatest transverse diameter		9.7
Superior canine, anteroposterior diameter	13.9	13.2
P ³ , anteroposterior diameter		18.8
P ³ , greatest transverse diameter		11.
P ⁴ , anteroposterior diameter	23.5	*28.
P ⁴ , greatest transverse diameter	25.	22.5
M ¹ , anteroposterior diameter	24.4	42.
M ¹ , greatest transverse diameter	31.	33.6
M ² , anteroposterior diameter	42.1	52.
M ² , greatest transverse diameter across protocone....	31.6	32.8
M ³ , greatest anteroposterior diameter	49.5	45.8
M ³ , greatest transverse diameter	31.4	27.2

	Type of <i>C. hes-</i> <i>ternus</i> specimen§	Cope's Texas	No. 20028	No. 20040
Length, anterior side of P ₄ to pos- terior side of M ₃		‡164.	142. mm.	‡162.2
I ₁ , greatest transverse diameter		a13.	17.9	19.
I ₂ , greatest transverse diameter		19.	20.4	18.8
I ₃ , anteroposterior diameter of alveolus		12.	28.5	25.3
Inferior canine, greatest anteropos- terior diameter		a12.	16.1	
P ₄ , greatest anteroposterior diameter	27.	27. .	21.9	27.5
P ₄ , greatest transverse diameter			12.9	13.4
M ₁ , anteroposterior diameter	42.	38.	28.	39.
M ₁ , greatest transverse diameter			21.1	21.5
M ₂ , anteroposterior diameter	52.	44.	38.4	46.
M ₂ , greatest transverse diameter			22.	21.2
M ₃ , greatest anteroposterior diameter	58.	56.	58.2	58.
M ₃ , greatest transverse diameter across anterior lobe			21.6	18.5

a, approximate.

* at base of crown.

‡ M₃ not completely emerged.

§ From Cope's figure of the specimen.

§ Cope, E. D., *Geol. Surv. Tex.*, 3rd Ann. Rep. for 1891, pl. 21, figs. 3 and 4.

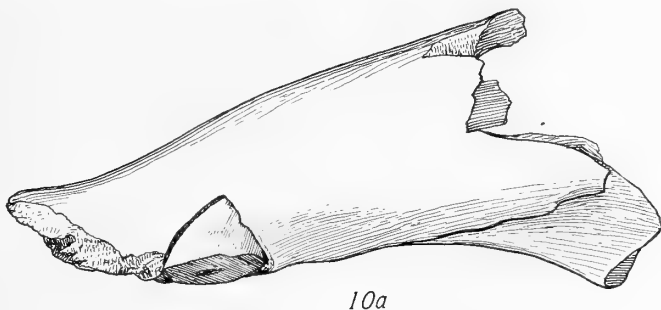
RELATION OF RANCHO LA BREA SPECIMENS TO PREVIOUSLY DESCRIBED PLEISTOCENE FORMS FROM NORTH AMERICA

It is perhaps undesirable at this stage in the study of the Rancho La Brea camels to attempt a final determination of their relationships to all of the known North America forms, but the broader outlines of the problem may be presented.

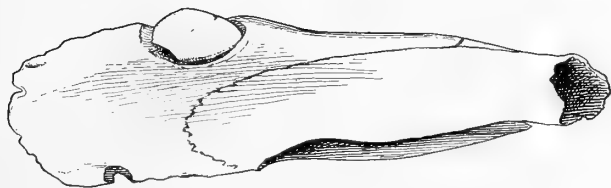
The Rancho La Brea specimens so far as known are clearly distinguished from the American Pleistocene species referred to the genera *Eschatius* and *Camelus*. They are separated from both *Camelus* and *Eschatius* by their dental formula of $\frac{1}{3}, \frac{1}{1}, \frac{2}{1}, \frac{3}{3}$.

In the mandible from Hay Springs referred by Wortman^r to the genus *Camelus* the formula is $\frac{3}{3}, \frac{1}{1}, \frac{2}{2}, \frac{3}{3}$; the inferior canine is more or less incisiform, and is not separated from I_3 by a marked diastema; and P_1 is caniniform.

The genus *Eschatius* is characterized by the most extreme reduction known in the cheek-tooth dentition, the formula of



10a



10b

Figs. 10a and 10b. *Camclaps kansanus* Leidy. Type specimen, adapted from Leidy, natural size. Fig. 10a, anterior end of rostral region, lateral view; fig. 10b, anterior end of rostral region, inferior view.

the upper series being P¹ M³. P³ is not represented, and P⁴ is reduced to a simple conical form not unlike the small P³ of the Rancho La Brea specimens.

The American Pleistocene forms with which the Rancho La Brea specimens are most closely related are those included in the species that have been referred to *Camelops*, *Auchenia*, and *Holomeniscus*.

Comparison with Type Specimens of Camelops.—Leidy's type of *Camelops* consisted of the anterior end of a premaxillary bone with the root of the last upper incisor, and a small piece of the maxillary, with the alveolus of the canine (figs. 10a and 10b). Compared with this specimen, the anterior end of the rostral region of the Rancho La Brea skulls shows little to distinguish it. The general proportions of the elements present and the location of the teeth are nearly the same. The extension of the maxillary forward around the anterior end of the anterior palatine foramen noted in the Rancho La Brea specimens is much as in the type of *Camelops*.

Comparison with the Type Specimen of Auchenia hesternae Leidy.—The type specimen of *Auchenia hesternae* was discovered by Dr. Lorenzo G. Yates in Livermore Valley, California, in a gravel deposit which was presumed by Dr. Yates to represent an old river channel. A statement by Leidy, based upon the communication of Professor E. O. Hovey, to the effect that it was found twenty-five miles inland from San Leandro, California,⁸ is erroneous, according to Dr. Yates.⁹

The type consists of a lower molar series and a single upper molar. There is some uncertainty as to whether these teeth all represent the same individual. The fact that the relative stages of wear are approximately what one might expect to find in the same series is evidence in favor of the view that the lower teeth are all from one animal.

The dentition of the Rancho La Brea specimens resembles that of the type of *Auchenia hesternae* in the presence of a single

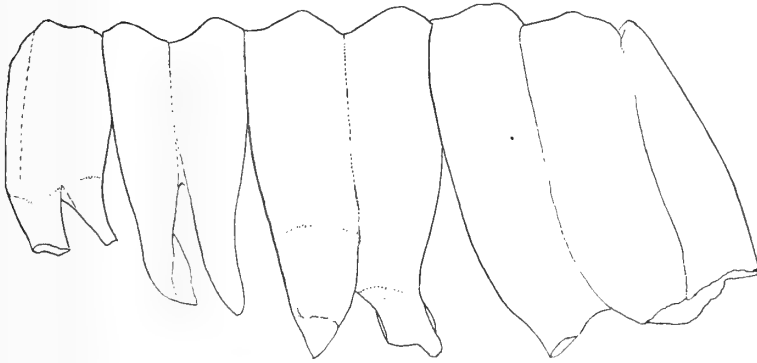
⁷ Wortman, J. L., Bull. Am. Mus. Nat. Hist., vol. 10, p. 133, 1898.

⁸ Leidy, J., Geol. Surv. Terr., vol. 1, Fossil Vertebrates, pp. 228, 229, 256, 1873.

⁹ Yates, L. G., Proc. Acad. Nat. Sci., Philad., vol. 26, p. 18, 1874.



11a



11b

Figs. 11a and 11b. *Camelops hesternus* (Leidy). Inferior cheek-tooth series of type specimen, $\times \frac{1}{2}$. Fig. 11a, oclusal view; fig. 11b, lateral view. (Adapted from Leidy.)

premolar, P_4 , with a wedge-shaped cross-section. The general form and relative dimensions of this tooth are much the same in the type of *A. hesternus* and in specimen 20040 from Rancho La Brea. The nature of the posterior enamel fold of the crown is similar in the two. In the type of *A. hesternus* (Leidy, pl. 37, fig. 2) P_4 is represented with a distinct groove on the outer side marking the division of the tooth into anterior and posterior regions, each terminating inferiorly in a distinct root. In Rancho La Brea specimen 20028 there is an exceedingly faint separation of the two roots, and the inner face of the crown may show a faint groove, marking this division; there is, however, no external groove as represented for *A. hesternus*. In

Leidy's figure 1 of the plate to which reference is made above the identical P_4 represented in figure 2 seems to show almost no external groove.

In the type of *Auchenia hesterna*, M_1 and M_2 are both very considerably larger than in specimen 20028, and M_2 seems relatively much larger, especially compared with M_3 . In specimen 20040 the dimensions of P_4 and M_3 are practically identical with those in the type of *A. hesterna*. M_1 is only seven per cent smaller, and M_2 eleven per cent smaller. The slight differences between specimen 20040 and the type of *A. hesterna* seem to the writer of less than specific value, and the Rancho La Brea form may be considered as typifying that species. The differences between nos. 20040 and 20028 are greater than between 20040 and the type of *hesterna*, but considering the close similarity in form and dimensions of the skull, together with the evident difference in age of the two individuals, the writer is not inclined to believe the difference in tooth measurement as of specific rank. No. 20028 represents a much older animal than no. 20040. During a considerable period in the life history of each individual P_4 and M_3 increase in anteroposterior diameter of the crushing face as the crowns wear down; while M_1 and M_2 , with crowns narrowing inferiorly much earlier than the other teeth, shorten the anteroposterior diameter of the occlusal surface. There seems also to be some individual variation in tooth dimensions, so that age, with sex and individual variation, may produce rather large differences in relative size of the teeth.

The upper molar of *Auchenia hesterna* figured by Leidy does not differ greatly from M^2 of the Rancho La Brea form.

A California species described by Leidy¹⁰ as *Auchenia californica* previous to the publication of *A. hesterna* may be identical with *hesterna*, and may therefore include the specimens here described. This can best be determined by a careful comparative study of all skeletal material obtained, as *A. californica* was based solely upon limb and arch bones of very large size. If we give full value to the statement on the label accompanying the type specimen of *A. californica*, to the effect that it came from beneath the lavas at Table Mountain, it is probable that this

¹⁰ Leidy, J., Proc. Acad. Nat. Sci., Phila., 1870, p. 126.

species is of Tertiary age, and presumably specifically if not generically distinct from the Rancho La Brea form.

Comparison with the Forms referred to by Cope as Holomeniscus hesternus, H. sulcatus, H. vitikerianus, and H. macrocephalus.—A fine mandibular ramus from Bowie Bend, Austin County, Texas, was considered by Cope¹¹ to represent the same species as the type of Leidy's *Auchenia hesternus*. Cope's specimen is undoubtedly near *hesterna*, and resembles it more closely in the dimensions of M_1 and M_2 than does specimen no. 20028 from Rancho La Brea. The reference of this specimen to *hesterna* by Cope on the basis of evidence then available seems justified.

Compared with Cope's Texas type of *Holomeniscus hesternus* the specimens from Rancho La Brea show a slightly larger mandible with more widely spreading incisors and a larger I_3 . As nearly as can be determined, I_3 of the Rancho La Brea specimens is much larger compared with I_2 than in the Texas form. The dimensions of the cheek-teeth are closely similar in Cope's specimen and no. 20040 from Rancho La Brea. The Texas specimen and those from Rancho La Brea are evidently generically identical. The characters separating them are doubtfully of specific rank. The determination of the exact specific relationship of these two forms may well await an examination of all possible collections from Rancho La Brea, to determine the limits of variability of the California form.

A specimen from Tequixquiac, Mexico, described by Cope¹² is near the form from Texas.

Holomeniscus sulcatus Cope from Texas is near the Rancho La Brea species in many characters. The type of *H. sulcatus* is an old individual with worn P_4 and M_1 , and measurements of the dentition are very close to those of no. 20028 from Rancho La Brea, in which the teeth give evidence of a similar stage of wear. As has been suggested by Wortman, the peculiar characters of this species may be shown later to come within the limits of individual or age variations of one of the previously described forms, like *Camelops kansanus* or *C. hesternus*.

¹¹ Cope, E. D., Geol. Surv. Texas, 3rd Ann. Rep. for 1891, pp. 71 and 85.

¹² Cope, E. D., Amer. Phil. Soc. Proc., vol. 22, p. 18, May 16, 1884.

The Pleistocene species described by Cope as *Auchenia vitikeriana*¹³ and *Holomeniscus macrocephalus*¹⁴ are possibly generically identical with the Rancho La Brea species, but are specifically distinct. The form of the posterior lobe of M_3 in *H. macrocephalus* is quite different from that of *Camelops hesternus*.

SUMMARY

The Rancho La Brea form seen in specimens nos. 20040 and 20028 closely resembles as much as is known of the type specimen of *Camelops* Leidy. Although no satisfactory generic description of *Camelops* was given by Leidy, it is probable that the Rancho La Brea specimens represent the same generic group as the type specimen. Rancho La Brea specimen no. 20040 is evidently generically and specifically identical with Leidy's type of *Auchenia hesterna*. It is also generically identical with Cope's specimen identified as *Holomeniscus hesternus*, from Texas. Cope's type of *Holomeniscus sulcatus* is evidently in the same generic group. *Holomeniscus vitikerianus* presumably belongs in the same genus with the species just mentioned, and possibly also *H. macrocephalus*.

As shown by Wortman the separation of the North American Pleistocene camels from *Auchenia* is justified on the basis of differences in the form of the inferior molars, and the characters given by Cope to *Holomeniscus* are not distinctive. For the present at least the writer adopts the suggestion of Wortman that the name *Camelops* should be used for the group of species represented by *C. kansanus* and *C. hesternus*, since it is the earliest designation applied.

The group of camels referred to *Camelops*, and represented by specimens nos. 20040 and 20028 from Rancho La Brea, is much nearer to *Auchenia* than to *Camelus*, but is nevertheless distinct from the typical *Auchenia*. It is separated from *Camelus* by the premolar formula of $\frac{2}{1}$, instead of $\frac{3}{2}$, relatively small size of P^3 , broad contact of the nasals and premaxillaries,

¹³ Cope, E. D., Bull. U. S. Geol. and Geog. Surv. Terr., vol. 4, p. 380, 1878.

¹⁴ Cope, E. D., Geol. Surv. Texas, 3rd Ann. Rep. for 1891, p. 85 and pl. 23, figs. 5 and 5a.

presence of well-defined maxillary fossae, relatively great anterior extension of the zygomatic process of the squamosal, absence of a lateral bordering wall on the glenoid fossa, and the higher mandible which tapers more gradually anteriorly.

The *Camelops* group as here comprised resembles *Auchenia* in the general form of the skull and especially of the mandible, the relation of the nasals and premaxillaries, relatively great anterior extension of the zygomatic process of the squamosal, form of the glenoid fossa, and in premolar formula. The group differs from *Auchenia* in the form of the frontal region, narrower nasals, presence of large maxillary fossae, form of the mastoid process, more nearly quadrate form of P^4 , more distinctly wedge-shaped cross-section of P_4 , absence of folds on medial side of P_4 , less marked development of styles and ribs on outer side of upper molars and inner side of lower molars, and absence of strongly marked anteroexternal styles in M_2 and M_3 .

Although a definite statement as to the affinities of *Camelops* would be premature if presented in advance of a study of the entire skeleton, it seems desirable to call attention to the resemblance in characters of skull and dentition in the Rancho La Brea form to those of *Pliauchenia* (*Megatylopus*) of Matthew and Cook.¹⁵

¹⁵ Matthew, W. D., and Cook, H. J., Bull. Amer. Mus. Nat. Hist., vol. 26, pp. 396-401, 1909.



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THE PETROGRAPHIC DESIGNATION OF
ALLUVIAL FAN FORMATIONS

BY

ANDREW C. LAWSON

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Use of the Term 'Breccia.'—The following quotations referring to the significance of the word "breccia" are taken from the current edition of a well-known American text-book of geology:

"Volcanic agglomerate, or *breccia*, is a mass of angular blocks of lava, with which may be mingled fragments of sedimentary rocks, which the volcano has torn from the sides of its chimney. . . . Ordinarily the *breccia* is found only near the vent, etc."

"*Breccia* is a rock composed of angular fragments cemented by deposition of material, commonly CaCO_3 , in the interstices. The fragments may be any kind of rock. *Breccia* is also found in zones of fracturing and shattering of the rocks along fault-planes and is then called fault-breccia."

"Coral conglomerate or *breccia* is a cemented mass of coral pebbles or angular pieces or is made up of fragments of an older coral rock."

“Great masses of angular blocks of all sizes accumulate at the foot of cliffs and on mountain slopes as talus, which shows an imperfect division into layers and is slowly but continually creeping downward. By the deposition of some cementing material (usually CaCO_3) in the interstices of the talus the blocks may be bound into a solid mass, called *breccia*, of which the peculiarity is that the fragments composing it are angular, not rounded.”

“In a cave it frequently happens that angular fragments fall from the roof and are cemented into *breccia* by deposits of stalagmite.”

The diversity of use to which the word *breccia* is put by this author is not peculiar to his text. It is equally well exemplified in other books, some authors emphasizing one use of the word and some another, but nearly all using it in more than one sense. The term is, indeed, applied to other things than are indicated by the foregoing quotations. For example, the aggregate of blocks of rock imbedded in lava due to the breaking up of a lava crust while the flow beneath is still molten, is commonly called a *breccia*; and certain gangues of ore that have been broken and recemented, such as the zinc ores of the Joplin district, are similarly designated.

It is evident from this current usage that *breccia* is a generic term applicable to a rock of any kind which is composed of an aggregate of angular fragments, the origin of the fragments and their mode of aggregation being ignored except by the introduction of a supplementary word or phrase. The usefulness of the term inheres in that comprehensiveness which is characteristic of the terminology of an immature science.

Alluvial Fans are Formations of Vast Extent.—In arid regions of bold relief there are vast deposits of “wash” or rock detritus in the form of confluent or interdigitating alluvial fans, which are among the most important continental formations now in process of accumulation. Probably more than half of the area of the state of Nevada is occupied by such deposits and in large parts of Utah, New Mexico, Arizona, California, and Mexico, they are the most extensive formations encountered by the geologist. These alluvial fans consist of rock detritus which grades in size from coarse blocks near the mountains to fine silt in the playas or river bottoms. The assortment of materials is effected by the diminishing capacity and carrying power of running water in

its descent from the mountains to the valley, and the result is in general a fairly regular gradation; although large blocks are of common occurrence far down the slopes of the fans, due to exceptional rushes of water from the mountain cañons.

The material in general is but little rounded by attrition, being prevailingly angular or at best sub-angular. There may, however, be admixtures of well water-worn pebbles derived from old conglomerates in the mountains whence all the detritus comes. Some of the larger blocks may have a rounded or boulder-like shape, but this is due to exfoliation rather than attrition.

Use of the Term Conglomerate.—Such alluvial fan deposits when they become cemented, and so become coherent rocks, may in accordance with current usage be called *breccia*. But this word, as I have pointed out, is so overburdened with meanings that it has no particular connotation suggestive of what kind of rock we are speaking of, other than that it is composed of angular fragments; and an aggregate of angular fragments may originate in several different ways. The insufficiency of the term *breccia* as a designation for the kind of rock here considered is well illustrated in the use of the term Gila Conglomerate for the Quaternary alluvial fan deposits of Arizona. This term was first used for this formation by Gilbert¹ in 1873, and has more recently been adopted by Ransome.² But Ransome's description of the formation makes it clear that it is different from the rocks to which the term conglomerate is usually and properly applied. Indeed, he says that "the formation might appropriately be termed a *breccia*." Geologic usage and formal definitions are fairly consistent in applying the term conglomerate to an aggregate of well rounded water worn pebbles, and there can be little doubt of the advantage of adhering to this practice.

It is the purpose of this paper to raise the question from a general point of view of the advantage or disadvantage of continuing the use of the term conglomerate for formations having an origin geologically distinctive from that of ordinary conglomerate, and physical characteristics which are those of a *breccia*; (2) to call attention to the insufficiency for geological

¹ Wheeler Survey, vol. III, 1875, p. 540.

² U. S. G. S. Prof. Paper no. 12, 1903, p. 47. U. S. G. S., folio 111, p. 5.

purposes of the term breccia as applied to alluvial fan deposits owing to its comprehensive or generic meaning; and (3) to suggest a petrographical name for such deposits.

Ancient Alluvial Fan at Battle Mountain, Nevada.—My attention was drawn particularly to the question of a suitable designation for alluvial fan deposits in the course of a recent visit to Battle Mountain, Nevada. The rocks of Battle Mountain consist chiefly of quartzite, shale and limestone of Paleozoic age.³ These are traversed by dykes of igneous rock prevailingly of rhyolitic type, some of these dykes having an abundance of large phenocrysts of quartz. The rock of the dykes is in some cases quite fresh but in other cases it is decomposed and is then charged with copper ores to such an extent as to have stimulated much prospecting. In the northeastern portion of the mountain with which I became particularly familiar the Palaeozoic strata dip prevailingly to the eastward, but in some localities westerly dips were also observed. According to the report on the Geology of the 40th Parallel⁴ the prevailing dip of the mountain, presumably farther west, is westward, thus indicating that the general structure is anticlinal.

Resting unconformably on the upturned edges of these strata, and occurring chiefly as a mesa-like cap on various hilltops, is a later formation composed of angular fragments of the underlying rocks, but so thoroughly silicified and cemented that it is one of the hardest and most resistant formations of the district. Here and there in the midst of the angular fragments there may be found well water worn pebbles which have probably been derived from some earlier conglomerate. The fragments range in size up to several inches in diameter, and it is evident that any sorting action to which they may have been subjected in the process of accumulation has been an inefficient one. There are many holes or cavernous spaces in the rock which have the same range of dimension as have the fragments which make up the rock. These spaces were originally probably occupied by fragments of limestone which have been dissolved out by meteoric

³ Hague and Emmons (Geology of the 40th Parallel, vol. II, p. 666, *et seq.*) refer the limestone to the upper coal measures and the quartzite to the Weber quartzite on the basis of fossils found in the limestone.

⁴ *Loc. cit.*

waters. Except for the fact that it is thoroughly cemented and indurated, the rock is very similar to the detritus which flanks the margins of the mountain in the form of alluvial fans. There can be little doubt but that the formation is the remnant of an alluvial fan deposit spread over the region in the remote past. The antiquity of the deposit can be indicated only in a general way. The induration itself distinguishes the formation from any of the Quaternary deposits which the writer has observed in many parts of Nevada. Its position as a cap on the residual hills of the degraded mountain mass, perhaps a thousand feet above the floors of the adjacent valleys, indicates that it antedates the uplift which inaugurated the present erosional cycle. It also antedates the invasion of the country by the igneous rocks, since some of the copper bearing dykes cut the deposit. Moreover, it is traversed by several of the numerous faults which have dislocated the formations of Battle Mountain, since it is found at various sharply contrasted levels. This faulting probably belongs to an older period of disturbance which affected the region anterior to the degradation which in turn preceded the late Tertiary faulting concerned in the up-tilting of the Basin Ranges. Relying upon this interpretation of the age of the faulting, which of course requires the confirmation of more extended field work, this interesting formation appears to have been deposited between the close of the Paleozoic and the period of deformation which occurred at the close of the Jurassic. Leaving the definite determination of its age, however, an open question, the formation is of peculiar interest as revealing a physiographic condition analogous to the present which prevailed in this part of Nevada in the remote past.*

Term Fanglomerate Proposed.—For the discussion of this formation a petrographical designation is necessary. I hesitate to call the rock a conglomerate because that does violence to our current definition of this term and suggests an erroneous conception of the mode of deposit and the climatic conditions which determined that mode. I am equally loath to refer to it as a breccia because that term suggests nothing as to its genesis, nor does it as a purely descriptive term differentiate the rock from others similarly designated. To fill the gap in our nomen-

clature I propose that this and similar rocks be known as *fanglomerate*. The word is a hybrid and objection will doubtless be made to it on this score. It is, however, a descriptive term with specific connotation as to both the character of the rock and its mode of formation. My purpose in suggesting the term is not so much to amplify the terminology of petrography as to emphasize the geological significance of a class of rocks which have received but little attention.

Limitations of the Term.—In defining the term I must first make clear that it is not intended to include the finer sediments on the lower flanks of alluvial fans, but only the coarser deposits in the upper part of the embankment. In setting limits of texture or size of grain within which the term *fanglomerate* shall apply we encountered the same difficulty as in the case of conglomerate. When the constituent units of a conglomerate are very large the aggregation is often referred to as a “boulder bed”; and when they become small the rock passes insensibly into a sandstone. Barrell in a recent paper⁵ places the lower limit of the diameter of pebbles in a conglomerate at 5 mm., but states that common usage places it at about 2 mm. The transitional condition may be, and usually is, designated by various descriptive phrases, there being no hard and fast line between common conglomerate and common sandstone.

As to the coarseness of texture of *fanglomerate* there appears to be no convenient upper limit other than that set by nature. In many alluvial fans the constituent blocks are of extraordinary size near the apex, and sporadic blocks several feet in diameter are by no means uncommon far down the slope where the average size of the fragments may be less than an inch. Whether the large blocks be aggregated, or whether they occur more or less isolated in the midst of finer material, they form an integral part of the deposit and are of course included in the term *fanglomerate*. It is evident from this that some of the most interesting facies of *fanglomerate* cannot be illustrated by specimens, and that students will be able to familiarize themselves with them only by field examination.

⁵ Bull. G. S. A., vol. 23, p. 442, 1912.

It is to be noted here that cliff talus is to be discriminated from alluvial fan accumulations. A typical talus or scree, whether cemented or not should not be included under the term used to designate fan deposits. The latter are transported and laid down by running water and are therefore sedimentary. The former accumulate under the direct action of gravity and are not sedimentary in their mode of deposition. Slight admixtures of talus may enter into the composition of certain fans on their upper margins, but this fact will not ordinarily affect the discrimination. Should it be found expedient to refer to talus formations by a specific petrographical designation, as it well may be in a complete account of detrital rocks, it is desirable that the term should be distinct from that applied to fan deposits.

Toward its lower limit of coarseness fanglomerate grades into what is ordinarily termed arkose. This arkose is far from uniform in size of grain, however, and if we set arbitrarily 5 mm. as the maximum diameter of fragments in arkose, pieces of this and smaller sizes will be found intimately mixed with much finer material. The same defect in sorting which characterizes the fanglomerate is also exemplified in the arkose.

On the lower slopes of the alluvial fans the arkose passes into silt and mud which also occupy the bottoms of the playas and river flood plains.

In these alluvial embankments, which form such notable continental deposits of sedimentary origin, we have thus three rock types, viz: fanglomerate, arkose and silt. The first two of these may be easily discriminated from marine deposits, and it seems probable that microscopic methods of study will supply the criteria for distinguishing the third, in cases where this cannot be done on the basis of field associations.

Varieties of Fanglomerate.—Fanglomerates may vary greatly in the character of the materials of which they are composed. The most typical embankments are composed of fragments of variously indurated sedimentary rocks of mountain ranges undergoing rapid degradation in an arid climate. Some of these ranges may, however, be made up chiefly of igneous rocks, either plutonic or volcanic and the composition of the flanking fanglomerate will correspond to the character of the detritus sup-

plied. When the range is composed chiefly of volcanic rocks the fanglomerate may resemble an agglomerate. These distinctions are, however, matters for petrographical description rather than for a special varietal nomenclature.

Other varieties are based upon the degree of induration and the nature of the cementing material. The fanglomerates now in process of accumulation in Nevada, Utah, and California are usually incoherent or but feebly cemented; but in parts of Arizona, New Mexico and over a large part of Mexico, the embankments of fanglomerate are to a varying depth strongly cemented by carbonate of lime. The process of cementation is now in progress on a vast scale and proceeds as fast as the detritus accumulates. This cemented detritus forms one of the numerous kinds of deposits called in Spanish countries *caliche*. This variety of fanglomerate has an additional geological interest in that it constitutes a continental deposit at the local base level of arid erosion, which is in a large measure resistant to erosion, when, in the course of time, the base level is lowered. It is little affected by structural planes, such as joints and bedding, and is thus not so susceptible to disintegration as the rocks from which it is derived. Neither is it susceptible to waste by aeolian ablation. The cementing carbonate of lime though occupying the spaces between the rock fragments is practically syngenetic with their accumulation.

A genetically distinct process of cementation is similar to that which indurates ordinary sedimentary rocks and which is apparently conditioned by the burial of the strata by later deposits. In this way sands are converted into hard sandstones and quartzite. Similarly the incoherent materials of an alluvial fan may in the course of time be so strongly cemented that when broken by a blow the fracture will traverse the constituent fragments rather than pass around them. This is the case with the fanglomerate of Battle Mountain.

Geological Significance of the Battle Mountain Fanglomerate. Apart from its interest as a type of sedimentary rock the fanglomerate of Battle Mountain is significant of the existence of conditions in the far past similar to those which prevail in the Great Basin today. Those conditions are bold relief and aridity.

But bold relief is the immediate result of acute diastrophism and this fact must be taken into consideration in the attempt to determine the geological age of the formation. Such disturbances occurred at the close of the Carboniferous, and at the close of the Jurassic. The correlatives of the formation doubtless occur in other parts of Nevada where post-Jurassic granite abounds and if in such localities the formation should be found to be devoid of granite fragments a presumption would be established in favor of a pre-Jurassic age. Whether it be pre-Triassic or post-Triassic can probably be determined by its relations to the Triassic rocks to the west of Battle Mountain.

The tracing out of the distribution of this fanglomerate will be an interesting contribution to the geology of Nevada since it affords a definite datum of a peculiar kind from which the geological history of the region may be reckoned. It is not only a positive mark in the geological time scale, but a mark which may be interpreted in terms of climate, diastrophism and physiography.

Scarcity of Fanglomerate among the Rocks of the Past.—The abundance of fanglomerate now in process of accumulation in the arid regions of North America at the present time suggests that similar rocks should be found among the continental deposits of the past more commonly than the observations recorded in geological literature would indicate. It is possible that such rocks have been described under the name of "breccia," and that this term has been inadequate to discriminate them from other types of fragmental rocks, so that their significance has been overlooked. This may be the case, for example, with the so-called "breccias" and "brecciated conglomerates" of the Newark system. But making due allowance for this possibility it is remarkable that there are so few, if any, descriptions of continental formations that correspond with the alluvial fan deposits of Pleistocene and Recent age so abundant in the western part of the continent. If such rocks existed they could hardly fail of recognition and description; and the inference seems warranted that, in those portions of the continent with which geologists are particularly familiar, fanglomerate does not occur. If this be so then one or the other or both of the conditions which determine

the accumulation of alluvial fans must have been lacking. The failure to recognize alluvial fan formations as constituent elements of the stratigraphic column may, therefore, be explained by the supposition that the combination of bold relief and aridity was not common in the geological past. Perhaps the inference may be carried so far as to warrant the belief that this combination of conditions failed entirely except in those periods in which fanglomerate is represented in stratigraphy, such as the uncertainly defined divisions of the Mesozoic of Nevada here described, and possibly the Newark Triassic. It may be urged that alluvial fan formations may have existed and been swept away either by peneplanation or by marine transgression. But it may be pointed out that the increasing recognition of continental formations indicates that they are not particularly prone to destruction by transgressing seas; and that, while peneplanation would bring to an end the formation of coarse alluvial fans by doing away with bold relief, it would only be in extreme cases of perfect peneplanation, due to continental emergence through a succession of geological periods, that the earlier formed alluvial material would be swept away. In those portions of the continent in which there is an approximately complete stratigraphic record of any large portion of geological time, and in the stratigraphy of which there is no representation of fanglomerate, it may be safely inferred that, for the time in question, bold relief and aridity were never coexistent conditions. It may further be concluded that the period of time extending through the Quaternary to the present is exceptional in geological history in respect to the coexistence of these two conditions over a large portion of the continent.

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A PECULIAR HORN OR ANTLER FROM THE
MOHAVE MIOCENE OF
CALIFORNIA

BY

JOHN C. MERRIAM



UNIVERSITY OF CALIFORNIA PRESS

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UNIVERSITY OF CALIFORNIA PUBLICATIONS

BULLETIN OF THE DEPARTMENT OF

GEOLOGY

Vol. 7, No. 16, pp. 335-339

Issued September 19, 1913

A PECULIAR HORN OR ANTLER FROM THE
MOHAVE MIOCENE OF
CALIFORNIA

BY

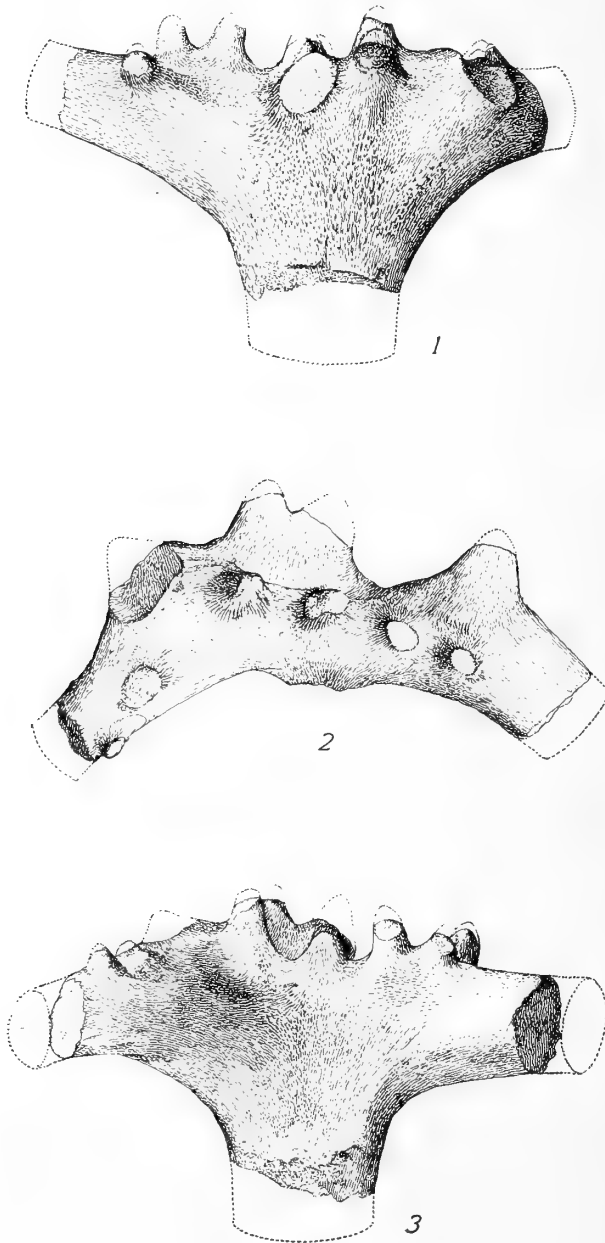
JOHN C. MERRIAM

In a collection of mammalian remains from Miocene beds in the Mohave Desert recently obtained by H. S. Mourning and J. P. Buwalda, there is a horn or antler of peculiar type, unlike any form known to the writer. This specimen is described in advance of a discussion of the whole fauna, in the hope that a fuller expression of opinion may be obtained through the discussion.

The specimen consists of a single fragmentary horn or antler (no. 20052), which had been considerably weathered. It was found at the University of California collecting locality, no. 2057, in the Mohave Miocene north of Barstow, California. From earlier studies the fauna in the beds of this region has been considered as upper Miocene.¹ Much larger collections than those originally available are now at hand for study, and it is possible that in this material more than one faunal zone may be represented, but the largest part of the Mohave Beds seems quite certainly to represent an upper phase of the Miocene.

The portion of the horn or antler represented in specimen 20052 consists of a part of the beam, which divides into two nearly equal branches diverging almost horizontally. Upon the nearly even superior surface of the branches are a considerable number of small spikes or papillae. Of the two branches, one

¹ Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 169, 1911.



Figs. 1, 2, and 3. *Merycodus coronatus*, n. sp. No. 20052, natural size. Mohave Beds, Mohave Desert, California. Fig. 1, outer side of horn; fig. 2, superior aspect of horn; fig. 3, medial side of horn.

is projected approximately in the plane of the flattened beam. The other branch curves rather sharply away from this plane. (See fig. 2). The branch bending away from the plane of the beam is the smaller. A number of the superior spikes or papillae bend out at a low angle from the convex side of the curve formed by the two branches. It seems probable that the plane of the beam was anteroposterior rather than transverse to the skull, and that the papillae on the convex side of the bow are on the outer or lateral, rather than on the inner side of the horn. If the smaller of these two horizontal branches is the anterior, this is the right horn.

The spikes or papillae on the upper side of the horn are in two rows. There are six on the concave side, and four on the convex side. The inner six are arranged in three pairs. Of the outer four there is a single large spike opposite the posterior inner pair and a similar one opposite the space between the anterior and middle inner pairs, and a pair of papillae arising from a common base opposite the middle inner pair. The inner papillae are nearly erect excepting the most anterior one. The papillae on the outer side are directed outward at a low angle.

Judging from the single specimen available, the anterior branches of the right and left horns of this animal curved in toward each other over the face, the other branch extended backward and slightly inward, making a crown-like or horseshoe-like structure above the head. One row of the small spikes or papillae was directed upward, and the other row was directed outward around the margin of the crown.

Specimen 20052 most nearly resembles the horn or antler of *Merycodus*, which it also approaches in size, and to some extent in the texture of the horn. It differs from *Merycodus* in the form of branching, and in the presence of the double row of superior spikes. The texture of the surface of specimen 20052 differs somewhat from that of any of the numerous *Merycodus* horns available from the Mohave Miocene. In no. 20052 the surface is marked by numerous wavy reticulating lines or ridges, which are not matched exactly on any available *Merycodus* specimen. It is possible that the contrast is due in part to condition of weathering, but it seems partly due to difference in structure.

The peculiarity of specimen 20052 may be accounted for on the assumption that it is a "sport" or "monstrosity" of *Merycodus necatus*, a common form in the Mohave region. A large



Fig. 4. *Merycodus necatus* Leidy. Outer side of horn. No. 19832, $\times \frac{1}{2}$. Mohave Beds, Mohave Desert, California.

number of *Merycodus* horns have been found in the Mohave Beds, but on no other specimen has there been noted any suggestion of the form seen in no. 20052, so that there was no common tendency to develop this type of horn.

Specimen 20052 represents a type distinct from the other available specimens of the Mohave fauna and, so far as the writer is aware, it is the only known specimen. This may possibly be urged against the view that it is an undescribed form, and not a variation or a sport of a known *Merycodus* species. In this connection it should be noted that the Mohave fauna is as yet very imperfectly known, and that a considerable number of the most important elements in the fauna have been represented by single fragmentary specimens. For a considerable time the oreodont group was known from the Mohave region only by a fragment of a lower jaw with two imperfect teeth, this being the only oreodont found in an area including all of California and nearly all of Nevada.

If the peculiar horn here described represents a type heretofore unknown, it would appear to be a form nearly related to *Merycodus necatus*, the common Mohave species. (See fig. 4). *Merycodus necatus* is characterized by the possession of a short horn with a short, wide, flattened beam, from the broad summit of which two nearly equal branches arise. The form seen in no. 20052 would be produced by flaring the branches, bending them toward the branches of the opposite horn, and developing the superior spikes or papillae.

While the writer is not inclined to consider the specimen seen in no. 20052 as certainly representing a new type of horn or antler, or a previously undescribed animal, it seems desirable to give a specific designation to this type, which may be known as *Merycodus coronatus*. While the form of horn or antler seen here suggests various kinds of antlers of the modern Cervidae, there is no evidence to indicate that this Miocene animal represents anything more than a foreshadowing of a modern type.

Transmitted June 28, 1913.

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NOTHROTHERIUM AND MEGALONYX
FROM THE
PLEISTOCENE OF SOUTHERN CALIFORNIA

BY
CHESTER STOCK



UNIVERSITY OF CALIFORNIA PRESS
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NOTHROTHERIUM AND MEGALONYX
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INTRODUCTION

Remains of *Nothrotherium* and *Megalonyx* have been recorded from the cave deposits of northern California, but have not been reported from the southern part of the state. In the Pleistocene asphalt deposits of Rancho La Brea numerous remains of gravi-grade edentates include both *Nothrotherium* and *Megalonyx*, along with representatives of the Mylodontidae. The genera *Nothrotherium* and *Megalonyx*, which are usually thought of as living in a region of more rugged topography than the habitat of *Mylodon*, are but sparsely represented in this fauna, in contrast with the abundant remains of the Mylodontidae. In the

present paper *Nothrotherium* is doubtfully recorded as occurring also in the type section of the San Pedro beds at San Pedro, California.

The material of *Nothrotherium* available for study consists of a skull and a tooth from the Rancho La Brea deposits; and a second phalanx, tentatively assigned to the same genus, from the San Pedro beds. *Megalonyx* is thus far represented by a left humerus, a left calcaneum, a single metapodial of the posterior foot, and various digital elements of both anterior and posterior feet, all from Rancho La Brea.

The tooth of *Nothrotherium* was secured by the University of California in 1906, while the skull of *Nothrotherium* was excavated by the Southern California Academy of Sciences in 1909. The metapodial and digital elements of *Megalonyx* were found closely associated and presumably belong to the same individual. They were discovered by the University party at Rancho La Brea in 1907; the humerus and calcaneum were found in 1912.

The writer's sincere thanks are due to Professor John C. Merriam, under whose guidance this study was conducted. The obligation of the writer is also expressed to Director F. H. Daggett of the Museum of History, Science and Art of Los Angeles, who kindly loaned the skull of *Nothrotherium* for study and description.

NOTHROTHERIUM GRACILICEPS, n. sp.

Type specimen, a skull in the Museum of History, Science and Art, Los Angeles, California, from the asphalt deposits of Rancho La Brea.

Paratype: A second superior tooth, no. 10485, Univ. Calif. Col. Vert. Palae., from the asphalt deposits of Rancho La Brea.

Nothrotherium was first described by Lund,¹ in 1839, under the name of *Coelodon maquinense* from remains found in the Cavern of Maquinè in Brazil. In 1878, Reinhardt² distinguished another species, *Coelodon escrivanense*, also from a Brazilian

¹ Lund, P. W., Recherches sur les mammifères fossiles du Brésil, Ann. Sci. Nat., 2. sér. (Zool.), vol. 11, p. 220, 1839.

² Reinhardt, J., Kaempedovendyr-Slaegten Coelodon, Vidensk. Selsk. Skr., 5 Raekke, naturvidenskabelig og mathematisk Afd., vol. 12, 3, pp. 253-349, V Tav. Kjobenhavn, 1878.

cave, differing from *C. maquinense* by the absence of a furrow from the posterior face of the last superior tooth. The genus received its present name from Lydekker³ in 1889. *Nothrotherium(?) shastense* was described by Sinclair⁴ from Potter Creek Cave, Shasta County, California, in 1905, the type specimen being a portion of the right ramus of the mandible without teeth. Fourteen molariform teeth were also referred to this species by Sinclair.

Diagnostic Characters of Species.—Skull slender; larger than in *Nothrotherium escrivanense*, and cranial portion more elevated; point of greatest elevation on frontals; superior border of zygomatic arch distinctly convex; median wall of tympanic bulla pierced by a large aperture; post-palatine notch acute; post-palatine foramina large; inner face of last superior tooth wider, outer face more rounding and narrower than in *N. shastense*.

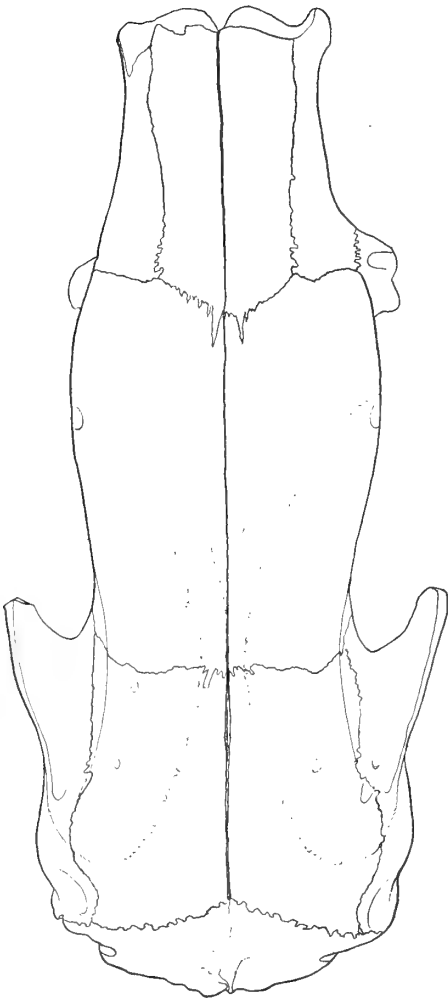
Skull.—The skull from the asphalt beds is fairly well preserved and the sutures clearly defined. No teeth were associated with this specimen. A tooth found separate from the skull corresponds in section to the second alveolus of the right side. The skull is elongate and more nearly cylindrical than in the genus *Megalonyx*. The muzzle tapers gradually forward from the frontals. The greatest width of the skull occurs at the posterior end of the zygoma. The tympanic bulla is prominent. The transverse crest of the occiput divides this region into two subequal areas.

The *nasals* (fig. 1) are long. Close to the median line each nasal pushes a small wedge-like projection sharply into the frontal. The dorsal surface of the nasals is convex in their anterior half, becoming flattened posteriorly. The anterior margin has been broken away.

In *Nothrotherium graciliceps* the point of greatest elevation is reached at the junction of the middle and posterior thirds of the frontal (fig. 3), while in *N. escrivanense* the highest point is on the parietal. The *frontals* are widest across the anterior half.

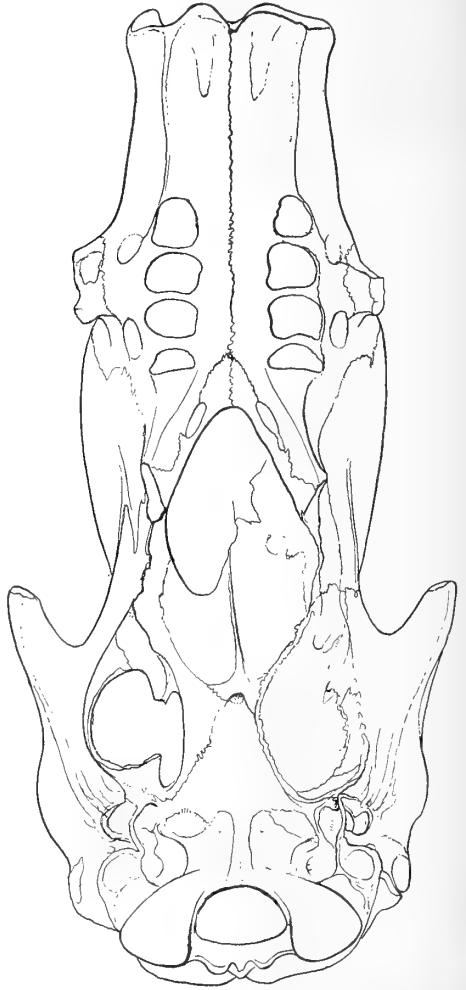
³ Lydekker, R., Nicholson and Lydekker, *Manual of Palaeontology*, ed. 3, vol. 2, p. 1299, 1889.

⁴ Sinclair, W. J., *New Mammalia from the Quaternary Caves of California*, Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, pp. 153–155, pl. 23, figs. 1–5a and 8, 1905.



1

Fig. 1. *Nothrotherium graciliceps*, n. sp. Skull, superior view, $\times \frac{2}{3}$. Rancho La Brea Beds.



2

Fig. 2. *Nothrotherium graciliceps*, n. sp. Skull, inferior view, $\times \frac{2}{3}$. Rancho La Brea Beds.

They are narrowed by the constriction of the cranium above the base of the zygoma and indicated by the arch of the coronal suture. Their surfaces show but a faint indication of the temporal ridges, which swing back from the widest part of the frontals to the median line, where they approach each other at the coronal suture, but do not meet. In *Megalonyx jeffersonii* these ridges are more pronounced and meet in the median line at the coronal suture. This difference may be due in part to sex or to age. There is no blunt postorbital process as in *N. esquivanense*. A shallow depression occurs posterior to the end of the temporal ridge. On the orbital portion of the frontal a sharp undulating ridge, which continues posteriorly over the temporal, curving outward to form the inner border of its zygomatic process, overhangs the orbitosphenoidal region, as in *M. jeffersonii*.

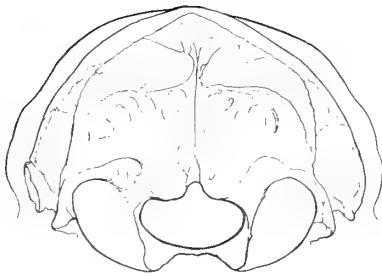
On the *parietals* the temporal ridges swing outward to the widest portion of these bones above the posterior end of the superior border of the zygoma. The parietals are distinctly swollen at the posterior end of the temporal ridges. Between the temporal ridges the parietals are flattened and show only a suggestion of a sagittal crest, which is restricted to the posterior half of the parietal region. In *Megalonyx jeffersonii* the rugged sagittal crest extends from the coronal suture posteriorly to the lambdoidal crest, which in this form is also more sharply defined than in *Nothrotherium graciliceps*. This difference is probably not due to age. On the vault of the parietals below the temporal ridges are several foramina, comparable to the "venous foramina" of Leidy's material of *M. jeffersonii*.

The *temporal* is very long, with a comparatively small vertical width. It is depressed above the mastoid area and close to the lambdoidal suture. The trihedral *zygomatic process* is short, with the superior border distinctly convex at the middle and a slight corresponding concavity on the inferior border. In the Brazilian species these two borders are straight. The zygomatic arch of *Megalonyx* differs greatly from that of *Nothrotherium* in bending more markedly downward and outward from the cranial wall. A vascular foramen pierces the middle of the lateral face of the zygomatic process.

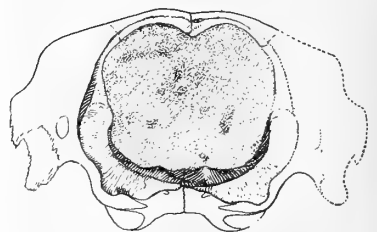
Behind the weak lambdoidal crest the rugose *supraoccipital* slopes back at an angle of about 40° from the plane of the parietals. In *Nothrotherium* the supraoccipital is more prominent in superior view than in *Megalonyx*.



3



4



5

- Fig. 3. *Nothrotherium graciliceps*, n. sp. Skull, lateral view, $\times \frac{2}{3}$.
Rancho La Brea Beds.
- Fig. 4. *Nothrotherium graciliceps*, n. sp. Skull, posterior view, $\times \frac{2}{3}$.
Rancho La Brea Beds.
- Fig. 5. *Nothrotherium graciliceps*, n. sp. Skull, anterior view, $\times \frac{2}{3}$.
Rancho La Brea Beds.

The thickening of the *maxillaries* inferiorly (fig. 5) and the pointed anterior margin of their palatal portions (fig. 2) seem to indicate the original presence of *premaxillaries*. The lateral wall of the maxillary is convex above, becoming slightly concave

in its lower half as in the Brazilian species. A line of small vascular foramina extends from the orbital opening of the infra-orbital canal to a point posterior to the last alveolus. The palate is elongate, slightly convex transversely, and appears to be more strongly pitted than in *M. jeffersonii*. Posterior to the last alveoli it becomes transversely concave. Anterior to the first alveolus the palatal and lateral portions of the maxillary meet almost at right angles. The tooth rows are nearly parallel. The alveoli, with outer walls somewhat broken, are quadrate in form with rounded corners, as is typical of the genus *Nothrotherium*. With the exception of the last alveolus their lateral walls are ribbed on the median line. All have the anterior wall concave inwardly and the posterior wall convex, with the exception of the first alveolus, which has its posterior wall slightly concave. The posterior wall of the last alveolus projects below the level of the palate and is continued posteriorly as a strong ridge.

The *lachrymal* narrows ventrally as a bluntly rounded extension on the zygomatic process of the maxillary. The lachrymal foramen is just anterior to the middle of the bone. A deep furrow extends downward from this foramen. The *jugal* was not found with the skull.

The *palatines* are narrow and the palatal portion is restricted chiefly to the margin of the postpalatine notch. The postpalatine foramina are much larger in *Nothrotherium graciliceps* than in the Brazilian species, and the postpalatine notch is more acute anteriorly than in the latter form. The anterior portion of the *vomer* is broken; posteriorly it is sharply keeled in the median line, as in *Megalonyx jeffersonii*, and narrows toward the basisphenoid. In *N. escrivanense* the keel of the vomer appears thickened posteriorly.

A portion of the *tympanic bulla* remains on the right side. Unfortunately its connection with the palatine is too imperfect to show clearly its relation to the pterygoid. Reinhardt states⁵ that in *N. escrivanense* the expanded backward projections of the *pterygoids* form the tympanic bullae. The inner wall of

⁵ Reinhardt, J., *Kaempedovendyr-Slaegten Coelodon*, Vidensk. Selsk. Skr., 5 Raekke, naturvidenskabelig og matematisk Afd., vol. 12, 3, p. 336, Kjobenhavn, 1878.

the right bulla is pierced by an elongate opening, which appears not to have been present in *N. escrivanense*.

A small projection of the *alisphenoid* is suturally defined on the left side, where it lies below the overhanging frontal ridge. On the left side, where the tympanic bulla has been removed, the alisphenoid is seen to form the roof of the auditory capsule. The orbital fissure is large. The large combined opening of the foramen rotundum and foramen ovale is about as far posterior to the orbital fissure as the optic foramen is anterior to it. Since the outer wall of the bulla, formed by the pterygoid, projects ventrally from the margin of the alisphenoid, the two foramina open externally through the pterygoid. In *Megalonyx* these two foramina open separately.

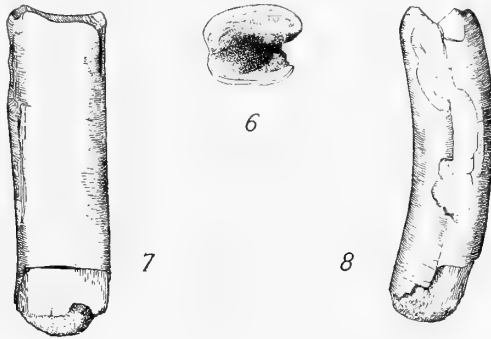
The concave *basisphenoid* narrows anteriorly, the apex being indicated by a foramen opening above the vomer. Leidy states⁶ that in *Megalonyx jeffersonii* the sphenoidal surface is plane, and cites a similar foramen above the vomer. The median portion of the *basioccipital* is relatively much more prominent than in *N. escrivanense*. The condylar foramen is small.

The glenoid fossa is but slightly concave. The base of the zygoma has a much greater anteroposterior diameter than in *M. jeffersonii*. Below the rugose mastoid area is the large stylohyal process. Anterior to the base of this process is the large jugular foramen. In Reinhardt's figure⁷ of the skull of *Nothrotherium escrivanense* a much smaller foramen is indicated in this region. The anteroexternal face of the stylohyal process is grooved inferiorly. Superiorly this groove is converted into a closed canal, the stylohyal canal, which leads to the jugular foramen. Extending anterior to the process is a vertical plate which abuts upon the posterior wall of the bulla. The stylohyal process is continuous dorsally and posteriorly with the transverse crest of the occiput (fig. 4), which is midway between the lambdoidal suture and the foramen magnum. In *Megalonyx jeffersonii* this crest is one-third the vertical distance from the lambdoidal suture.

⁶ Leidy, J., A Memoir on the Extinct Sloth Tribe of North America, . . . Smithsonian. Contrib. Knowl., vol. 7, p. 10, 1855.

⁷ Reinhardt, J., *op. cit.*, Tab. 1, fig. 2.

The *foramen magnum* is moderately large and subcircular in outline. The superior margin is notched at the middle. In *N. esquivanense* this border is entire. The *occipital condyles* are similar to those of the Brazilian species, having their larger articular face directed outward and forward.



Figs. 6, 7, and 8. *Nothrotherium graciliceps*, n.sp. Right second superior tooth, no. 10485, $\times \frac{4}{5}$. Rancho La Brea Beds. Fig. 6, view of tritulating surface; fig. 7, posterior view; fig. 8, lateral view.

Dentition.—A single tooth, no. 10485 (figs. 6, 7, and 8) corresponds in section to the second alveolus of the right side. It differs from a similar tooth (no. 8702) of *Nothrotherium shastense* from the Potter Creek Cave in lacking the curvature of the inner face. Its anterior face is longitudinally concave and broadly convex transversely. The posterior face is slightly concave transversely, and the lateral faces are furrowed. The tritulating surface is deeply troughed transversely, especially toward the inner side.

MEASUREMENTS OF SKULL AND DENTITION

Length of skull, anterior end of palate to posterior end of occipital condyles	300. mm.
Length of palate, anterior end to post-palatine notch	131.
Width of palate between second alveoli	22.9
Greatest width of muzzle	71.
Greatest width above orbits	102.
Least width behind orbits	77.2
Mastoid width above the stylohyal processes	112.6
Vertical height of occiput from plane of basioccipital to lambdoidal suture	83.
Length of dental series, from anterior wall of first alveolus to posterior wall of last alveolus	57.5
M ² , no. 10485, anteroposterior diameter at tritulating surface..	13.
M ² , no. 10485, transverse diameter at tritulating surface	16.

Relation to Nothrotherium shastense.—The mandibular ramus from Potter Creek Cave, although belonging to an adult individual, is shorter than the lower jaw in the Rancho La Brea species. The well-defined and open sutures in the skull of the latter species seem to indicate a young adult.

Specimen 8202 from the Shasta cave is a first superior tooth of the left side, which fits almost perfectly into the first alveolus of the Rancho La Brea skull. It is a small tooth with posterior face slightly convex longitudinally and lateral faces furrowed. Its anterior half is decidedly smaller transversely than the posterior half. No. 8702⁸ is a second superior tooth of the right side. The outline of its triturating surface is very similar to that of the Rancho La Brea specimen 10485, which is assigned to the same position. Its inner face is, however, longitudinally concave. The last superior alveolus of the left side in the Rancho La Brea skull indicates a tooth wider on the inner or lingual side and with a more rounding outer face of less width than is shown in the corresponding tooth of *N. shastense*.⁹ Tooth 8337¹⁰ probably belongs to the inferior dentition.

Judging from the evidence presented, there is reason to believe that the Rancho La Brea and Potter Creek Cave specimens represent distinct species. *Nothrotherium* teeth have been found also in Samwel Cave, Shasta County, California.

NOTHROTHERIUM(?), sp.

The second phalanx upon which this tentative determination is based, was obtained by Dr. L. H. Miller and Dr. F. C. Clark from the Upper San Pedro beds exposed just behind the yard of the San Pedro Lumber Company at San Pedro, California. A single dermal ossicle was also found in these deposits. The marine Pleistocene fauna of these beds was described by Arnold¹¹

⁸ Sinclair, W. J., *New Mammalia from the Quaternary Caves of California*, Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, 1905, pl. 23, figs. 3 and 3a. In fig. 3 the lower margin of the tooth is the anterior margin; in fig. 3a the anterior face is shown.

⁹ Sinclair, W. J., *op. cit.*, p. 154, pl. 23, fig. 8.

¹⁰ *Ibid.*, pl. 23, figs. 5 and 5a.

¹¹ Arnold, R., *The Palaeontology and Stratigraphy of the marine Pliocene and Pleistocene of San Pedro, California*, Mem. Cal. Acad. Sci., vol. 3, pp. 420, pls. 37, June, 1903.

in 1903. Miller¹² lists the following vertebrates from the Upper San Pedro Pleistocene:

Mammals—	Birds—
Equus	Aechmophorus, n. sp.
Bison	Nettion carolinense (Gmelin)
Camelid	Sturnella neglecta Audubon

The specimen, no. 19720, shown in figures 9, 10, and 11, is very long and narrow, differing greatly in this respect from the shorter and stouter second phalanges of *Myiodon* and *Megalonyx*.



Figs. 9, 10, and 11. *Nothrotherium*(?), sp. Second phalanx, no. 19720, $\times \frac{2}{5}$. Upper San Pedro Beds, San Pedro, California. Fig. 9, superior view; fig. 10, view of proximal face; fig. 11, lateral view.

The median groove of the distal trochlea is of the broad and rather shallow type as in *Myiodon*, differing in this respect from *Megalonyx*. The depression at the end of the groove on both the dorsal and ventral surfaces is broad, and is deepest on the ventral surface. The condyles, unequal in size, are more definitely constricted off from the rest of the shaft than in *Megalonyx*, and have their postero-dorsal muscle ridges but little developed. The two lateral facets of the proximal end are divided by a thick median ridge, which widens superiorly and inferiorly. Below this expansion the shaft is grooved for a short distance on its inferior surface.

¹² Miller, L. H., Contributions to Avian Palaeontology from the Pacific Coast of North America, Univ. Calif. Publ. Dept. Geol., vol. 7, p. 115, 1912.

MEASUREMENTS OF PHALANX. No. 19720

Greatest length through middle of shaft	73. mm.
Depth of proximal end	34.6
Width of distal end	23.2

MEGALONYX CALIFORNICUS, n. sp.

Type specimen, a left humerus, no. 21003, Univ. Calif. Col. Vert. Palae., from the asphalt deposits of Rancho La Brea.

Paratypes: A left calcaneum, no. 20095; a third right metatarsal, no. 20001; various digital elements of anterior and posterior feet, nos. 20002-20004 inclusive, Univ. Calif. Col. Vert. Palae., from the asphalt deposits of Rancho La Brea.

Diagnostic Characters of Species.—The material thus far available represents a form somewhat smaller in size than *Megalonyx jeffersonii* Desmarest. Head of humerus prominent, two tuberosities farther separated than in *M. jeffersonii*; distal trochlea wider than in *M. jeffersonii*, ulnar and radial facets of equal width; dorsal surface of tuberos apex of internal condyle with short closed canal. Neck of calcaneum with relatively greater vertical width than in *M. jeffersonii*; postero-inferior extremity not decidedly directed to either outer or inner side. Articulating surface of third metatarsal for cuneiform tri-lobed.

Anterior Limb.—The head of the *humerus*, no. 21003 (fig. 12) is more prominent in anterior view than in *M. jeffersonii*, due to a wider separation of the two tuberosities. This separation in *M. californicus* resembles that of *Nothrotherium*, but is not as great as in *Hapalops*. The short and narrow bicipital groove is distinct. The pectoral ridge, which is faintly indicated along the upper half of the shaft, becomes prominent below the middle. It is more distinct than in *M. jeffersonii* but less so than in *Myiodon*. A slight projection occurs at the middle of the inner border of the shaft.

The "musculo-spiral course" is well defined laterally, the dorso-lateral margin differing from *M. jeffersonii* in protruding slightly. A tendency toward a similar projection is seen in *Myiodon*. The distal trochlea is relatively wider than in *M. jeffersonii*, the ulnar and radial facets being of the same width in *M. californicus*, while in the former species the radial facet is

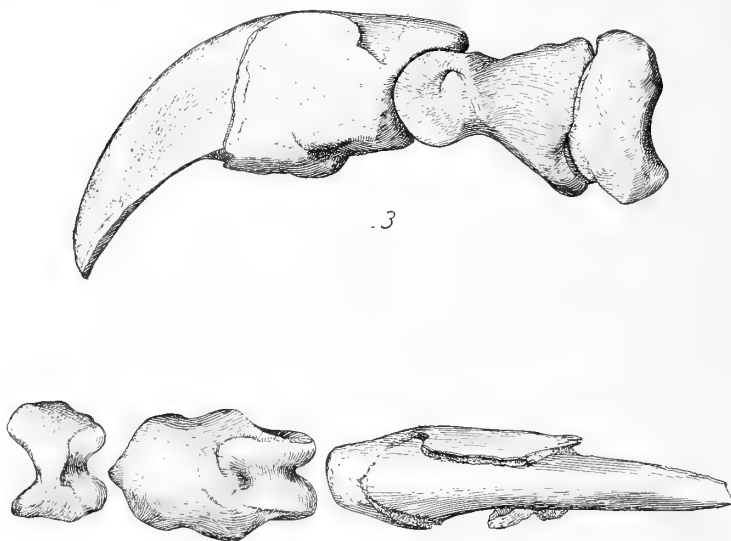
distinctly the wider. On the dorsal surface of the tuberos apex of the internal condyle is a short closed canal, which is not present in *M. jeffersonii*, *Hapalops*, or *Myiodon*.



Fig. 12. *Megalonyx californicus*, n. sp. Left humerus, no. 21003, approximately one-fourth natural size (i.e., $\times .27$). Rancho La Brea Beds.

In the *third left digit* (?), no. 20002 (figs. 13 and 14) the lateral faces of the proximal end of the first phalanx for metacarpal articulation are curved dorso-ventrally, and the concave median face narrows below. The outer offset is more abrupt than the inner one. The outer face has a greater width, but the base

of the inner face extends farther inferiorly. The groove between the two distal condyles widens inferiorly.



14

Figs. 13 and 14. *Megalonyx californicus*, n. sp. Third digit of left anterior limb (?), no. 20002, $\times \frac{2}{5}$. Rancho La Brea Beds. Fig. 13, lateral view; fig. 14, superior view.

The second phalanx is heavier than in *M. jeffersonii*. The median ridge of the proximal articular face is thick and widens inferiorly, forming a slight protuberance below the inner facet. The postero-dorsal ligamental ridges of the distal condyles are very pronounced.

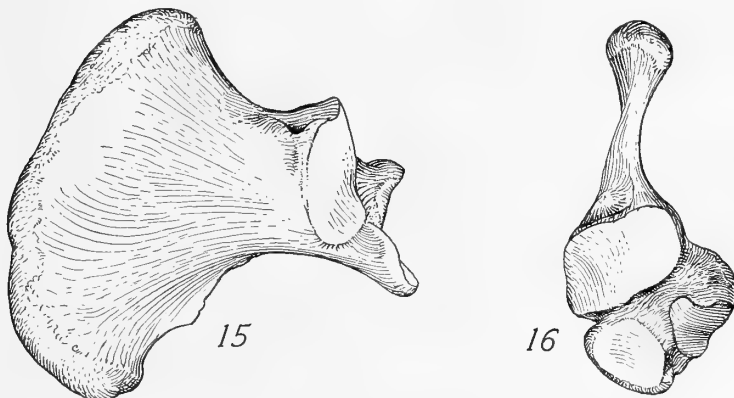
The osseous sheath on the inner side of the ungual phalanx has been broken away. The upper portion of the proximal articular face differs from *M. jeffersonii* in that the outer side is produced backward farther than the inner side.

The tentative position of this digit is based upon Leidy's statement that in the first phalanges of the front foot "the proximal or metacarpal articulation is a deep, vertical concavity, extending from top to bottom of the bone, with an offset on each side inferiorly in the median phalanx, but on one side only in

the annular and index phalanges.¹³ There is an equal possibility that this is a second left digit of the posterior foot.

No. 20003 belongs possibly to either the second or fourth digit of the front foot. In the first phalanx there is no indication of dorso-ventral curvature on the lateral faces of the proximal end nor does the middle articulation narrow ventrally. An offset occurs only on the inferior half of one side. The side bordered proximally by the offset is distinctly narrower than the opposite side. On the distal trochlear face, the condyle of the shorter side widens inferiorly.

On the proximal articular face of the second phalanx the surface articulating with the inferiorly broadened condyle of the first phalanx is very slightly concave. The postero-dorsal ligamentular ridges are not prominent. The dorsal surface of the smaller condyle is beveled laterally.



Figs. 15 and 16. *Megalonyx californicus*, n. sp. Left calcaneum, no. 20095, $\times \frac{1}{4}$. Rancho La Brea Beds. Fig. 15, view of right side; fig. 16, view of proximal end.

Posterior Limb.—The left *calcaneum*, no. 20095 (figs. 15 and 16) agrees essentially with *M. jeffersonii* in its differences from the *calcaneum* of *M. sierrensis* as described by Sinclair.¹⁴ Important differences exist, however, between the Rancho La Brea *calcaneum* and the *calcaneum* of *M. jeffersonii*.

¹³ Leidy, J., A Memoir on the Extinct Sloth Tribe of North America, *Smithson. Contrib. Knowl.*, vol. 7, p. 35, 1855. "Median phalanx" here means the first phalanx of the median digit.

¹⁴ Sinclair, W. J., *op. cit.*, pp. 158-159, pl. 22, figs. 2 and 3.

Although the calcaneum is of smaller size, the neck has a relatively greater width than in *M. jeffersonii*. The superior border of the fanlike tuber calcis is strongly concave, while the inferior border is less arched than in the latter species. The middle region of the inferior border is sharply edged. A depression occurs on the superior border close to the large astragalar facet. Viewed from the proximal end (fig. 16), the postero-inferior extremity is not decidedly directed toward either the outer or the inner side, differing in this respect from both *M. jeffersonii* and *M. sierrensis*. The lower half of the posterior border is much thicker than the upper half.

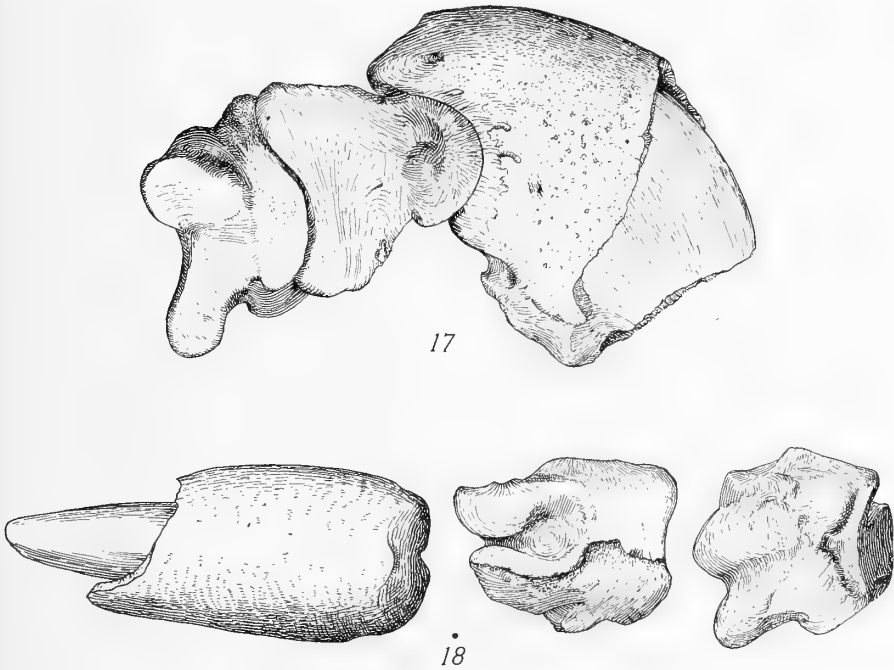
The proximal end is, on the whole, similar to that of *M. jeffersonii* and has the following characteristics: The grooves separating the three articular facets are well defined and are broadest between the cuboidal and large astragalar facets. Externally the large astragalar facet is flat, becoming slightly concave internally as it curves down to the inferior border. The small astragalar facet is concave in its longest (transverse) diameter. The cuboidal facet is concave vertically and curves toward the external margin. The inner lip is flattened almost at right angles to the rest of the surface and articulates with the astragalus.

The facet for articulation of the cuneiform with the *third right metatarsal*, no. 20001, is tri-lobed. The ventral lobe is much the largest. Leidy states¹⁵ that in *M. jeffersonii* this surface is quadrate. Of the two dorsal lobes, the lateral is larger than the medial one. The proximal face is concave both dorso-ventrally and transversely. The articular facet for the second metatarsal has its greatest diameter dorso-ventrally, while the articular facet for the fourth metatarsal is widest transversely.

The median distal convex surface of the metatarsal is oblique, the lower end being nearest the inner side. At its ventral third it curves slightly outward. The broad offsets on each side follow this course more or less. The median convexity is wide and well rounded in its dorsal two-thirds but narrows in its ventral third, the arch becoming pointed.

¹⁵ Leidy, J., Remarks on the Structure of the Feet of *Megalonyx*, Trans. Amer. Philos. Soc., n.s. vol. 11, p. 107, pl. 6, fig. 1, 1860.

In the co-ossified first and second phalanges of the *third right digit*, no. 20004 (figs. 17 and 18), the offsets on each side of the median concavity of the proximal end are transversely concave. This is especially noticeable on the inner offset, which is wider than the outer one. In *M. jeffersonii* there is "an oblique offset on each side inferiorly."¹⁶ The inner condyle of the distal trochlea is well worn. The groove between the two condyles widens inferiorly.



Figs. 17 and 18. *Megalonyx californicus*, n. sp. Third right metatarsal and digit, nos. 20001 and 20004, $\times \frac{2}{3}$. Rancho La Brea Beds. Fig. 17, lateral view; fig. 18, superior view.

The claw-core is broken away anterior to the ventral tuberosity in the unguinal phalanx. The median ridge of the proximal articular face is sharp and widens inferiorly. Just above the median ridge on the overhanging process of the proximal end is a small emargination. In *M. jeffersonii* the overhanging

¹⁶ Leidy, J., A Memoir on the Extinct Sloth Tribe of North America, *Smithson. Contrib. Knowl.*, vol. 7, p. 44, pl. 13, figs. 17 and 18, 1855.

process is more strongly notched. Following the margin of the proximal end on each side is a ridge for ligament attachment. The margin of the ventral tuberosity is distinctly set off from its middle convex portion. The osseous sheath is thinnest on the sides.

The terminal claw was retracted chiefly by a movement of the entire digit upon the third metatarsal.

MEASUREMENTS

Humerus—		No. 21003
Greatest length		447. mm.
Width at tuberosities		128.
Least width of shaft		60.5
Greatest width of distal expansion		221.
Width of distal trochlea		127.5
First Phalanx—	No. 20002	No. 20003
Greatest depth	59.5	60.
Length of longer side	28.3	32.7
Greatest breadth	38.2	39.6
Second Phalanx—	No. 20002	No. 20003
Greatest length through middle	61.4	57.5
Depth of proximal end	52.3	53.
Depth of distal end	34.5	32.1
Third Phalanx—	No. 20002	
Greatest length	149.4	
Greatest depth	56.6	
Calcaneum—		No. 20095
Vertical width of neck		67.8
Greatest anteroposterior diameter		206.
Greatest diameter of fanlike tuber calcis		202.
Greatest thickness of posterior border		38.2
Least thickness of posterior border		16.
Third Metatarsal—		No. 20001
Anteroposterior diameter through middle		50.5
Depth of median vertical convexity of distal end		74.9
Depth of proximal articular face		60.5
Greatest width		67.6
Co-ossified First and Second Phalanges—		No. 20004
Length along middle of outer side		60.8
Greatest depth of proximal face		69.4
Depth of lateral condyle of distal end		44.
Third Phalanx—		No. 20004
Greatest depth		92.7
Width just posterior to ventral tuberosity		52.

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NOTES ON THE CANID GENUS
TEPHROCYON

BY
JOHN G. MERRIAM



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NOTES ON THE CANID GENUS
TEPHROCYON

BY

JOHN C. MERRIAM

The genus *Tephrocyon* includes a group of American canids with characters in some respects foreshadowing *Aelurodon*, and in other points resembling *Canis*. These forms range from the middle Miocene to early Pliocene, and are found distributed over the western portion of the continent.

The material representing the described forms is mostly fragmentary and imperfectly known, and the species were in a considerable part originally referred to *Canis* in the absence of clearly distinguishing characters. Since the description of the generic type of *Tephrocyon*, based upon a good skull and dentition from the Middle Miocene of Oregon, it has been noted that a number of the species from the West-American Miocene which were previously referred to *Canis* find a place in this genus; and it is probable that still other species of uncertain position belong here. On the other hand, it is probable that some of the species based on fragmentary material and referred to *Tephrocyon* do not represent that genus.

The following notes are presented with a view to bringing together such information as is available relating to this group, in the hope that this statement may serve to stimulate further assembling of information, and more careful revision of the forms related to *Tephrocyon*.

In preparing the following paper the writer has made a re-examination of the type specimen of *Tephrocyon*, and several figures representing phases of the structure not previously illustrated accompany this discussion.

For the loan of the type specimen from the University of Oregon, the writer is much indebted to Professor A. J. Collier and Professor J. F. Bovard.

GENUS TEPHROCYON

Type species *Tephrocyon rurestris* (Condon).

Skull of the type specimen short-muzzled, shortening of the muzzle accompanied by backward extension of the premaxillaries beyond the anterior ends of the nasal processes of the frontals, auditory bullae large. Paroccipital process prominent. Mandible heavy, uncommonly convex below the anterior border of the masseteric fossa. Crushing region of the molar teeth relatively large. M^1 and M^2 with inner lobe relatively wide antero-posteriorly. M_1 with well-developed metaconid and large heel. M_2 relatively long anteroposteriorly, paraconid ridge or tubercle distinct, antero-external ridge of the cingulum strongly marked. Premolars usually relatively short. P^4 with an incipient proto-style in the type specimen of the genus. Posterior opening of the vertebrarterial canal of the atlas situated farther back than in *Canis*.

The forms that have been referred to *Tephrocyon* include the following:

T. rurestris (Condon). Mascall Beds, Oregon. Middle Miocene.

T. hippophagus Matthew and Cook. Snake Creek, Nebraska. Early Pliocene.

T. temerarius (Leidy). Sands of the Niobrara River, Snake Creek?, and Whistle Creek, Nebraska; Mohave Beds, Mohave Desert, California. Upper Miocene.

T. kelloggi Merriam. Virgin Valley Beds, Nevada, Middle Miocene; Cedar Mountain, Nevada, Middle to Upper Miocene.

T., near *kelloggi* Merriam. Thousand Creek Beds, Nevada, Early Pliocene.

Tephrocyon, sp. (Matthew and Cook). Snake Creek, Nebraska, Early Pliocene.

Tephrocyon?, sp. (Merriam). High Rock Canyon, Nevada. Middle Miocene.

T. vafer (Leidy)? Snake Creek, Nebraska. Early Pliocene.

So far as known, the several species may be characterized as follows:

T. rurestris. Mandible short and massive, relatively convex below anterior end of the masseteric fossa. Inferior premolar series short, inferior premolars without anterior cusps, metaconid of M_1 moderately developed, M_2 relatively shorter anteroposteriorly than in *T. kelloggi*, but longer than in *T. hippophagus* and *T. temerarius*.

T. hippophagus. Characters in general much as in *T. rurestris*. Inferior premolar series somewhat longer than in *T. rurestris*. Inferior premolars larger and thicker than in *T. rurestris*, and with anterior cusps on P_2 , P_3 , and P_4 . M_2 slightly shorter and relatively thicker transversely than in *T. rurestris*.

T. kelloggi. Mandible more slender than in *T. rurestris* and *T. hippophagus*. Inferior premolar series relatively long. Inferior premolars small, relatively simple, and without anterior cusps. Metaconid of M_1 relatively large. M_2 relatively long anteroposteriorly.

T. temerarius. Mandible more slender than in *T. rurestris* and *T. hippophagus*. Mandible of Mohave Desert specimen lighter than in *T. kelloggi*; other referred specimens not heavier than *T. kelloggi*. P_4 with anterior cusp or tubercle, other premolars imperfectly known. Metaconid of M_1 of medium size. M_2 relatively much shorter than *T. kelloggi*, and slightly shorter than in the other two species.

COMPARATIVE MEASUREMENTS

	T. rurestris Type specimen	T. hippo- phagus Type specimen	T. kelloggi Type specimen	T. temer- arius No. 19402 Mohave
Length of mandible from anterior side of P ₁ to posterior side of condyle	a112 mm.	107.	103.7	.....
Height of mandible below protocone of M ₁	20.	22.5	21.	16.
Greatest thickness of mandible below talonid of M ₂ .....	.....	10.	9.	8.4
P ₂ , anteroposterior diameter	7.5	8.	6.	.....
P ₃ , anteroposterior diameter	9.	9.3	6.7	7.
P ₄ , anteroposterior diameter	11.5	12.	8.4	8.5
M ₁ , anteroposterior diameter	20.	19.8	15.	17.
M ₁ , transverse diameter of heel	a8.7	8.3	7.	6.5
M ₂ , anteroposterior diameter	11.5	10.1	10.5	9.
M ₂ , greatest transverse diameter	6.8	6.9	6.7	5.7
Length, posterior side inferior canine to posterior side M ₃	63 a	65.5a	61.	.....
Length, posterior side inferior canine to posterior side P ₄	33 a	35.5	36.	.....

a, approximate.

TEPHROCYON RURESTRIS (Condon)

Canis rurestris Condon. The Two Islands, p. 139, pl. 18, 1902.

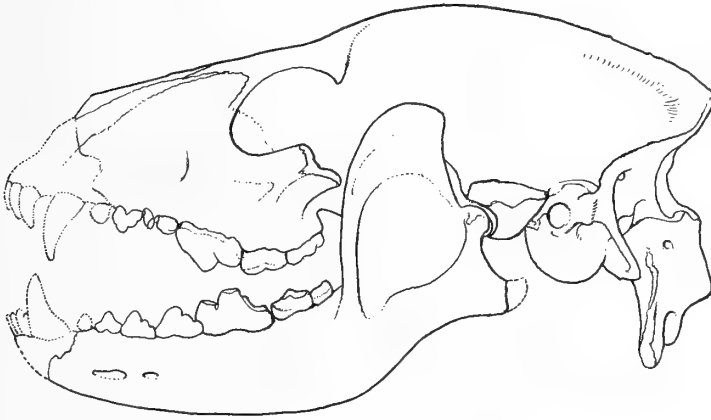
Tephrocyon rurestris. Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 5, p. 6, 1906.

The type specimen was originally no. 382 in the private collection of Professor Thomas Condon. It is now in the collections of the University of Oregon. The fragmentary specimen consisting of four upper cheek-teeth shown in the lower right hand corner of Condon's figure of *Canis rurestris* (Two Islands, pl. 18) does not pertain to the type of *Tephrocyon rurestris*. These detached teeth represent a species of *Temnocyon*, near *T. altigenis* Cope from the John Day Series.

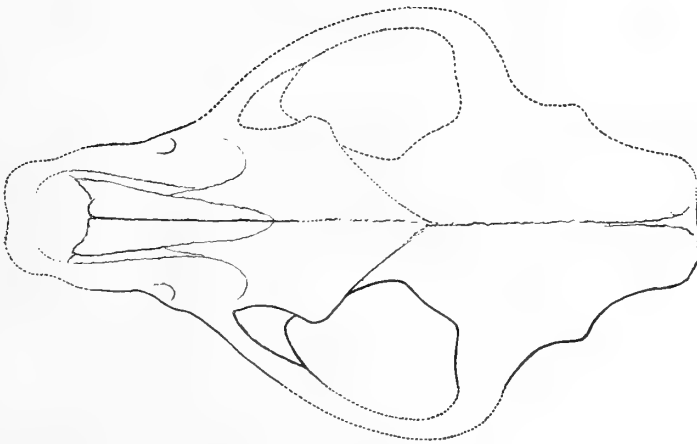
The type specimen, consisting of a good skull with the atlas and a portion of a tibia, was obtained in the Mascall Beds near Cottonwood, Grant County, Oregon. As nearly as could be determined in conversation with Professor Condon, this specimen was found at the type locality of the Mascall Beds. This horizon is of Middle Miocene age. Other fragmentary material from the Mascall may represent this species.

The skull and dentition of *Tephrocyon rurestris* represents a rather short-headed, heavy-jawed dog with an unusually large crushing area on the molars.

The accompanying figures present the principal characters of this species. (See figs. 1 to 5.)

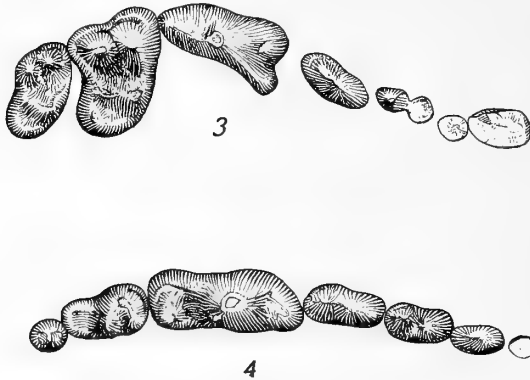


1



2

Figs. 1 and 2. *Tephrocyon rurestris* (Condon). Type specimen, $\times \frac{1}{2}$. Mascall Beds, John Day Valley, Oregon. Fig. 1, lateral view of skull; fig. 2, superior view of skull.



Figs. 3 and 4. *Tephrocyon rurestris* (Condon). Dentition of type specimen, natural size. Mascall Beds, John Day Valley, Oregon. Fig. 3, superior dentition, oclusal view; fig. 4, inferior dentition, oclusal view.

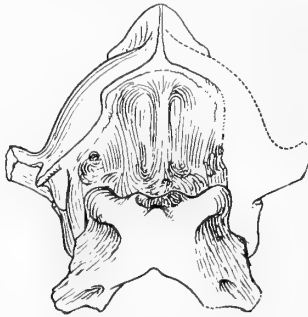


Fig. 5. *Tephrocyon rurestris* (Condon). Type specimen. Posterior view of skull with atlas, $\times \frac{1}{2}$. Mascall Beds, John Day Valley, Oregon.

TEPHROCYON HIPPOPHAGUS Matthew and Cook

Tephrocyon hippophagus Matthew and Cook. Bull. Am. Mus. Nat. Hist., vol. 26, p. 374, 1909.

To this species Matthew and Cook referred eight lower jaws, and a portion of an upper jaw from Snake Creek. The Snake Creek Beds are considered by Matthew and Cook as representing an early phase of the Pliocene.

After an examination of the type specimen of *T. hippophagus*, and a comparison with the type of *T. rurestris* of an excellent cast, kindly furnished by Dr. Matthew, there seems no doubt

that this is a form closely related to *Tephrocyon rurestris* and yet is specifically distinct from it.

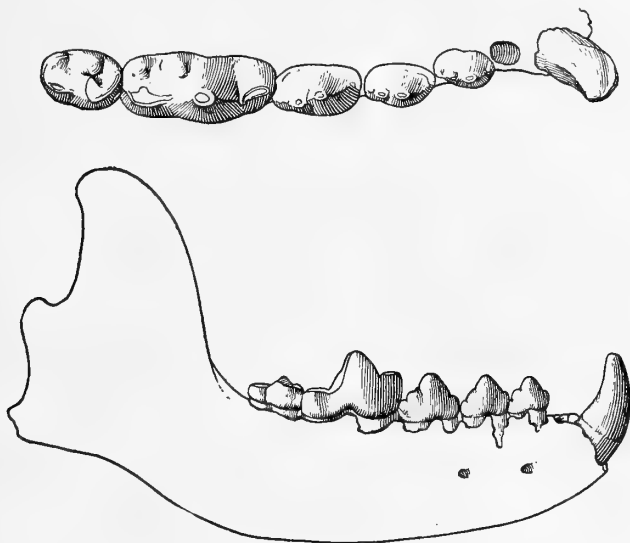


Fig. 6. *Tephrocyon hippophagus* Matthew and Cook. Lower jaw of type specimen, external view, $\times \frac{2}{3}$; and occlusal view of teeth natural size. Am. Mus. N. H., no. 13836. (After Matthew and Cook).

TEPHROCYON TEMERARIUS (Leidy)

Canis temerarius Leidy. Proc. Acad. Nat. Sc. Philad., p. 21, 1858.

Canis temerarius Leidy. Jour Acad. Nat. Sc. Philad., vol. 7, p. 29, pl. 1, fig. 12, 1869.

? *Tephrocyon* cf. *temerarius*. Matthew and Cook, Bull. Am. Mus. Nat. Hist., vol. 26, p. 376, 1909.

Tephrocyon temerarius. Peterson, O. A., Mem. Carneg. Mus., vol. 4, p. 268, 1910.

The typical material of this species consisted of a piece of a lower jaw containing the carnassial tooth, and a portion of an upper jaw with two teeth both badly preserved. This material was obtained by Dr. Hayden from the Niobrara Sands. The horizon is presumably Upper Miocene. The lower jaw and M₁ figured by Leidy¹ show form and dimensions closely similar to those of a specimen obtained by Peterson² from beds at Whistle

¹ Leidy, J., Jour. Acad. Nat. Sc. Philad., vol. 7, second series, pl. 1, fig. 12, 1869.

² Peterson, O. A., Mem. Carneg. Mus., vol. 4, p. 268, 1910.

Creek, Nebraska, possibly belonging to late Miocene or Pliocene deposits.

A portion of a lower jaw (no. 19402), with P_3 to M_2 inclusive, from the Mohave Beds of the Mohave region, California, very closely resembles the type of Leidy's *Canis temerarius* from the Nebraska formation and also resembles the specimen from Whistle Creek, Nebraska, referred to this species by Peterson. M_1 of the

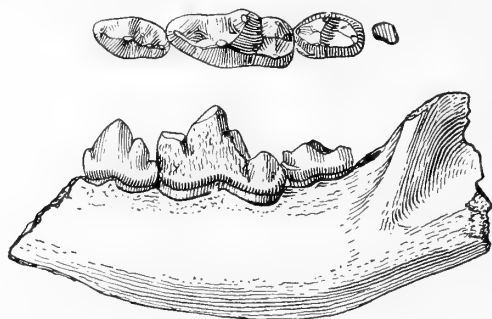


Fig. 7. *Tephrocyon temerarius* (Leidy). Occlusal view of teeth and external view of lower jaw, natural size. (Carneg. Mus. Cat. Vert. Foss. no. 2404). (After Peterson).

Mohave specimen very nearly approaches in form and dimensions the original figured specimen of *Canis temerarius* (Leidy), and the Mohave species is almost identical in form and dimensions with the corresponding parts of the specimen described by Peterson.

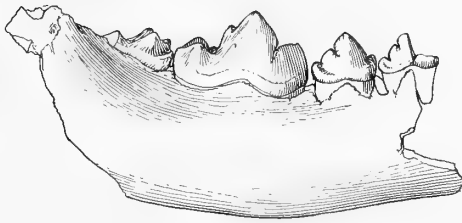
The specimen from Mohave Beds (figs. 8a and 8b) represents a species of *Tephrocyon* differing slightly from those thus far known in the Great Basin region. The relationship of this form to the genus *Tephrocyon* is shown in the large size of the metaconid and of the crushing heel of M_1 , and in the presence of a well-developed paraconid with a large antero-external shelf on the cingulum of M_2 .

The Mohave form is distinguished from *Tephrocyon rurestris* and *T. hippophagus* by the smaller, more slender teeth. From *T. kelloggi* it differs in the relatively larger M_1 and smaller M_2 , and smaller metaconid of M_1 . M_1 in the Mohave specimen measures 17 mm. in anteroposterior diameter as compared with

9 mm. in anteroposterior diameter in M_2 . In *T. kelloggi* the anteroposterior diameter of M_1 is 15 mm.; of M_2 , 10.5 mm. There is a small hypoconulid on the heel of M_1 in the Mohave specimen, while in the type of *T. kelloggi* this tubercle is not suggested. The heel of M_2 seems somewhat shorter than in *T. kelloggi*.



8a



8b

Figs. 8a and 8b. *Tephrocyon temerarius* (Leidy). A portion of the mandible with dentition. No. 19402, natural size. Mohave Beds, Mohave Desert, California. Fig. 8a, superior view; fig. 8b, lateral view.

P_4 and P_3 both possess a posterior cusp and a posterior basal tubercle. P_4 shows a small anterior basal tubercle. The anterior side of P_3 is not preserved.

Several specimens of mandibles slightly larger than no. 19402 represent a *Tephrocyon* species from the Mohave Beds very near *T. temerarius*. It is possible that they belong to another species, but age and sex are presumably competent to account for the differences.

TEPHROCYON KELLOGGI Merriam, J. C.

Tephrocyon kelloggi Merriam. Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, p. 235, 1911.

To this species there have been referred several jaws and detached teeth from the middle Miocene Virgin Valley Beds of northern Nevada. A single tooth from the early Pliocene of

Thousand Creek, Nevada, closely approaches this species, and a lower carnassial from Cedar Mountain in middle Nevada represents a closely allied form.

This species differs farther from all of the other three species than any one of these three differs from the others and further study may suggest subgeneric separation. The mandible is more slender than in *T. rurestris* or in *T. hippophagus*; the premolars



Figs. 9a and 9b. *Tephrocyon kelloggi* Merriam. Type specimen, $\times 1\frac{1}{2}$. No. 11562. Virgin Valley Beds, Virgin Valley, Nevada. Fig. 9a, M_1 and M_2 lateral view; fig. 9b, M_1 superior view.

Fig. 10. *Tephrocyon*, near *kelloggi* Merriam. M_1 , no. 19767, $\times 1\frac{1}{2}$. Stewart Valley Beds, Nevada.

are relatively smaller, more simple, and more widely spaced than in the other forms; M_2 and the heel of M_1 are relatively long; and the metaconid of M_1 is unusually large and high. The characters of the jaw and dentition are in general those of *Tephrocyon*, and the species is evidently nearer the group of three including *T. rurestris*, *T. temerarius*, and *T. hippophagus* than to any other known dogs.



Figs. 11a and 11b. *Tephrocyon kelloggi* Merriam. M_2 , unworn tooth, no. 10651, $\times 1\frac{1}{2}$. Virgin Valley Beds, Virgin Valley, Nevada. Fig. 11a, outer side; fig. 11b, superior side.

Fig. 12. *Tephrocyon kelloggi* Merriam. M_2 , worn tooth, no. 11474, $\times 1\frac{1}{2}$. Virgin Valley Beds, Virgin Valley, Nevada.

Fig. 13. *Tephrocyon*, near *kelloggi* Merriam. M_2 , no. 12542, $\times 1\frac{1}{2}$. Thousand Creek Beds, Thousand Creek, Nevada.

The specimen from the Cedar Mountain region of middle Nevada referred to above consists of the greater portion of a single lower carnassial (see fig. 10) from Stewart Valley (locality 2027). It is almost identical in form with M_1 of the type specimen of *Tephrocyon kelloggi* from Virgin Valley, Nevada. The very slight differences between these two specimens are due in a large part to the fact that the Stewart Valley specimen is unworn, while the type has been subjected to moderate wear.

In addition to showing closely similar dimensions, the Stewart Valley specimen resembles M_1 of the type of *T. kelloggi* in the very long heel, and the very large metaconid. There is also close correspondence in a number of minor details, as in the position and form of the small inner and outer tubercles intermediate between trigonid and talonid, the presence of a faint ridge of the cingulum on the outer side of the heel, and the development of a faint ridge on the outer portion of the posterior end of the heel.

COMPARATIVE MEASUREMENTS

	No. 19767	<i>T. kelloggi</i>
M_1 , anteroposterior diameter of heel on inner side..	4.3 mm.	4.1
M_1 , greatest transverse diameter of heel	6.5	7.

SPECIES OF UNCERTAIN RELATIONSHIPS

Several fragmentary specimens representing forms in or near *Tephrocyon* have been described in recent palaeontologic papers. The exact position of the forms represented by this material can not be satisfactorily determined until better specimens are obtained.

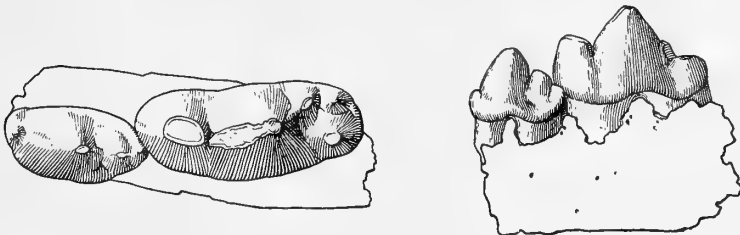
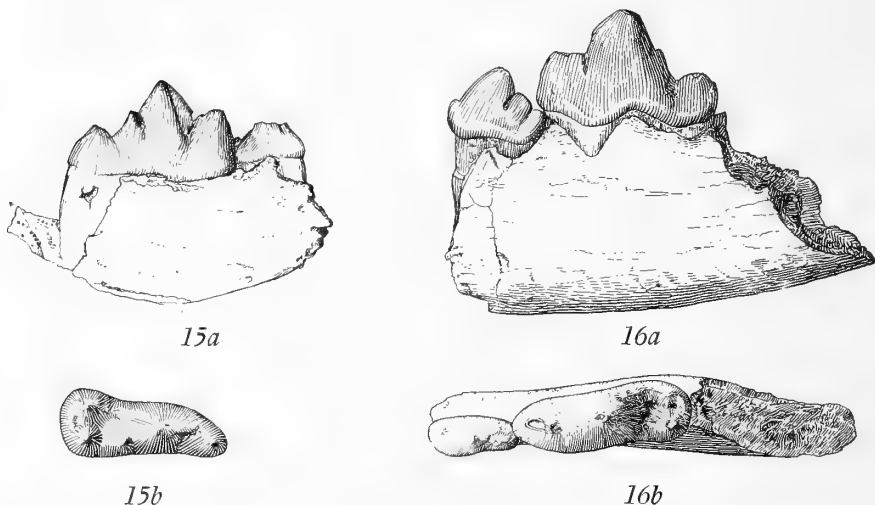


Fig. 14. *Tephrocyon?*, sp. Part of lower jaw with P_4 and M_1 . External view $\times \frac{2}{3}$, occlusal view of teeth natural size. (Amer. Mus. Nat. Hist., no. 13843). (After Matthew and Cook).

A jaw fragment with M_1 and P_4 (no. 13843) obtained by Matthew and Cook³ at Snake Creek, Nebraska, is doubtfully referred to *Tephrocyon*. It represents a form one half larger than *T. hippophagus*. The heel of M_1 in this form seems shorter than in any other specimen referred to *Tephrocyon*.



Figs. 15a and 15b. *Tephrocyon?*, compare *rurestris* (Condon). No. 12503, natural size. Virgin Valley Beds, Little High Rock Canyon, Humboldt County, Nevada. Fig. 15a, M_1 and P_4 inner view; fig. 15b, M_1 oclusal view.

Figs. 16a and 16b. *Tephrocyon?*, sp. No. 12504, natural size. Virgin Valley Beds, High Rock Canyon, Humboldt County, Nevada. Fig. 16a, outer side; fig. 16b, oclusal view.

A jaw fragment with M_1 and P_4 (no. 12503) from the Middle Miocene of Little High Rock Canyon, Humboldt County, Nevada, is compared with *Tephrocyon rurestris* by Merriam.⁴ The general form and measurements are near those of the type specimen of *T. rurestris*. The metaconid of M_1 seems relatively a little smaller and the protoconid and paraconid more acute. This difference, especially as represented in the figure, is largely due

³ Matthew, W. D., and Cook, H. J., Bull. Am. Mus. Nat. Hist., vol. 26, p. 376, 1909.

⁴ Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, p. 239 and 240, text-figs. 8a and 8b, 1911.

to difference in wear. It will be necessary to have more material, and especially to secure a specimen with M_2 , before the exact relationship of this form can be determined.

A portion of a mandible with M_1 and P_4 (12504) from the Middle Miocene of High Rock Canyon, Humboldt County, Nevada, represents a species larger than that from Little High Rock Canyon. P_4 differs from that of *Tephrocyon rurestris* in the possession of an anterior cusp. The entoconid of the heel of M_1 is relatively smaller than in the specimen from Little High Rock Canyon. In several characters this specimen resembles *T. hippophagus* more nearly than it does *T. rurestris*, but it is probably distinct from both species.

Although the specimens from the High Rock and Little High Rock beds resemble the typical *Tephrocyon*, in many respects they are quite different from *T. kelloggi*, and future study of this group of canids may show that the fragmentary forms last described are separable at least by subgeneric characters from the *T. kelloggi* type.

Matthew and Cook⁵ have compared fragmentary material from the Snake Creek Beds to *Canis vafer* Leidy, and have tentatively referred this form to *Tephrocyon*. It seems to the writer doubtful whether *Canis vafer* can be included in the same generic group with *Tephrocyon rurestris* and *T. hippophagus*.

RELATIONSHIPS OF TEPHROCYON

Writers⁶ who have expressed an opinion on the affinities of *Tephrocyon* have considered this group as distinguished by characters in some respects like those of *Canis*, and in some particulars like those of *Aelurodon*. The further study of the group bears out these assumptions, and future work may show that both *Canis* and *Aelurodon* are derivatives of the *Tephrocyon* type. Later study will probably reveal many varieties of the *Tephrocyon* group as yet unknown, some of which will be more like

⁵ Matthew, W. D., and Cook, H. J., Bull. Am. Mus. Nat. Hist., vol. 26, p. 376, 1909.

⁶ Merriam, J. C., *op. cit.*, 1906.

Matthew, W. D., and Cook, H. J., *op. cit.*, 1909.

Aelurodon than the species now available. Some of the fragmentary specimens to which reference has been made above show characters verging close to *Canis*.

Bear-like characters, such as are seen especially in M_1 and M_2 of *Tephrocyon kelloggi*, are not considered as indicating that this group is ancestral to any division of the *Ursidae*. *T. kelloggi* may, however, lead to a very specialized side branch of the *Caninae*.

Transmitted June 28, 1913.

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Issued September 24, 1913

VERTEBRATE FAUNA OF THE ORINDAN
AND SIESTAN BEDS IN MIDDLE
CALIFORNIA

BY

JOHN C. MERRIAM



UNIVERSITY OF CALIFORNIA PRESS

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INTRODUCTION

The Orindan and Siestan formations occurring in the hills immediately to the east of Berkeley form the larger part of a thick accumulation of fresh-water and alluvial beds resting uncomformably upon the marine Miocene. The Orindan formation is the lower portion of these beds, and comprises a great thickness of clays, shales, sands, conglomerates, and tuffs, with occasional beds of limestone. The Orindan is followed by a

series of igneous rocks consisting mainly of andesite and basalt. The Siestan rests upon the lavas covering the Orindan, and is in turn covered by a volcanic series made up largely of basalt.

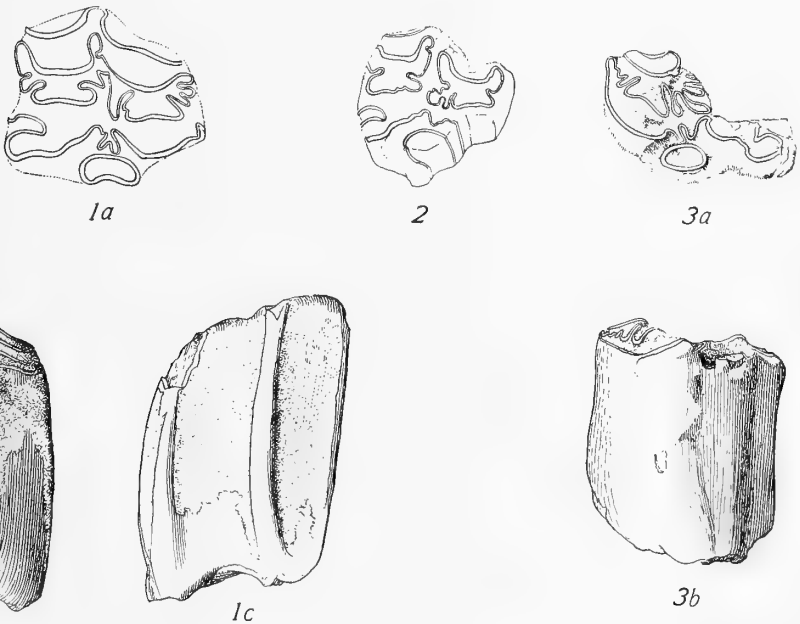
The section, from the base of the Orindan to the top of the lavas above the Siestan, contains no marine fossils. It shows scattered through it a few remains of fresh-water Mollusca and Crustacea, land Mollusca, land plants, and land or fresh-water vertebrates. The accumulation as a whole is evidently the result of deposition in a basin which was at times occupied, at least in part, by fresh water, and at other times may have received purely alluvial deposits.

As our knowledge of the land fauna of the California region west of the Sierras and north of Tehachapi is very meagre, the writer has made special effort during the past ten years to secure material which might furnish some information as to this phase of the palaeontologic record. The great thickness of strata in the Orindan and Siestan seems to offer some of the most favorable places to search for vertebrate forms. The beds being so situated that the relation of the vertebrate fauna to the earlier marine Tertiary faunas is determinable, any information acquired is especially valuable for use in connection with work on the correlation of the great marine marginal province and the epicontinental Great Basin province of western North America.

Being easily accessible for investigation, the Orindan and Siestan formations have probably been examined for vertebrate remains more carefully than any other non-marine formations in the California area of the Pacific Coast marginal province. In spite of the efforts put forth, only a very scant fauna has been obtained in the course of the eighteen years since the first systematic search was conducted in these beds. Although the results of our investigation of this fauna are very unsatisfactory, it seems desirable to put the available information on record, as the known relation of these formations to the marine Tertiary of middle California gives unusual significance to all data obtained. It is hoped that presentation of the evidence offered here may serve as a stimulus and a guide to future students of the Orindan and Siestan, so that a much more satisfactory representation of the fauna may be secured.

EQUIDAE

Remains of early horses have been found at two localities in the Orindan beds. No specimens representing this group are certainly known from the Siestan. It is stated that bones of a horse were found in a shaft sunk in Siestan beds on Frowning Ridge near the upper end of Telegraph Cañon, but the writer has been unable to obtain any definite information as to this occurrence. Two teeth representing species near *Neohipparion*, and an astragalus that may well represent a horse of Miocene age have been obtained near Bolinger Cañon. A single tooth was obtained by Mr. J. P. Buwalda from Mr. Williams, who discovered it in extensive Orindan exposures about two and one-half miles from the mouth of Tassajara Cañon, on the southwest side of Mount Diablo. The specimen from Tassajara Cañon and



Figs. 1a to 1c. *Neohipparion*, sp. Upper premolar. No. 19830, natural size. Orindan beds, southwest of Mount Diablo.

Fig. 2. *Neohipparion* or *Merychippus*. Upper premolar. No. 1323, natural size. Orindan?, west of Bolinger Cañon.

Figs. 3a and 3b. *Hipparion*(?) or *Neohipparion*. Upper cheek-tooth. No. 1324, natural size. Orindan?, near Bolinger Cañon.

the better preserved tooth from Bolinger Cañon (no. 1324) seem to represent different species. The second specimen (no. 1323) from near Bolinger Cañon is imperfectly preserved, but is possibly different from the other two teeth.

NEOHIPPARION, sp.

Specimen no. 19830, from Orindan beds two and one-half miles southwest of Tassajara Post Office.

This form is represented by a single tooth, P² (figs. 1a to 1c). The crown is rather large, it has been well cemented, and the outer styles are strong. The flattened protocone is distinct almost to the base. The anterior and posterior fossettes are narrow transversely, and the borders are formed into numerous deep plications. The two fossettes are lightly connected. If this connection is due to lack of wear, it is evident that the crown was not greatly elongated.

This tooth does not agree closely with any form known to the writer, but it does not seem desirable with the present material to give it a special designation other than to recognize it as a distinct form. A species of *Neohipparion* apparently different from that from near Tassajara is known from late Tertiary beds near Ricardo Post Office on the northwestern boundary of the Mohave Desert.

MEASUREMENTS OF CHEEK-TOOTH No. 19830

P ² , greatest anteroposterior diameter of crown	25.8 mm.
P ² , greatest transverse diameter of crown	21.6
P ² , anteroposterior diameter of protocone	8.2

HIPPARION(?) OR NEOHIPPARION

Specimen no. 1324, from Orindan beds near Bolinger Cañon.

A fragmentary tooth (no. 1324, figs. 3a and 3b) differs from that seen in the form from Tassajara Cañon in the round protocone and more pronounced plication of the walls of the anterior fossette. This type does not differ greatly from one of the *Neohipparion* specimens from near Ricardo on the Mohave Desert.

MEASUREMENTS OF UPPER CHEEK-TOOTH No. 1324

Greatest anteroposterior diameter	24.2 mm.
Anteroposterior diameter of protocone	6.2

NEOHIPPARION OR MERYCHIPPUS

A specimen (fig. 2, no. 1323) from beds presumably of Orindan age west of Bolinger Cañon is smaller than no. 1324. The protocone is free to the base, the fossettes seem a little wider transversely and show less marked plications than in the specimens tentatively referred to *Hipparion*.

This form may represent a species distinct from the other two forms of the *Hipparion* group or may be included in the genus *Merychippus*.

MEASUREMENTS OF CHEEK-TOOTH No. 1323

Approximate greatest anteroposterior diameter	18.3 mm.
Approximate greatest transverse diameter	17.7
Greatest anteroposterior diameter of protocone	5.7

PROTOHIPPIE(?) ASTRAGALUS

An astragalus (fig. 4, no. 9858) from near Bolinger Cañon represents a stage of development approximating that of certain

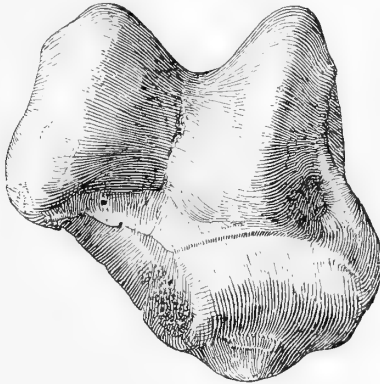


Fig. 4. Protohippie(?) astragalus. No. 9858, natural size. Orindan?, near Bolinger Cañon.

Miocene horses. The deeply-cut groove of the trochlea is rather narrow, and is markedly oblique.

PROSTHENNOPS(?), sp.

Some months ago the class in field geology, working under the direction of Professor Andrew C. Lawson, obtained in fresh-water shales of the Siestan beds near Bald Peak a specimen representing a portion of the skull of a dicotyline form not previously known from California. The specimen consists of a portion of the cranium showing part of the palate with M^2 and M^3 of the right side, and the left cheek-tooth dentition excepting M^1 . The teeth are much worn, but enough of the characters are indicated to make possible an approximate determination. The fragment containing the anterior portion of the upper dentition of the left side was separate from the portion with the molar teeth when it came into the writer's hands. It seems to fit

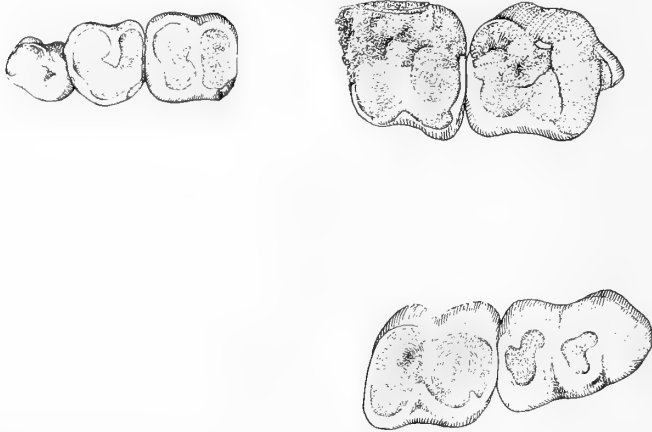


Fig. 5. *Prosthennops*(?), sp. Upper cheek-teeth. No. 19826, natural size. Siestan beds, near Bald Peak.

imperfectly against the anterior end of the piece with the molars. If this diagnosis of the relation of these pieces to each other is correct, a gap approximately fifteen millimeters long between P^4 and M^2 represents the space occupied by M^1 .

The most anterior element of the cheek-tooth series, considered as P^2 , is double-rooted. The posterior root is wide transversely and suggests incipient division into two. The crown is relatively wide posteriorly, and shows a large anterior tubercle with a posterior tubercle or cusp which has an anteroposterior diameter not more than half that of the anterior tubercle. It is

barely possible that other tubercles were present, but in the present worn condition of the crown no evidence of other features appears. This tooth is near the stage of advance in *Tayassu*, but is perhaps a little less advanced in that the posterior root is narrower and not distinctly divided. If the crown were complete it might show the posterior tubercle or cusp divided into two. This tubercle is, however, smaller than in *Tayassu*.

The tooth considered to represent P³ is nearly quadrate, the hypocone region being slightly less developed than the protocone region. The posterior or hypocone-metacone region is narrower anteroposteriorly than the protocone-paracone region. The stage of advance of this tooth is approximately that of *Tayassu*.

P⁴ is quadrate in outline, but the hypocone-metacone region is narrower than the protocone-paracone region. The stage of advance is near that of *Tayassu*, with a tendency to show a smaller posterior lobe than in the Siestan form.

The proportions of M² and M³ are much as in *Tayassu* or in *Prosthennops*.

The material available indicates that the form represented by specimen 19826 is near the stage of development of *Tayassu* with the exception that the premolars are slightly less advanced. The character of the upper canines and the length of the diastema are not known.

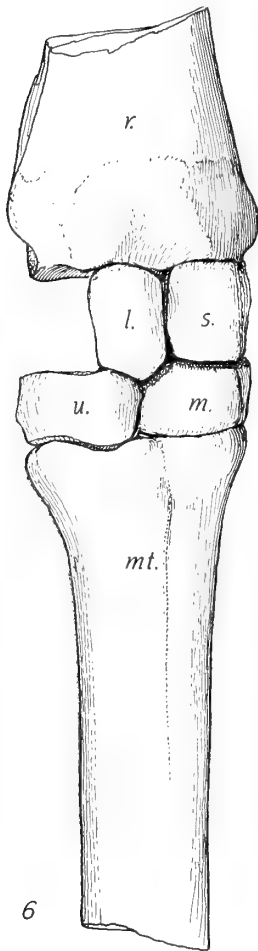
So far as represented, the characters in this specimen are those of the genus *Prosthennops* known from the Upper Miocene and Lower Pliocene. A specimen from the Pliocene of Thousand Creek in northern Nevada referred to *Prosthennops*¹ resembles this specimen in the general proportions of the teeth, but apparently differs somewhat in the character of the crowns. As nearly as one can judge from the imperfect material, P² is quite differently constructed in the two forms. From the evidence available, it does not seem probable that they represent the same species.

Although the material is not at hand for a satisfactory comparison of the Siestan specimen with the *Prosthennops* species known east of the Rocky Mountains, it is probable that the Siestan form is distinct from any of the described species.

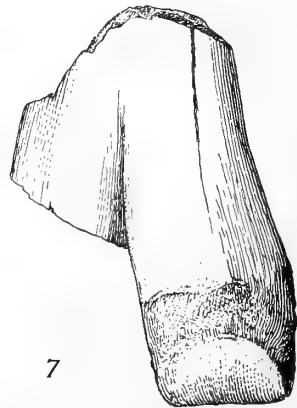
¹ Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, p. 273, 1911.

MEASUREMENTS

	No. 19826
P ² , anteroposterior diameter	9.2 mm.
P ² , transverse diameter	7.9
P ³ , anteroposterior diameter	10.8
P ³ , greatest width	11.1
P ⁴ , anteroposterior diameter	12.2
P ⁴ , greatest width	12.
M ¹ , anteroposterior diameter	15.(?)
M ² , anteroposterior diameter	17.
M ² , greatest width	15.
M ³ , anteroposterior diameter	18.1
M ³ , greatest width	14.4



6



7

Fig. 6. *Procamelus*(?), sp. Portion of anterior limb. No. 1560, $\times \frac{1}{2}$. Orindan, Bolinger Cañon.

Fig. 7. *Phauchenia*(?), sp. Portion of cannon bone. No. 1982, $\times \frac{1}{2}$. Siestan, Siesta Valley.

PROCAMELUS(?), sp.

A portion of the anterior limb (fig. 6, no. 1560) of a camel somewhat larger than the existing llama was found at locality 299 near the middle of the Orindan beds at Bolinger Cañon. This specimen does not show any characters which are recognized by the writer as certainly indicating its specific or generic position, but it is evidently near *Procamelus*, a genus well known in the Upper Miocene of the Great Plains and Basin regions. The species represented by this specimen is larger than the forms found in the Basin region, but the dimensions shown here are approached by *Procamelus robustus* of the Great Plains.

MEASUREMENTS

Radius, greatest transverse diameter of distal end	62.5 mm.
Cannon bone, greatest transverse diameter of proximal end	58.6
Scaphoid, greatest anteroposterior diameter	38.8
Lunar, greatest height	31.
Magnum, greatest anteroposterior diameter	34.7

PLIAUCHENIA(?), sp.

A fragment of the distal end of a cannon bone (fig. 7, no. 1982) was obtained by J. P. Buwalda at locality 707 in the Siestan beds of Siesta Valley, in the hills immediately to the east of Berkeley. This specimen, though very fragmentary, certainly represents a large camel approximating the dimensions of the Recent *Camelus*. It evidently belongs to a form considerably larger than the species from the Orindan of Bolinger Cañon and probably represents a species of the genus *Pliauchenia*, a large camel of a more advanced stage of development than *Procamelus*. *Pliauchenia* is a characteristic form of late Miocene to Pliocene time.

MEASUREMENTS

Transverse diameter of cannon bone 60 mm. above the distal end....	64. mm.
Thickness of cannon bone 60 mm. above the distal end	26.6
Least width of one of the two distal divisions of the cannon bone below the point of fusion	39.

TETRABELODON(?), sp.

Remains of mastodon-like forms have been found by R. E. Dickerson in the upper portion of the Orindan section of Bolinger Cañon, and by J. P. Buwalda in the lower portion of

the Orindan section near Tassajara Cañon on the south side of Mount Diablo. The material is all very fragmentary and is not susceptible of even certain generic determination.

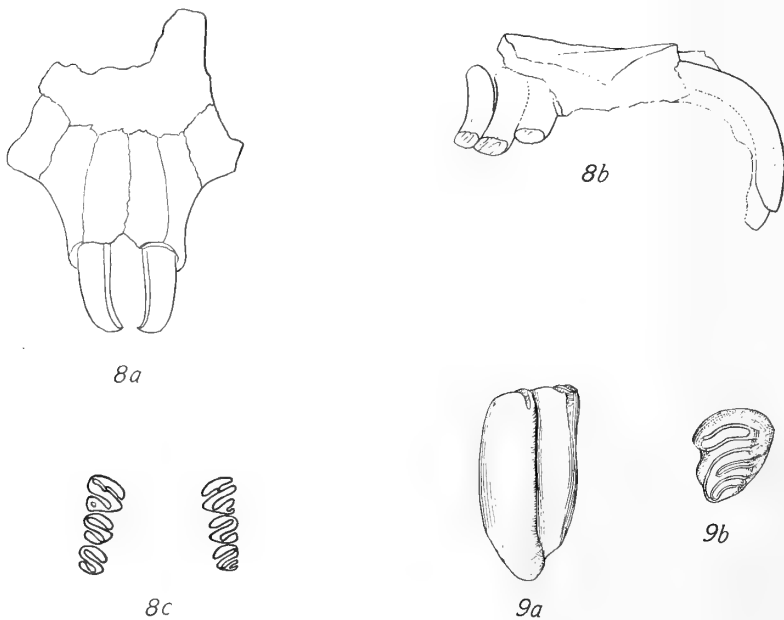
The specimen from Bolinger Cañon consists of fragments of cheek-teeth and portions of a lower jaw of an animal of considerable size.

The specimens from near Tassajara Cañon include fragments of teeth. They represent an animal of the mastodon type but the fragments are too imperfect for certain generic identification.

DIPOIDES LECONTEI (Merriam, J. C.)

From Siestan beds near Bald Peak.

The type specimen (figs. 8a to 8c), consisting of the anterior part of a skull with three cheek-teeth on each side, was discovered in the Siestan beds near Bald Peak. A single lower molar has since been found in the same beds.



Figs. 8a to 8c. *Dipoides lecontei* (Merriam, J. C.). Type specimen natural size. Fig. 8a, superior view of skull; fig. 8b, lateral view of skull; fig. 8c, superior cheek-teeth. Siestan beds, near Bald Peak.

Figs. 9a and 9b. *Dipoides*, sp. P., $\times 2$. Fig. 9a, outer side; fig. 9b, occlusal view. Siestan beds, near Bald Peak.

This form was originally described under the generic name of *Sigmogomphius*, on the assumption that there were but three superior cheek-teeth. In the original description, the writer called attention to the similarity of the dentition to that of *Eucastor* Leidy, but separated it from that genus owing to the difference in pattern of the enamel folds. Comparative material was not available at that time, and the writer was not aware of the extent of change possible in the tooth pattern of these forms with wear. There seems now good reason to believe that a worn *Sigmogomphius* molar would develop a tooth pattern similar to that of *Eucastor*, and that both *Sigmogomphius* and *Eucastor* are not to be distinguished from the Old World genus *Dipoides* Jager. It is, however, worth noting that the reduction of the posterior molars in some of these forms suggests a possible reduction of the cheek-tooth formula to three, as was assumed for the genus *Sigmogomphius*. It is not certain that this reduction occurs in *Dipoides lecontei*, as the last molars may have been lost from the type specimen.

A single lower cheek-tooth, P₄, (figs. 9a and 9b) from the Siestan beds resembles the European type of *Dipoides*, and the tooth pattern shows close similarity to that of a somewhat larger form found in the Thousand Creek beds of northern Nevada.

LEPUS, sp.

Fragmentary remains of two rabbits are known from fresh-water beds in the hills near Berkeley. They consist of a lower tooth (no. 19827), from the Siestan beds near Bald Peak, and a portion of a lower jaw from an Orindan exposure in Wildeat Cañon. It is doubtful whether the two specimens represent the same species, but neither one is certainly specifically determinable.

PLANT REMAINS

At several localities in the Siestan formation, imperfectly preserved plant remains have been found in clays and sands containing fresh-water shells, a few land shells, and remains of land vertebrates. The plant remains consist largely of fragments of stems and leaves of rushes and grass, but include also a few

leaves of trees. Professor W. L. Jepson, who has examined these specimens, considers the leaves as representing *Acer*, sp., *Sterculia* or *Acer*?, and *Dirca*, sp.

AGE OF THE ORINDAN AND SIESTAN VERTEBRATE FAUNAS

Although the vertebrate remains from the Orindan and Siestan are probably obtained from horizons comprising quite a wide range in time, they represent collectively the greater part of the known land fauna of this region in a period following the San Pablo Miocene and preceding the Pleistocene. Such field work as has been done up to this time does not lead us to expect large collections from these formations, though the discovery of strata rich in determinable remains is always possible. The Siestan beds seem to offer a possible fruitful field for future collecting.

The mammalian remains known from both the Orindan and Siestan up to the present time all represent forms such as might be expected in the late Miocene or in the earliest Pliocene, but it will be necessary both to have better material from the Orindan and Siestan and to have well-known faunas of western Miocene and Pliocene for comparison before the last word on the age determination can be pronounced.

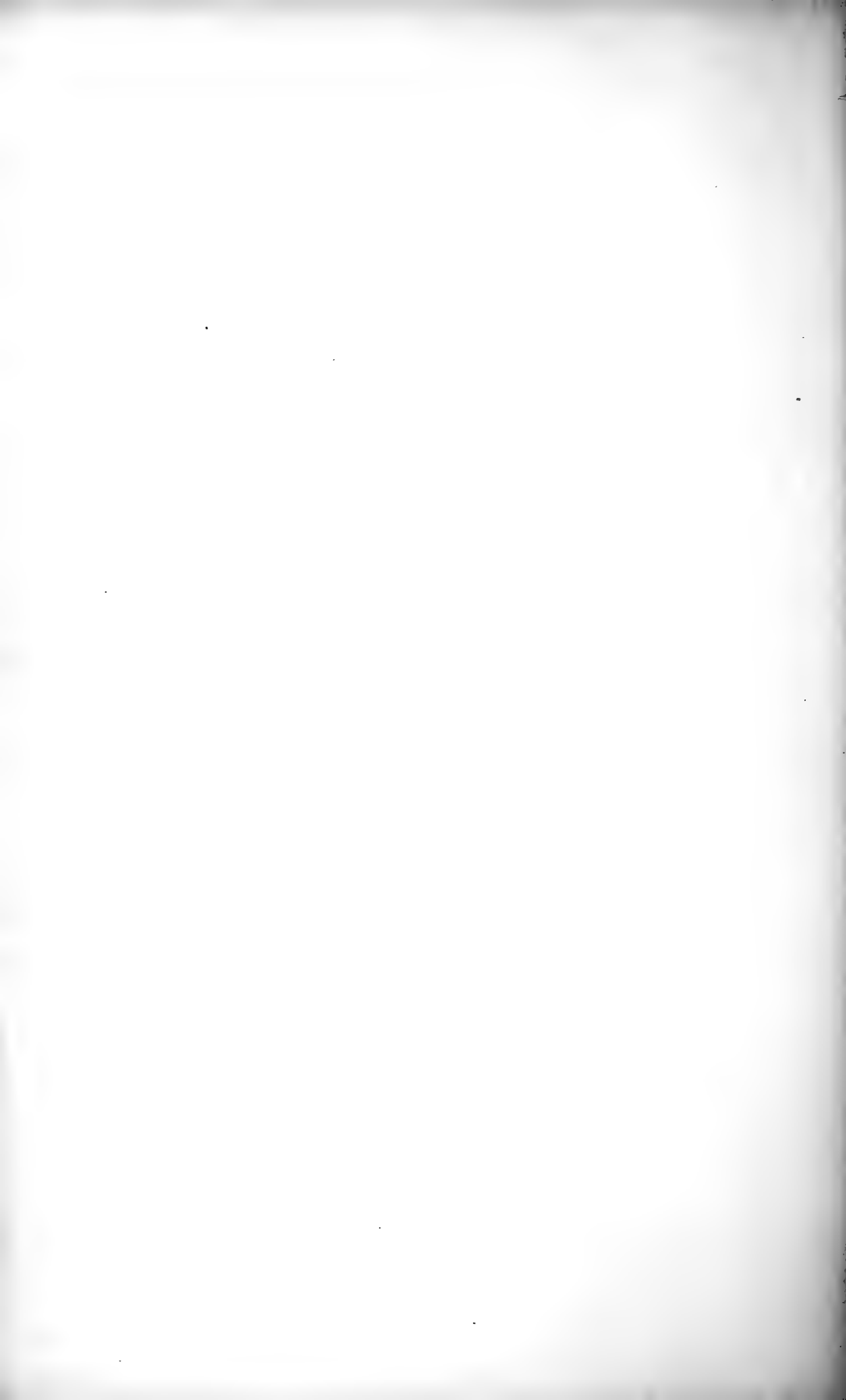
The late Tertiary mammalian faunas which are most available for comparison with the forms from California are those of the Basin region, including the Tertiary beds of the Mohave Desert region of California, those of the Cedar Mountain region of Nevada, and the Thousand Creek beds of northern Nevada. All of these faunas are as yet imperfectly known, but there seems reason for considering the Thousand Creek as representing early Pliocene, and the deposits of the Mohave and Cedar Mountain regions as at least in part near late Miocene.

Compared with these faunas there seems in some respects less suggestion of similarity with Thousand Creek than with the other two. On the other hand, there is no indication of identity with the so-called Mohave fauna of the Barstow region. The beds referred to the Rosamond series, in the Ricardo region on the western border of the Mohave Desert, contain a fauna with

Neohipparion, suggesting the Orindan fauna. The Ricardo fauna is possibly somewhat later than that of the best known horizon containing the Mohave fauna in the Barstow syncline.

Considering the indefiniteness of all the factors concerned, one would not seem justified in being more definite than to state that the Orindan and Siestan faunas are near a late Miocene stage. When the faunas of the two formations are better known, it may appear that more than one stage is represented.

Transmitted June 28, 1913.



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RECENT OBSERVATIONS ON THE MODE OF
ACCUMULATION OF THE PLEISTOCENE
BONE DEPOSITS OF RANCHO
LA BREA

BY

REGINALD C. STONER

UNIVERSITY OF CALIFORNIA PRESS

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INTRODUCTION

Beginning in 1906, the University of California has collected in the Pleistocene mammal beds at Rancho La Brea at irregular intervals up to 1913. The Los Angeles Normal School, Los Angeles High School, and the Southern California Academy of Sciences have also collected a large quantity of bones from these deposits. During the past winter the University of California engaged in excavation work at Rancho La Brea on a much more extensive scale than in previous years. A careful working over of the material found before this time indicated that certain of the rarer animals would be obtained only by examination of a much larger collection than had been available up to that time.

These excavations were made possible through the generosity of the late Madam Ida Hancock Ross and Mr. G. Allan Hancock, who kindly granted a concession to work the deposits. The work was carried on between September, 1912, and April, 1913, under the direction of Dr. John C. Merriam and under the immediate supervision of the writer. An average of about ten men were employed. As our knowledge of the accumulation of the deposits was increased somewhat by the results of these excavations it seems desirable to record such information as relates to origin of the bone beds.

DESCRIPTION OF THE LOCALITIES INVESTIGATED

Locality 2050.—This locality was chosen for the first work in 1912, as it was known that excellent material had been obtained here in a pocket opened by Dr. L. H. Miller in excavating for the State Normal School of Los Angeles some years ago.

The bones exposed at this point covered an area not larger than four feet square. The larger part of the pocket was covered with green and brown clays. The bones found on the surface were embedded in a hard asphalt and were very much decayed from weathering. Two feet under the surface valuable material in perfect state of preservation was encountered. In the western half of the pocket the bones were embedded in a soft, sandy asphalt, which also contained many sticks and a few large branches of trees. In the other half of the pocket the asphalt was mixed with green clay, which in places was filled with coarse quartz grains. The area of bone-bearing asphalt within two feet of the surface was small, probably about sixteen square feet. At a depth of ten feet the area covered was about fifty square feet. The majority of the bones were taken from soft, sticky asphalt, and in this matrix they were the most numerous and best preserved. Around the edge of the pocket where clay tended to overlap the asphalt few bones were found in the clay. In some cases where the asphalt was soft small bones had been forced into cracks in the clay, forming veins of bones which could be followed for two or three feet. Only a small percentage of the total number of bones obtained came from the fillings of these fissures. It should be noted that the

edges of the asphalt pool were usually irregular. At some points the deposit of clay overlapped the asphalt, at other places the asphalt was forced into the surrounding matrix.

At a depth of from ten to twelve feet this pocket reached its maximum area. From this depth to seventeen feet it contained only few bones. From eight to twelve feet the floor of the pocket was a tangled mass of bones closely pressed together and interlocked in all possible ways. At this horizon there were exposed at one time two horse skulls, a sloth skull, a camel skull, and several tiger and wolf skulls, besides many other bones of these animals.

*Locality 2051*¹.—The largest part of the material was obtained at this locality in 1912. The locality as shown in plate 18 includes three separate pockets, which were completely excavated. In pocket no. 1 the University had worked before and had taken bones from a small hole carried to a depth of twelve feet. From this exposure the work was extended, and two other pockets immediately to the east were located.

The surface at locality 2051 was covered with a hard, black asphalt, the tar having flowed out over the surface of the bones and collected sand and clay, forming a capping for the bone pockets. This capping contained a few bones and some vegetable material, and varied in thickness from a few inches to four feet. It completely covered the three bone-bearing pockets. After the hard surface was removed, the bones were exposed in patches as shown in plate 18. As was noted in locality 2050, the bone pockets were relatively narrow at the top. As deeper horizons were reached the pockets widened out, and in plate 19 the largest horizontal section of the pockets is shown. It is interesting to note here that the bone pockets, even at their greatest extent, are not at any point connected. In the study of plate 20, which is a vertical section of this locality, the three distinct bone pockets are shown separated by the green and brown clays. The persistent separation of these three pockets, which accumulated within a short space of sixty feet and still remained distinct from one another, may be explained by slow exudation of the oil which did not allow the pools to overflow and unite

¹ The former number of this locality was 1059.

The bones in pocket no. 1 are not so well preserved as those in pocket no. 2. This difference in preservation is rather difficult to explain, since they accumulated at the same time and were only a few feet distant. From the evidence obtained a suggestion may be offered. In pocket no. 1 there are large lumps of brittle asphaltic clay scattered among the bones, and at a depth of fourteen feet the floor of the pit was nearly covered with this clay, veined with asphalt-bearing bones. The fact that this clay contains globules of asphalt and also has a brown color, which is probably due to the asphalt, leads us to believe that it was deposited in juxtaposition to the tar pools. It is safe to say that this pool was covered with water for a considerable length of time, allowing the deposition of clay, and so affecting the preservation of the bones. It is quite possible also that at intervals the exudation of the tar was stopped and allowed these pools to be capped with clay. Afterward the tar again came to the surface and another pool was formed in which bones were deposited. In pocket no. 2 the brown lumps of clay are not found among the bones, and there is no evidence to indicate that water once covered this pocket.

Pocket no. 2 was the largest pocket of well-preserved bones discovered. From within six feet of the surface to twenty-one feet there was a solid mass of bones, the pocket varying in outline and narrowing toward the bottom. After the hard cover was removed the matrix lying beneath was found to be very soft and much tar oozed out at two or three points. Where the tar was most abundant the bones were not so well preserved. From a depth of ten to twenty feet the bones in this pocket were of a light brown color and embedded in a fine sandy matrix with a rather small percentage of tar.

Pocket no. 3, as may be seen in plate 20, is much smaller than either of the others, but contained many bones in a fine state of preservation. Here bones were found at the surface and from this down to fourteen feet. Some of the bones obtained at the surface were poorly preserved, yet on the east side of the pocket sloth material was found that was of a bright red color and the bones as hard as Recent specimens. This pocket was quite small and therefore only parts of skeletons seemed to be

present. Aside from the sloth material bones of large animals were rare. Along one side of the pocket parts of many rodents, birds and other small animals were found. These remains were in a more sticky matrix and had probably been caught and entombed in the tar chimney at a relatively recent date. Very near the surface in a soft, sticky mass there were a large number of these small bones. This pocket reached its maximum size at eight feet, and from there to thirteen feet it narrowed down to a small area where bones were rare.

Locality 2052.—When work was begun at this locality there was a small mass of asphalt exposed, which contained few bones. After clearing the surface around this exposure another pocket was located immediately to the south. In the first pocket the matrix was sandy, dry, and contained many twigs and small limbs. Here the bird and rodent bones were plentiful. There were a few horse and coyote remains, and one camel bone was found. The dire wolf and sabre-tooth tiger were absent. In the other pocket the bones were those of birds and rodents, excepting a few antelope and coyote specimens. In this pocket the bones were embedded in a sticky matrix containing little sand and having a recent appearance. At a depth of four feet this pocket narrowed down to a foot in width and the bones disappeared. These two pockets are joined, but are united only within a foot of the surface. The more recent exudation of oil which took place in the second pocket flowed toward the first, and so joined them in rather recent time. Each of the pockets extended to a depth of four feet and there disappeared. Further excavation showed no evidence of another pocket below. Judging from the nature of the matrix and the size of the pockets, the bones seem to be very young, and the second pocket where the antelope was found is possibly Recent; but the first pocket, which has a more sandy matrix and generally a much older aspect, is probably Pleistocene. This idea is supported by the finding of a camel metapodial in this area.

GENERAL CONCLUSIONS AS TO THE MODE OF ACCUMULATION
AT THE LOCALITIES INVESTIGATED

The most interesting observation on the deposition of material found in the recent excavations in the asphalt is that bones accumulated in holes of such small size, and that the deposits were built up to such a thickness. As seen in the section in plate 21, the maximum depth of one pocket is at least twenty-three feet, while the area over which it extends is comparatively small. These pockets were not at any time depressions, twenty to twenty-five feet deep in the Pleistocene surface, which later filled up gradually with sand, clay and bones. From the presence of green clay dividing pockets no. 1 and no. 2 (plate 20) it may look as though they were filled up in this manner, but it is obviously impossible for this wall of clay between the pockets to have resisted ordinary rain erosion during the time in which the pockets could receive by any natural process the enormous mass of bones found in them. It seems quite certain that these deposits were slowly built up along with the surrounding Pleistocene formation, and that the tar pools were constantly renewing their surfaces as the tar came out and trapped the life of that time. Locality 2051 affords the best example of this manner of deposition, as at this point three distinct pockets were found in a space of sixty feet. Through all the years that must have been required for the building up of these asphalt masses the exudation of the tar was so slow that the pools never joined to form a large pool and a single large mass of bones, but remained distinct. However slow the accumulation of the bones was, the pools were evidently large enough to catch one or two tigers, several wolves and an ungulate at the same time, the latter serving as prey for the carnivores. This association is quite clearly shown in some places, and at one point in particular there were eight wolf skulls and many wolf bones mixed with the bones and skull of a large bison.

In all the localities investigated the quantity of bones obtained was very large compared with the amount of asphalt removed. Each pocket represented a mass of tangled bones so closely matted that when one bone was removed there was always another exposed. Soon after the animals were caught in the

tar the organic tissues decayed, leaving the bones disconnected and free to move about in the pools. Movement may have been caused by pressure and movement of the deposits above, or probably to a greater extent by the struggling of trapped animals and by the expulsion of the gas coming to the surface. The continual movement of the tar while it was in a liquid state scattered the bones of all the animals and formed a heterogeneous mass in which the parts of many different individuals were mixed in all possible ways. In the center of the pocket the bones were most numerous and so interlocked that much time was consumed in untangling them. Toward the periphery of the pocket the bones usually thinned out, and since they were embedded in a more sandy matrix they were much more easily extracted.

Summary.—In the recent excavations it is clear that the bones occur in rather deep, narrow pits; that during the accumulation of these deposits the different tar pools commonly remained distinct, due to the slow exudation of the tar; that the pockets represent a gradual accumulation built up along with the surrounding Pleistocene deposits. It is further shown that a number of the pockets contained several tons of bones massed together, representing thousands of individuals and scores of species. Since the bones are found only in connection with the tar pools, it is evident that their accumulation and preservation was due to the presence of the tar.

Transmitted June 9, 1913.

EXPLANATION OF PLATE 16

General view of Locality 2051. Showing pockets 2 and 3

Photograph by J. C. Merriam

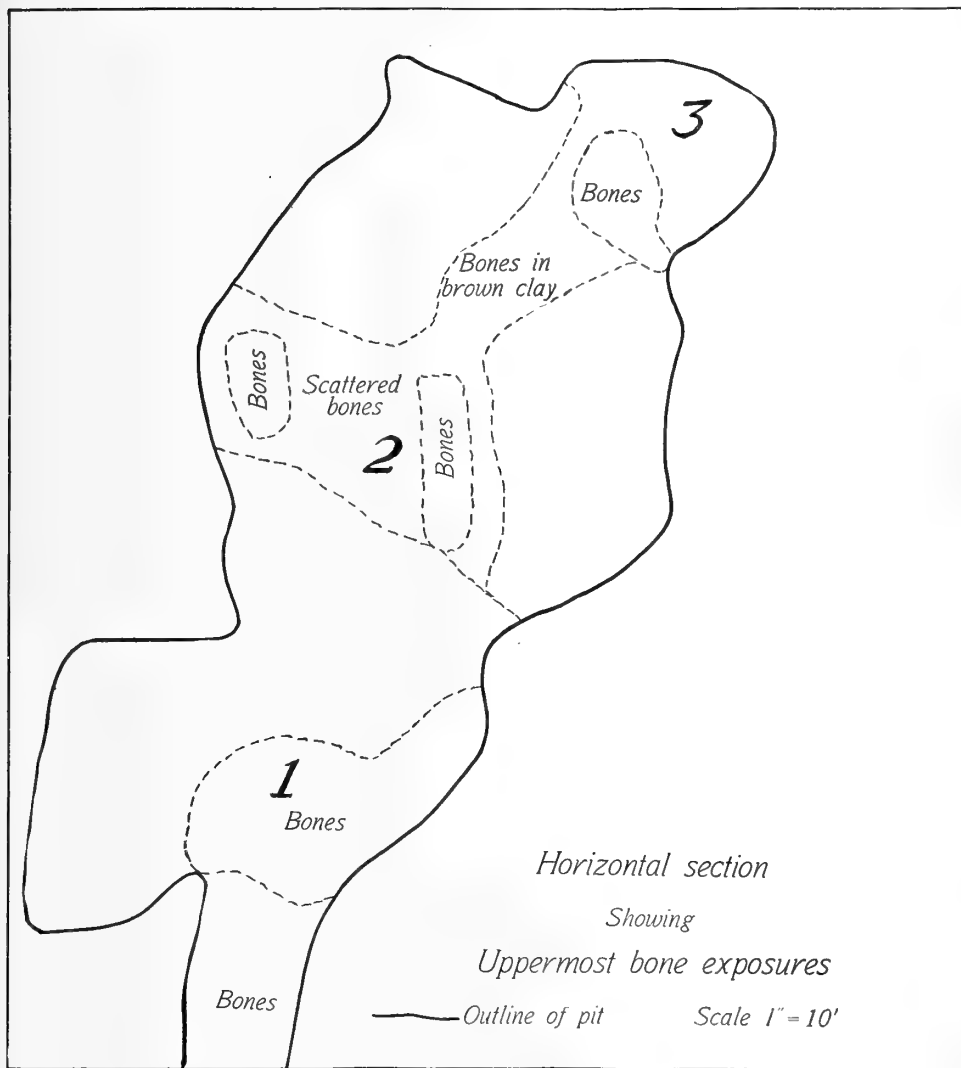


EXPLANATION OF PLATE 17

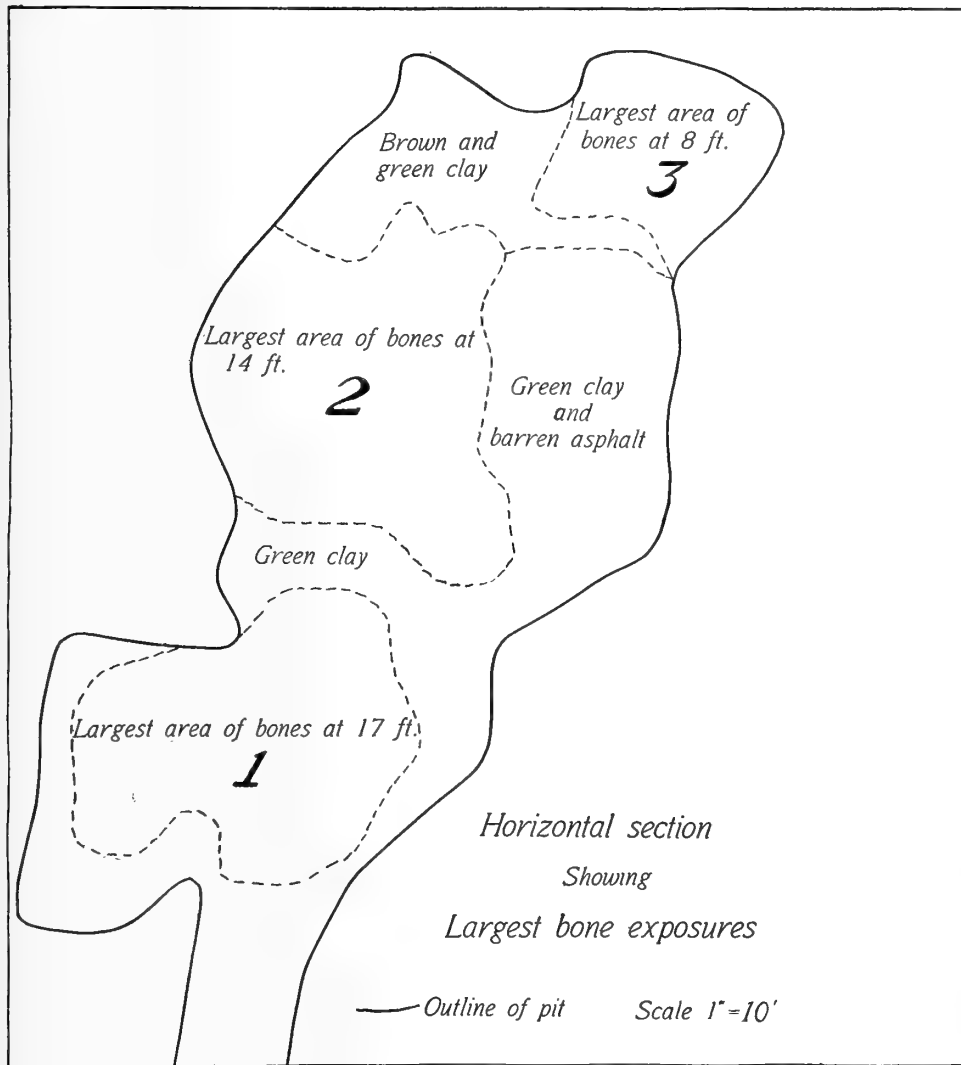
Locality 2051, showing mass of bones in pocket 2

Photograph by J. C. Merriam

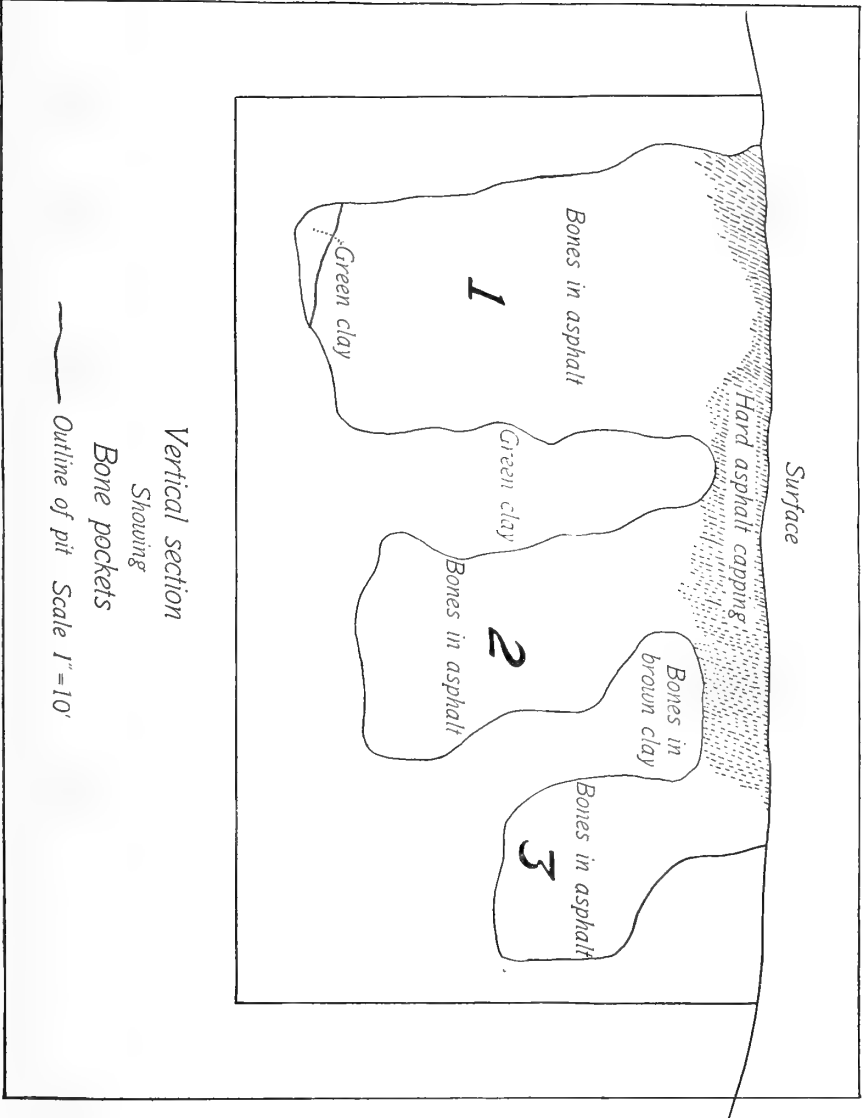




Locality 2051, Rancho La Brea

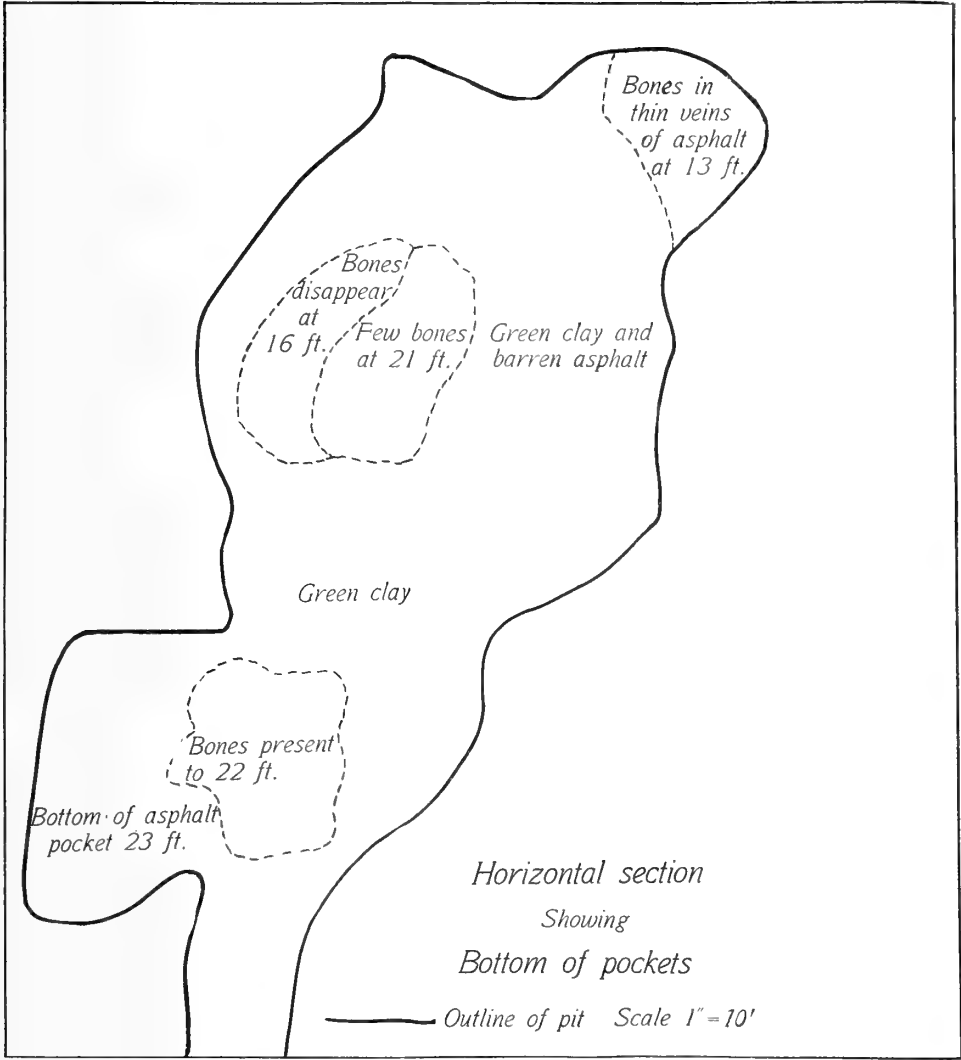


Locality 2051, Rancho La Brea



*Vertical section
Showing
Bone pockets*
— Outline of pit Scale 1"=10'

Locality 2051, Rancho La Brea



Locality 2051, Rancho La Brea

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OF RANCHO LA BREA

BY

JOHN C. MERRIAM

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PRELIMINARY REPORT ON THE HORSES
OF RANCHO LA BREA

BY

JOHN C. MERRIAM

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INTRODUCTION

Remains of horses have been obtained in considerable numbers from the Pleistocene beds of Rancho La Brea, but not until within the last year has skull material been found in such quantity as to make possible a critical study in which the important factors of individual and age variation could be considered with any degree of satisfaction. In the excavations recently carried on through the kind permission of the late Madam Hancock Ross, and her son, Mr. G. Allan Hancock, a number of good skulls have been obtained, with much material consisting of loose teeth and elements representing all parts of

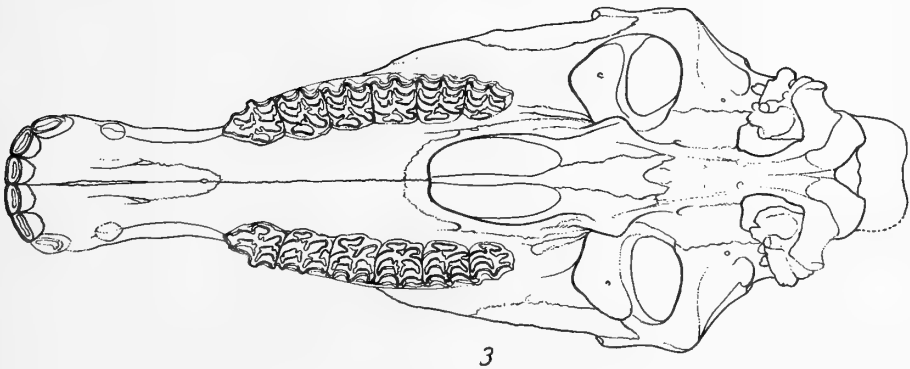
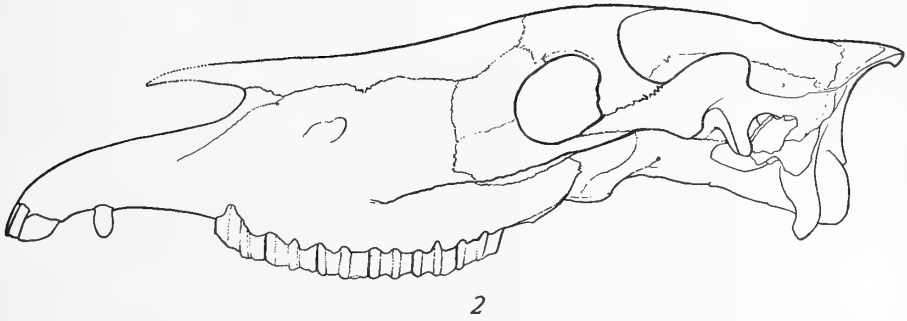
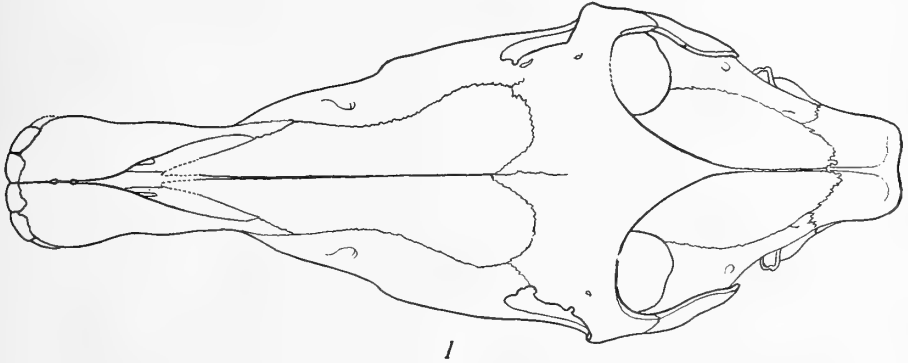
the skeleton. These collections, together with several skulls and much scattered material already available, offer one of the fullest opportunities for study of American Pleistocene horses that has been presented. Satisfactory preparation and examination of the entire series of specimens will require many months' work. In advance of this study it is possible to give such a statement of the most important contributions made by this collection as will assist in the interpretation of other material.

The collection available contains eleven good skulls, several imperfect specimens, and much fragmentary material. It represents animals of both sexes, and of all ages from foals with unworn milk teeth to old individuals with dentition in advanced stages of wear. The specimens show considerable variation in the characteristics upon which our classification of American Pleistocene horses has of necessity been largely based, and an estimation of the significance of this variation will presumably assist to some extent in interpretation of a number of the numerous imperfectly known equine species described from the American Pleistocene.

Up to the present time the only descriptions of satisfactory skull material representing American Pleistocene horses are those of Gidley¹ on *Equus scotti* of the Texas Pleistocene, and Hay² on *Equus niobrarensis* and *Equus laurentius* from Nebraska and Kansas. Of *Equus scotti* several skulls representing individuals ranging from youth to maturity are available. Skeletal material accompanying the skulls gives to this species a full and satisfactory representation. Of *Equus laurentius* the single good skull known shows this form, with its slender skull and small teeth, to be distinctly separated from the heavy-headed *E. scotti* and *E. niobrarensis*. Of *Equus niobrarensis* an imperfect skull from Hay Springs, Nebraska, shows most of the characteristics satisfactorily excepting the frontal and facial regions. Another specimen from the Pleistocene of Tofty, Alaska, is referred to a subspecies, *Equus niobrarensis alaskae* by Hay. The lower jaws of this form were not found. The cranium lacks only

¹ Gidley, J. W., Bull. Am. Mus. Nat. Hist., vol. 13, pp. 111 to 116, 1900.

² Hay, O. P., Proc. U. S. Nat. Mus., vol. 44, pp. 576 to 591, 1913; and Smithsonian Misc. Coll., vol. 61, no. 2, 1913.



Figs. 1 to 3. *Equus occidentalis* Leidy. Skull, no. 20097, $\times \frac{1}{5}$. Rancho La Brea Beds, California. Fig. 1, superior view; fig. 2, lateral view; fig. 3, inferior view.

the nasal region. *Equus niobrarensis* is distinguished from *Equus laurentius* by its shorter and wider nose, heavier and anteriorly much higher mandible. The teeth are larger and wider than in *Equus laurentius*. From *Equus scotti* this species seems to be distinguished by its smaller teeth.

Before the discovery of specimens at Rancho La Brea no good skulls and no complete skeletal specimens representing Pleistocene horses were known from the Pacific Coast region.

SKULL

The eleven practically complete horse crania from Rancho La Brea naturally show certain variations in form and size, but they are so near together in the assemblage of their characters, and present such gradations through the series, that there seems good reason for considering them all as one species, and they are treated by the writer as forms of a single specific type.

The skulls from Rancho La Brea equal or exceed those of the Recent *Equus caballus* in size. Compared with *E. caballus* the face is relatively a little wider, and the nose is relatively short and wide. The notch between the nasals and premaxillaries is wider or less acute posteriorly than in *E. caballus*. In profile the superior fronto-nasal surface is generally nearly flat, or very slightly concave above the middle of the nasals. Between the orbits the frontal region is in most specimens slightly more convex transversely than in *E. caballus*. This seems to be true in stages ranging from young adults to individuals of fairly advanced age. The nasals are relatively wide, and their anterior ends reach forward to a point a little behind the superior canines.

The orbits are near the size of those in *E. caballus*, but tend to be slightly larger. They are noticeably smaller than in *E. niobrarensis* and *E. laurentius*.

The occiput is higher and narrower than in the domestic horse, and the overhang of the inion is considerably greater. The greatest width across the condyles averages relatively smaller than in *E. caballus*.

The mandible is heavy in contrast with that of the modern horse, and the horizontal ramus is much higher below the anterior

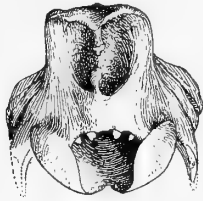
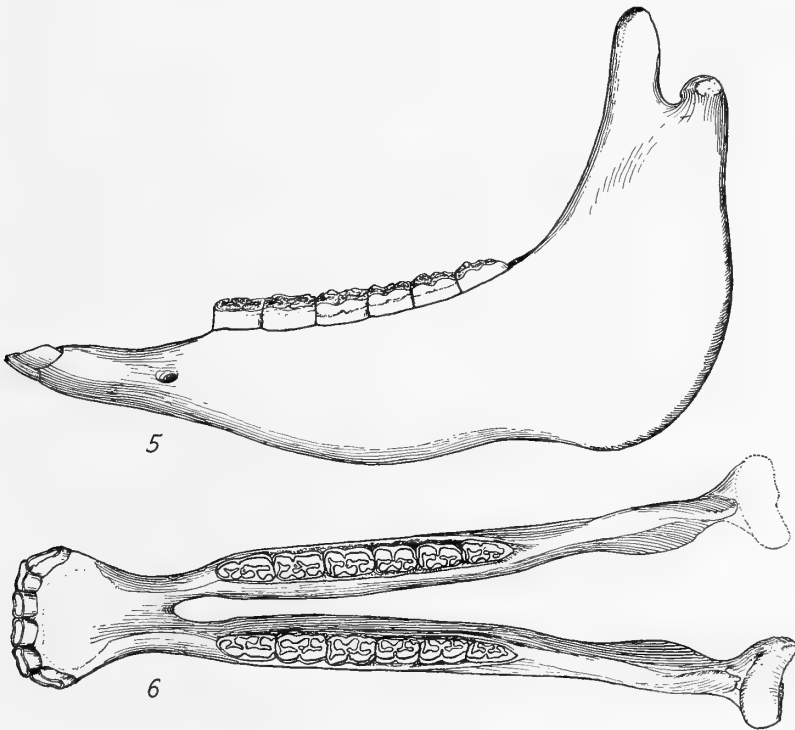


Fig. 4. *Equus occidentalis* Leidy. Posterior view of skull. No. 21002, $\times \frac{1}{5}$. Rancho La Brea Beds, California.

cheek-teeth and below the diastema. The symphyseal region is relatively wide. The mandible of a specimen (no. 21000), tentatively referred to *E. occidentalis*, shows unusual width



Figs. 5 and 6. *Equus occidentalis* Leidy(?). Mandible, no. 21000, $\times \frac{1}{6}$. Rancho La Brea Beds, California. Fig. 5, lateral view; fig. 6, superior view.

MEASUREMENTS OF SKULL

	<i>E. caballus</i>	<i>E. occidentalis</i> No. 20097 <i>a</i> Rancho La Brea	<i>E. occidentalis</i> No. 20098 <i>b</i> Rancho La Brea	<i>E. occidentalis</i> No. 19832 <i>c</i> Rancho La Brea	<i>E. occidentalis</i> No. 20099 <i>d</i> Rancho La Brea	<i>E. niobrarensis</i> Type	<i>E. laurentinus</i> Type
Anterior end of premaxillaries to posterior end of occipital condyles	568 mm.	555.	583.	589.	537.	556.	.....
Anterior end of premaxillaries to inferior margin of foramen magnum	538.	527.	555.	558.	507.	530.	481.
Anterior end of premaxillaries to a line connecting anterior border of second upper premolars	155.	121.	138.	136.	127.	137.	128.
Anterior end of premaxillaries to a line connecting posterior border of last upper molars	318.	312.	335.	313.	.....	.....	294.?
Anterior end of premaxillaries to a line connecting anterior border of orbits	344.	319.	345.	334.	305.	340.	293.
Anterior end of premaxillaries to a line connecting posterior border of orbits	391.	370.	417.	399.	364.	400.	.....
Least width across rostrum	58.3	71.8	68.8	75.5	60.6	.....	.....
Width of skull on maxillary ridge at maxillo-malar suture	188.	176.	184. <i>ap.</i>	190. <i>ap.</i>	158.	187.	.....
Greatest width across posterior border of orbits..	208.	218.	219.	227.	196.	240.	207.
Width between outer sides of second upper premolars	103.5	110.	115.3	113.1	99.3	.....	.....

MEASUREMENTS OF SKULL—Continued

	<i>E. caballus</i>	<i>E. occidentalis</i> No. 2007 ^a Rancho La Brea	<i>E. occidentalis</i> No. 2008 ^b Rancho La Brea	<i>E. occidentalis</i> No. 1983 ^c Rancho La Brea	No. 2009 ^d Rancho La Brea	<i>E. niobrarensis</i> Type	<i>E. laurentinus</i> Type
Width between outer sides of last upper molars....	126.5 mm.	119.6	123.	129.6	.....	123.	132.
Greatest anteroposterior diameter of orbits	57.5	63.	64.6	{ 60.9 <i>l</i> 69.7 <i>r</i> }	61.4	84.	65.
Height of occiput above base of occipital condyles	106.	111.	104.	127.8	127.	.....	.....
Least width of occiput below superior crest	69.5	81.5	56. <i>ap.</i>	72. <i>ap.</i>	72.	.....	.....
Greatest anteroposterior diameter of mandible measured along one ramus	44.5.	No. 2107 ² 404.	.....	458.	.....	.....	415.?
Anteroposterior diameter of symphysis	93.6	77.5	.....	97.3	.....	90.	85.
Least width of symphyseal region	40.	45.3	.....	46.8 <i>ap.</i>	.....	.....	.....
Height of mandible below anterior end of P ₂ , measured perpendicular to inferior border	50.	64.8	.....	71.7	.....	66. <i>ap.</i>	.....
Height of mandible below anterior end of M ₁ , measured normal to upper border	59.	87.4	.....	95.	.....	96. <i>ap.</i>	73.?

a Young adult, M³ in function; inner enamel ring of I¹ still present.

b Young adult, M³ slightly worn; inner enamel ring of I¹ still remaining.

c Old individual, molars well worn.

d Young individual, M³ just emerging.

ap. Approximate. *l*, left. *r*, right.

anteriorly. The inferior border is usually distinctly convex below the anterior cheek-teeth, and may show a slightly concave region below the posterior molars.

The anterior palatine foramina are situated much as in *E. caballus*. In some specimens they are relatively and absolutely shorter than in the domestic horse. The posterior palatine foramina are situated near the posterior end of M^2 in animals of middle age, and near the middle or anterior end of M^3 in old individuals. The palatine notch of the posterior nares is opposite the anterior half of M^2 in specimens of young adults, and extends forward approximately to a line joining the middle region of the second upper molars in individuals of advanced age. In *E. caballus* this opening is somewhat shorter and wider, and does not reach as far forward in the palate.

The infraorbital foramina are commonly situated in advance of the anterior end of the maxillary ridges and above P^3 . In no case do the maxillary ridges extend forward beyond the infraorbital foramina as may occur in some forms of *Equus*.

The mental foramina are approximately opposite the posterior end of the symphysis.

DENTITION

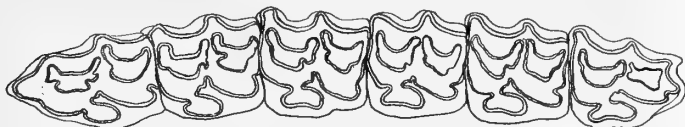
The dentition is represented by a series of specimens ranging from unworn milk teeth to those of old individuals in which the enamel folds of the fossettes and valleys have disappeared through wear. Variations in size and in enamel pattern of the cheek-teeth are considerable. There is, however, such a gradation in the teeth that there seems good reason for considering all of the specimens represented as a single species.

The incisors, where observed, are large. The lower incisors in no. 21000, an old individual, are especially wide. In none of the specimens available does the third lower incisor show evidence of formation of an inner fold or cup. The third upper incisor always shows a strongly marked cup.

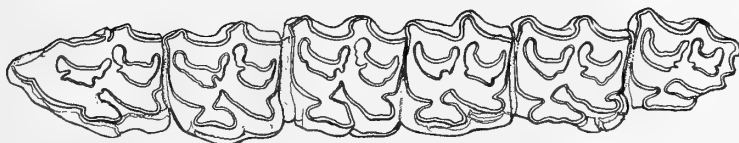
The canines are of moderate size compared with those of *Equus caballus*. In young individuals the crown shows distinct lateral compression.

In teeth of corresponding position in the upper cheek-tooth series there is considerable range in size. In general the variation falls within the limits which Gidley³ has shown to hold for modern *Equus caballus*. The variation in width of corresponding teeth between M² and P³ is commonly not more than two millimeters in individuals of approximately the same age. In the lower cheek-teeth there is also considerable variation in size.

As a rule the enamel pattern of the cheek-teeth is relatively simple compared with that of other described forms (figs. 7 and 8.) In some specimens there are noticeable variations from the



7



8

Figs. 7 and 8. *Equus occidentalis* Leidy. Rancho La Brea Beds, California. Fig. 7, superior dentition, no. 21001, $\times \frac{1}{2}$; fig. 8, superior dentition, no. 12269, $\times \frac{1}{2}$.

normal type of this species, but in no case is the enamel surrounding the fossettes as strongly folded as in *Equus pacificus*. Some of the principal variations in the pattern of the cheek-teeth are the following: (1) form of protocone; (2) form of post-protoconal valley; (3) position of the post-protoconal valley; (4) plication of the anterior border of prefossette and posterior border of postfossette.

Form and size of protocone vary considerably in the Rancho La Brea specimens. The anteroposterior diameter in M² runs from about 11 mm. in an old individual to 16 mm. in a young

³ Gidley, J. W., Bull. Amer. Mus. Nat. Hist., vol. 14, p. 102, 1901.

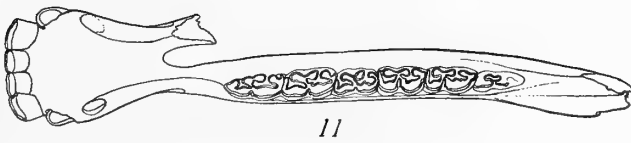
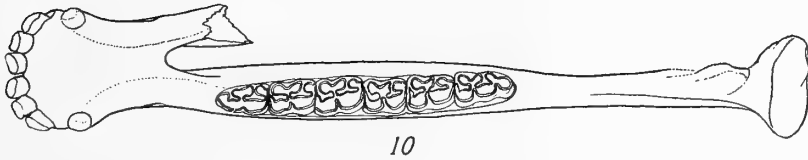
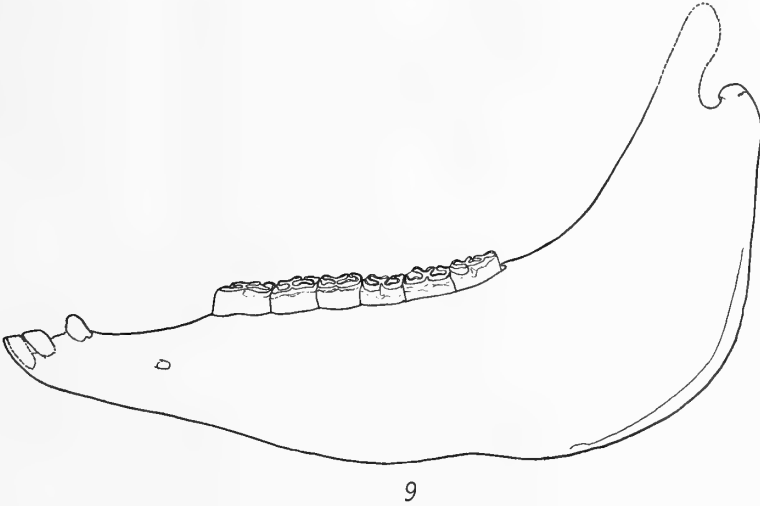
specimen. In general the protocone seems absolutely longer anteroposteriorly and narrower transversely in young individuals. It is shortest anteroposteriorly and thickest transversely in quite old individuals. Variation in stage of wear is probably in part responsible for the location of the longest protocone in one tooth rather than in another of the same series. The writer does not consider that variation in size or form of the protocone in the Rancho La Brea horses indicates the presence of more than one species.

In most specimens from Rancho La Brea the post-protoconal valley ends anteriorly with an oblique truncation, the truncated face being directed forward and outward. In a number of cases, particularly in young individuals, the enamel bordering the anterior end of the valley shows a single indentation. The fold is usually near the middle of the anterior end of the valley in P^3 and P^4 , but is commonly situated near the outer side of the anterior end in M^1 and M^2 . In individuals of fairly advanced age the fold is commonly absent. In aged individuals there is rarely a suggestion of the fold.

The position of the post-protoconal valley varies considerably with respect to the region of the tooth margin toward which the long axis of the valley points. In the molars the axis commonly points toward the inner or lingual half of the anterior border of the tooth, in P^3 and P^4 the anterior end is usually directed toward the outer half of the anterior side of the tooth. The position in P^3 and P^4 is referred to as erect, that in the molars as depressed. The difference in position is frequently related in part to difference in form of the protocone.

The anterior and posterior fossettes of the molars and premolars have in general relatively simple enamel borders compared with most Pleistocene horses of North America. There is quite uniformly a single clearly defined fold in the middle of the anterior side of the postfossette and one on the posterior inner region of the prefossette. A few minor wrinkles may also be present near the major folds just mentioned. On the anterior side of the prefossette there is often a single weak fold or indentation. This fold is usually strongest on the premolars and on M^1 , though it may be present on the other molars. The

anterior fold is generally absent in advanced stages of wear. On an individual with M^3 just coming into function it is absent or barely indicated on M^1 and M^2 , but is distinctly shown on



Figs. 9 and 10. *Equus occidentalis* Leidy. Mandible with dentition, no. 12269, $\times \frac{1}{5}$. Rancho La Brea Beds, California. Fig. 9, lateral view; fig. 10, superior view.

Fig. 11. *Equus occidentalis* Leidy. Mandible with dentition, no. 21002, $\times \frac{1}{5}$. Rancho La Brea Beds, California.

the last two premolars. On the posterior fossette a posterior indentation or fold is commonly present in young animals, but

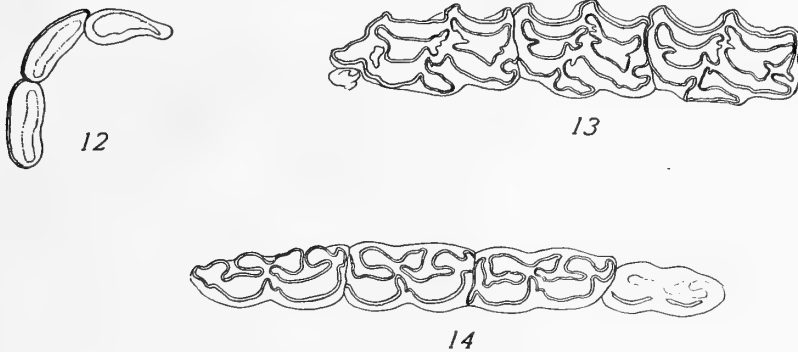
may be poorly developed. It is often most distinct on the premolars. Both the anterior fold of the prefossette and the posterior fold of the postfossette may, in rare cases, be accompanied by a few minor wrinkles.

In the upper cheek-teeth the external ribs formed by parastyle, mesostyle, and metastyle are very strong, but even in old individuals the mesostyle of the molars shows somewhat less flattening externally than in *E. caballus*.

The lower cheek-teeth (figs. 5, 6, 9, 10, 11) do not differ greatly from those of *E. caballus*. Compared with specimens of the domestic horse available, the Rancho La Brea form seems to have relatively narrower lower premolars, but measurements of other specimens of modern horses seem to indicate that this character may not show a constant difference. In the premolars the outer enamel fold between the protoconid and hypoconid is not produced between the anteroposterior folds separating the metaconid and metastylid from the protoconid and hypoconid. In the molars the inner end of the outer fold may extend between the two anteroposterior folds. Particularly in young specimens there may be a tendency to form a small secondary fold on the posterior side of the outer fold between protoconid and hypoconid. In some cases the anterior end of the anteroposterior fold between metastylid and hypoconid may show an indentation (fig. 6), and the enamel wall on the inner side of the hypoconid may show a slight crinkling. The groove between the metaconid and metastylid columns is well marked but wide. In general the characters of the lower teeth seem close to those of *E. niobrarensis*.

The *milk dentition* is well shown in several specimens. In the upper milk molars (fig. 13), the post-protoconal valley shows a light terminal indentation in specimen 20099, in which M^1 is just pushing through the jaw. In no. 19834, a slightly older specimen, the terminal indentation of the post-protoconal valley has almost disappeared. There is a single indentation at the anterior end of the anterior fossette, and one at the posterior end of the posterior fossette, in each of the cheek-teeth in both no. 20099 and no. 19834.

In the lower milk molars (fig. 14), the outer fold between the protoconid and hypoconid pushes farther in toward the middle of the tooth than in the permanent premolars. The small fold or jog on the posterior side of this outer fold is well marked. The small fold on the antero-external angle of Dm_4 is well shown.



Figs. 12 and 13. *Equus occidentalis* Leidy. Superior milk dentition, no. 20099, $\times \frac{1}{8}$. Rancho La Brea Beds, California. Fig. 12, temporary incisors; fig. 13, temporary molars.

Fig. 14. *Equus occidentalis* Leidy. Inferior temporary molars, no. 21072, $\times \frac{1}{2}$. Rancho La Brea Beds, California.

MEASUREMENTS OF DENTITION

Measurements of all cheek-teeth are made *exclusive of the cement*.

In the upper dentition, excepting in P^2 and M^3 , the anteroposterior diameter is measured along the middle of each tooth, between the principal anterior and posterior faces of contact with the adjoining teeth. In P^2 and M^3 the anteroposterior diameter is measured from the middle of the face of contact with the adjoining tooth to the extreme opposite limit of the tooth. In P^3 to M^2 the anteroposterior diameter does not include the anterior projection of the parastyle in advance of the principal anterior contact plane of the tooth. Transverse diameters are measured across from mesostyle to the innermost extent of the protocone.

In the lower cheek-teeth the anteroposterior diameter is measured as in the superior series, and includes the limits measured along the middle of the tooth. The transverse diameter of the lower cheek-teeth is the greatest diameter measured across the protoconid and metaconid excepting in P_2 . In P_2 the transverse measurement is across hypoconid and entoconid.

MEASUREMENTS* OF MILK DENTITION

	No. 20099 <i>a</i>	No. 19834 <i>b</i>	No. 21072 <i>c</i>	No. 19835 <i>d</i>
Dm ¹ , anteroposterior diameter	7.5 mm.	.....	.....	.....
Dm ² , anteroposterior diameter	50	48	.....	.....
Dm ² , transverse diameter	24.6	24.8	.....	.....
Dm ³ , anteroposterior diameter	34	33	.....	.....
Dm ³ , transverse diameter	26	26.5	.....	.....
Dm ⁴ , anteroposterior diameter	38	36.2	.....	.....
Dm ⁴ , transverse diameter	24.5	26.2	.....	.....
Di ¹ , greatest transverse diameter	22.9	.....	.....	.....
Di ² , greatest transverse diameter	25.8	.....	.....	.....
Di ³ , greatest transverse diameter	19.	.....	.....	.....
Dm ₂ , anteroposterior diameter .....	.....	.....	40	39.8
Dm ₂ , transverse diameter .....	.....	.....	14.2	14.8
Dm ₃ , anteroposterior diameter .....	.....	.....	34.	34.9
Dm ₃ , transverse diameter .....	.....	.....	14.5	16.2
Dm ₄ , anteroposterior diameter .....	.....	.....	37.2	34.6
Dm ₄ , transverse diameter .....	.....	.....	12.9	15.9
Di ₁ , greatest transverse diameter .....	.....	.....	.....	17.8
Di ₂ , greatest transverse diameter .....	.....	.....	.....	18.3
Di ₃ , greatest transverse diameter .....	.....	.....	.....	14.5

* Measurements taken in manner indicated in discussion on page 409.

a, M¹ just emerging through jaw.

b, M¹ erupting.

c, M₁ showing first traces of wear.

d, M₁ in function, M₂ erupting.

COMPARISON WITH EQUUS CABALLUS

The skulls of Rancho La Brea horses have approximately the size seen in the modern domesticated horse, but range upward to dimensions greater than those of the average domesticated horse. They differ from *Equus caballus* in the shorter and wider nose, more convex forehead, narrower occiput, and more massive lower jaw. The mandible is very noticeably higher below the premolars and the diastema.

The dentition of the Rancho La Brea species differs from that of *Equus caballus* in the more simple pattern of the enamel of the cheek-teeth. The dimensions do not differ markedly.

RELATIONSHIP TO PLEISTOCENE SPECIES OF WESTERN
NORTH AMERICA

In comparing the Rancho La Brea horses with the known Pleistocene species of America considerable difficulty is encountered, as the larger number of described forms are based upon very scanty material, usually cheek-teeth alone. Only three North American Pleistocene horses are known by skulls, and of these only *Equus scotti* is represented by more than one specimen. Of *Equus laurentius* there is one good skull, of typical *Equus niobrarensis* one specimen with imperfect facial and frontal region. It is probable that several of the American species of *Equus* which are considered distinct run near each other in skull characters, and until the approximate limits of variation are known in each, it will be difficult to make certain of specific distinctions.

Until the appearance of the important papers by Gidley⁴ on *Equus scotti*, and Hay⁵ on *Equus laurentius* and *Equus niobrarensis*, specific separation of American Pleistocene horses was based almost entirely upon characters of the cheek-teeth, and in a considerable number of species but little material was known. As has been shown by Gidley, horse teeth of the same stage of growth may vary markedly in size and pattern, and where various stages of wear are compared the range of difference is wide. As first noted by Gidley, the character of size, particularly as seen in the transverse diameter, of the cheek-teeth seems the most reliable.

While it is doubtless true that good specific differences appear in the enamel pattern of the cheek-teeth, it is certain that such characters must be used with caution. The final determination of the value of these characters must depend upon examination of considerable series of individuals of nearly the same age.

Relation to Equus occidentalis Leidy.—Typical horses of the genus *Equus* have been known fossil from California in two species represented by very fragmentary remains. The first form described, *Equus occidentalis* Leidy,⁶ was based upon a

⁴ Gidley, J. W., Bull. Amer. Mus. Nat. Hist., vol. 13, art. 13, 1900.

⁵ Hay, O. P., Proc. U. S. Nat. Mus., vol. 44 (no. 1969), 1913.

⁶ Leidy, J., Proc. Acad. Nat. Sc. Philad., 1865, p. 94.

specimen found in Pleistocene auriferous gravels at a depth of thirty feet below the surface in Tuolumne County, California. Better material from an asphalt bed near Buena Vista Lake in the southern end of the Great Valley of California was afterward referred to this species by Leidy⁷. The second species, *Equus pacificus* Leidy⁸, was based upon an upper premolar tooth from Martinez, California. Gidley⁹ recognizes this species as the common horse of the Pleistocene at Fossil Lake, Oregon. These two species have come to be well known in palaeontologic literature as representing the Pacific Coast horses, though relatively meagre information has been available concerning both forms.

The cheek-teeth from Tuolumne County, California, constituting Leidy's type of *Equus occidentalis* agree very closely in dimension and in enamel pattern with average specimens from Rancho La Brea. Considering that the typical *Equus occidentalis* occurs in approximately the same geographic region as the asphalt forms, there seems every reason to believe that the common horses from Rancho La Brea represent *Equus occidentalis*. The material from near Buena Vista Lake in the southern end of the Great Valley of California, which Leidy referred to *Equus occidentalis*, seems quite certainly to represent the same species as the specimens from Rancho La Brea.

In the table of measurements on p. 410, the dimension of Rancho La Brea specimens are shown in comparison with those of the type of *Equus occidentalis*.

Comparison with Equus pacificus Leidy.—The relation of the Rancho La Brea horses to the type described from Martinez, California under the name of *Equus pacificus* is not so easily determined as is their affinity to *E. occidentalis*. The type of *E. pacificus* as described by Leidy consisted of a single upper premolar three, which was not figured. The enamel is described as less simple than in the horses of the group referred to *E. occidentalis* of California, and there was stated to be an inflection

⁷ Leidy, J., *Extinct Mammalia of Dakota and Nebraska*, p. 267, 1869. Also *Geol. Surv. Terrs.*, vol. 1, p. 242, pl. 33, fig. 1, 1873.

⁸ Leidy, J., *Proc. Acad. Nat. Sc. Philad.*, 1868, p. 195.

⁹ Gidley, J. W., *Bull. Am. Mus. Nat. Hist.*, vol. 14, p. 116, 1901.

of the enamel at the anterior end of the post-protoconal valley. The tooth was characterized especially by its large size. The dimensions are compared with those of *E. occidentalis* in the table on p. 410. As is seen in the table of measurements, the largest specimens from Rancho La Brea approach the type of *E. pacificus* in dimensions. They are, however, quite different in average pattern of the enamel. Even the largest specimens from Rancho La Brea fall below the dimensions of Leidy's type of *E. pacificus*, and below Gidley's typical material from Fossil Lake. It is very doubtful whether any of the Rancho La Brea specimens thus far examined can be referred to *E. pacificus*. It is evident that the typical horses of Rancho La Brea are *E. occidentalis*.

Comparison with Equus excelsus Leidy.—The Great Plains species described as *Equus excelsus* by Leidy in 1858, from material obtained in Nebraska, approaches the California *E. occidentalis* very closely. In reviewing the species in 1869 Leidy¹⁰ stated that there was little doubt that *E. excelsus* and *E. occidentalis* were the same, and he united the two. In 1873 Leidy¹¹ referred to the two under the name of *E. occidentalis*. As pointed out by Gidley¹² the name *E. excelsus* really precedes *E. occidentalis*. Gidley suggests that the Nebraska form shows a tendency to more complicated enamel pattern of the cheek-teeth, and that it may be a relatively simple variation of a form normally with a much more complicated pattern than the typically simple teeth of the California *E. occidentalis*. Gidley also calls attention to the fact that *E. excelsus* and *E. occidentalis* were described from geographic stations widely separated, on opposite sides of the Rocky Mountain system. After weighing the evidence available, Gidley held it wisest to consider the two species as distinct.

Recently Hay¹³ has referred to *E. excelsus* additional material, and has discussed the relation of the species to *E. niobrarensis*.

¹⁰ Leidy, J., *Extinct Mammalian Fauna of Dakota and Nebraska*, p. 267, 1869.

¹¹ Leidy, J., *Geol. Surv. Terrs.*, vol. 1, p. 243, 1873.

¹² Gidley, J. W., *Bull. Am. Mus. Nat. Hist.*, vol. 14, p. 115, 1901.

¹³ Hay, O. P., *Proc. U. S. Nat. Mus.*, vol. 44 (no. 1969), p. 592, 1913.

With only meagre material representing the cheek-tooth dentition at hand, it seems futile to attempt to establish definitely the relationship of *E. excelsus* to the California *E. occidentalis*. It is certainly necessary to have a larger series of teeth, and it will probably be necessary to have good skull material before a satisfactory comparison can be made.

A character of the type of *E. excelsus* to which both Gidley and Hay have called attention is the position of the postpalatine foramina, which are unusually far forward, opposite the anterior half of M². In the Rancho La Brea skulls the postpalatine foramina range from a position opposite the middle of M³ in individuals of advanced age to a position opposite the posterior half of M² in individuals of middle age with all of the molars in function. The type of *E. excelsus* represents a young adult with M³ sufficiently worn to show the enamel pattern clearly. It is possible that the somewhat advanced position in the California form may be indicative of relationship to *E. excelsus*.

Comparison with Equus scotti Gidley.—Of the American Pleistocene horses known up to the present time *Equus scotti*, described by Gidley¹⁴, is the only form represented by more than a single skull. Unfortunately only one of several skulls obtained up to the time of Gidley's revision of the Pleistocene horses in 1901 was that of an adult in which all of the teeth had come into full use. The Rancho La Brea horses resemble *E. scotti* in being a large-headed form. They differ from *E. scotti* in the somewhat smaller cheek-teeth, less pronounced enamel folds around the fossettes and at the anterior end of the postprotoconal valley of the cheek-teeth, and possibly also in possessing a shorter and wider nose. Other differences will doubtless appear when the two species can be more fully compared.

Comparison with Equus niobrarensis Hay.—Hay's recently described species, *Equus niobrarensis*¹⁵, from Hay Springs, Nebraska, approaches the Rancho La Brea form closely in characters of skull and dentition. Both types have a heavy, short head, a heavy mandible, and a short, wide nose. The Rancho La Brea species differs slightly from *E. niobrarensis* in the

¹⁴ Gidley, J. W., Bull. Am. Mus. Nat. Hist., vol. 13, p. 111, 1900.

¹⁵ Hay, O. P., Proc. U. S. Nat. Mus., vol. 44 (no. 1969), p. 576, 1913.

shortness and width of nose, relative narrowness across the skull through the anterior region of the maxillary ridges, relative narrowness in superior view immediately in front of the inion, and smaller size of the orbits. The postpalatine foramina and the anterior end of the inferior nasal opening are somewhat farther forward in some specimens than in *E. niobrarensis*.

The cheek-teeth of the Rancho La Brea form are slightly larger than in *E. niobrarensis*, and the tooth row is in most specimens relatively longer. The relation of the tooth row to the basilar length in the type of *E. niobrarensis* is 33.8%. In no. 21002, a much older specimen, from Rancho La Brea, the proportion is 34.9%. In no. 20098 it is 36%.

As shown in the table of measurements on page 410, the average width of the cheek-teeth of the Great Plains form is somewhat less than in the average of the Rancho La Brea specimens. Unless the difference can be shown to hold for a large number of individuals it would hardly be considered of specific value. Between *E. niobrarensis* and the Rancho La Brea form there are certain small differences in the pattern of the enamel. In *E. niobrarensis* the folding of the enamel at the anterior and posterior borders of the fossettes, and at the anterior end of the post-protoconal valley is more pronounced, and in that species the anterior end of the post-protoconal valley is wider.

The relation of *E. niobrarensis* to the Rancho La Brea horses suggests a resemblance of the former species to *E. excelsus*. *E. excelsus* is apparently somewhat nearer to *E. niobrarensis* than is the California *E. occidentalis*. In a recent paper Hay¹⁶ has discussed the relationships of *E. niobrarensis* and *E. excelsus*, and considers them distinct. In Hay's paper a series of cheek-teeth referred to *E. excelsus* seems partly to bridge the gap between these two species, but other characters may still separate them.

The California *E. occidentalis* appears to be separable from *E. niobrarensis* by more simple pattern of the enamel of the cheek-teeth, and by several skull characters, no one of which seems, however, entirely reliable with the material available. The presumption is that these species are distinct, but it is

¹⁶ Hay, O. P., Proc. U. S. Nat. Mus., vol. 44 (no. 1969), p. 592, 1913.

very desirable to have more material of *E. niobrarensis* for a fully satisfactory comparison.

Comparison with Equus laurentius Hay.—A fine skull from supposed Pleistocene near Lawrence, Kansas, recently described by Hay,¹⁷ and designated as the type of a new species, *Equus laurentius*, represents a form quite different from the California *E. occidentalis*. The skull and teeth in *E. laurentius* are much smaller; the nose is relatively longer and narrower; the width behind the orbits is relatively greater; the mandible is much more slender, being narrower or lower below the premolars; the inferior border of the mandible is straight instead of sinuous as in *E. occidentalis*; the orbits seem to be relatively larger.

SUMMARY

The species of horse commonly represented in the Pleistocene beds of Rancho La Brea is not separable from *Equus occidentalis* first described by Leidy from Tuolumne County, California.

As represented by the excellent series of specimens from Rancho La Brea, *Equus occidentalis* is characterized by its large, heavy head, short and broad nose, high and heavy mandible, and relatively simple enamel pattern of the cheek-teeth.

¹⁷ Hay, O. P., Proc. U. S. Nat. Mus., vol. 44 (no. 1969), p. 584, 1913.

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BULLETIN OF THE DEPARTMENT OF

GEOLOGY

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NEW ANCHITHERIINE HORSES
FROM THE TERTIARY
OF THE GREAT BASIN AREA

BY

JOHN C. MERRIAM

UNIVERSITY OF CALIFORNIA PRESS
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NEW ANCHITHERIINE HORSES
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INTRODUCTION

Within the past two years, four expeditions from the University of California have visited the southern portion of the Great Basin region to search for vertebrate remains in Tertiary deposits. One party investigated the region southeast of Walker Lake, Nevada, in 1912, and three parties have worked in the Mohave Desert area in 1911, 1912, and 1913.

Of numerous palaeontologic contributions made by these expeditions, among the most interesting is the discovery of two anchitheriine horses presenting phases of structure or stages of development not previously known in the groups with which they are most nearly allied.

The first specimen found was obtained by Lawrence C. Baker in the Mohave Miocene of California in April, 1911. It represents the lower jaw of a form showing characters near those of both *Parahippus* and *Archaeohippus*. A fragmentary upper jaw, evidently belonging to an animal of the same species as that found by Mr. Baker, was discovered in the Mohave Beds by J. P. Buwalda and H. C. Mourning in January, 1913.

The second type of anchitheriine horse discovered is represented by a slab containing scattered parts of a skeleton obtained in the region southeast of Walker Lake, Nevada, by Baker and Buwalda in May, 1912. This specimen had previously been seen by Mr. T. H. Buck of Mina, Nevada. It was through the kindness of Mr. Buck that the slab was pointed out to Baker and Buwalda. The writer wishes to express his thanks for the kind assistance given by Mr. Buck in bringing the specimen to the railway station for shipment.

HYPOHIPPIUS (DRYMOHIPPIUS¹) NEVADENSIS, n. sub-gen. and n. sp.

Type specimen no. 21056, University of California Collections in Vertebrate Palaeontology. From the Stewart Valley Miocene, twenty-four miles northeast of Mina, Nevada.

Characters much as in *Hypohippus*, but metaloph of milk molars not connected with ectoloph.

The type specimen consists of a small portion of the skull with three milk molars, portions of all four limbs, and a number of scattered fragments of other skeletal parts. The elements of the limbs were in part connected.

Skull and Dentition.—The greater portion of the skull had been weathered away before the specimen was discovered. All that remains consists of a portion of the lower region of the cranium. Fortunately it was embedded in such a manner that it faced into the rock, and only the roots of the teeth were damaged. The portions of the cranium present show little of significance.

The dentition (figs. 1*a* and 1*b*) shows three well-preserved cheek-teeth. The incisors are not present. The cheek-teeth represent the milk dentition with Dm^4 just coming into function. They are referred to the milk dentition as they are relatively narrower than P^2 to P^4 of nearly related forms.

¹ δρυμός, wooded dell or glade; ἵππος, horse.

The teeth of no. 21056 represent an animal larger than any of the known forms of *Hypohippus*, but approaching in size *Hypohippus affinis*, the largest described species. They are absolutely larger than the permanent premolars of *H. osborni*, and larger than the milk molars of the type specimen of *H. affinis*. The excess in dimensions is evident in both the antero-posterior and transverse diameters.

COMPARATIVE MEASUREMENTS OF DENTITION

	Milk dentition		Permanent dentition	
	H. nevad- ensis No. 21056	H. affinis Type specimen	H. osborni	H. equinus
Dm ² , anteroposterior diameter along outer border	33 mm.	.....	P ² 27.3	25
Dm ² , greatest transverse diameter.	29	.....	P ² 26	25
Dm ³ , anteroposterior diameter along outer border	31.8	.....	P ³ 25.4	25
Dm ³ , anteroposterior diameter meas- ured through protoconule and hypostyle	29	.....	P ³ 24	22 <i>b</i>
Dm ³ , greatest transverse diameter.	30.5	.....	P ³ 30	27
Dm ⁴ , anteroposterior diameter along outer border	31.9 <i>ap.</i>	28.5 <i>ap.</i>	P ⁴ 30	25
Dm ⁴ , anteroposterior diameter meas- ured through protoconule and hypostyle .....	.....	26.7 <i>a</i>	P ⁴ 25	22 <i>b</i>
Dm ⁴ , greatest transverse diameter.	31.4	29	P ⁴ 30	26

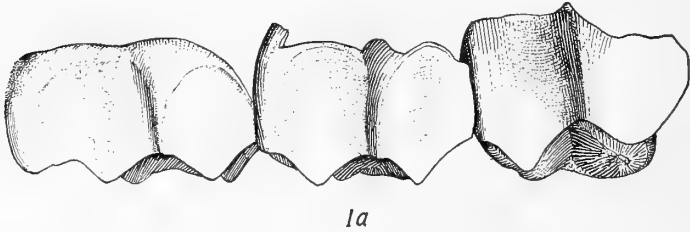
a, measurements from J. Leidy's figure of type specimen.

b, from W. B. Scott's figures of type specimen.

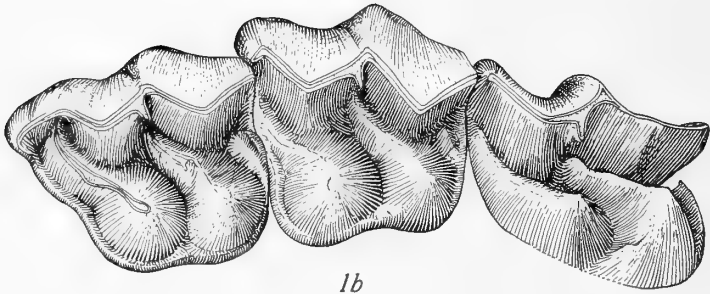
ap, approximate.

In form and pattern of the milk molars the Nevada specimen resembles in general the permanent dentition of *Hypohippus osborni*. The protoconule portion of the protoloph seems a little more distinctly marked off from the protocone in Dm² than in P² of *H. osborni*. In Dm³, however, the protoconule region of no. 21056 seems less distinct than in P³ of *H. osborni*. In Dm² of no. 21056 the longitudinal ridge or rib on the outer side of the paracone is much less distinct and the parastyle is more prominent than in P² of *H. osborni*. A small but distinct hypostyle is seen on Dm² and Dm³. The size of the hypostyle is near that in the premolars of *H. osborni*. On Dm² there is a strong

shelf of the cingulum extending around the anterior and inner sides and into the hypostyle region posteriorly. On Dm^3 the cingulum is faintly interrupted on the inner side opposite the middle of the protocone, and fully interrupted on the inner side of the hypocone.



1a



1b

Figs. 1a and 1b. *Hypohippus (Drymohippus) nevadensis*, n. sub-gen. and n. sp. Upper milk molars. No. 21056, natural size. Fig. 1a, lateral view; fig. 1b, oclusal view. Stewart Valley Beds, southwestern Nevada.

The principal difference between the Nevada specimen, no. 21056, and *Hypohippus osborni* is found in the separation of the outer end of the metaloph from the ectoloph. In none of the milk molars of the Nevada specimen is the summit of the outer end of the metaloph connected with the ectoloph. In Dm^2 and Dm^3 the base of the metaloph barely reaches the base of the ectoloph. In Dm^4 the base of the metaloph scarcely reaches the base of the ectoloph. In each of these teeth there is a small transverse ridge or tubercle pointing inward from the ectoloph at the posterior end of the paracone crescent. This transverse

prominence arising from the ectoloph extends inward near the outer end of the metaloph but fails to meet that ridge. The outer end of the metaloph tends to swing a little in front of the inner transverse prominence of the ectoloph.

The inner transverse prominences arising from the ectoloph attain their greatest elongation or height near the summit of the ectoloph, and rapidly diminish in height as they extend toward the base of the tooth. On Dm^4 the transverse prominence consists of two small tooth-like projections. On the longer or lower of these points the diameter, parallel with the height of the tooth crown, is not more than twice the anteroposterior diameter. The second projection, situated farther toward the base of the ectoloph, is an exceedingly small tubercle. The smaller projection does not reach the bottom of the valley between metaloph and metacone crescent. On Dm^3 the inner transverse prominence of the ectoloph is very small, and is situated near the crest of the ectoloph. On Dm^2 the prominence is higher, but is reduced rapidly at the proximal end and does not connect with the metaloph.

A certain significance may attach to the situation of the inner transverse ridge of the ectoloph. In the milk teeth of the Nevada form, this transverse crest or ridge rests upon the posterior end of the paracone crescent. In a permanent upper molar (no. 11570) of *Hypohippus* from the Middle Miocene of Virgin Valley, Nevada, the connection between metaloph and ectoloph is established at the posterior end of the paracone crescent. In the cheek-teeth from P^2 to M^3 in *H. osborni* the inner transverse ridge of the ectoloph arises almost exactly at the junction of the paracone and metacone crescents. In no. 12564, a very narrow *Hypohippus* tooth from the Virgin Valley Miocene of northern Nevada, the union of metaloph and ectoloph seems to be as in *H. osborni*. In the original reference to tooth no. 12564 the writer suggested² that this form might represent a species distinct from no. 11570, which is much wider anteroposteriorly and shows the more anterior position of the inner transverse ridge of the ectoloph.

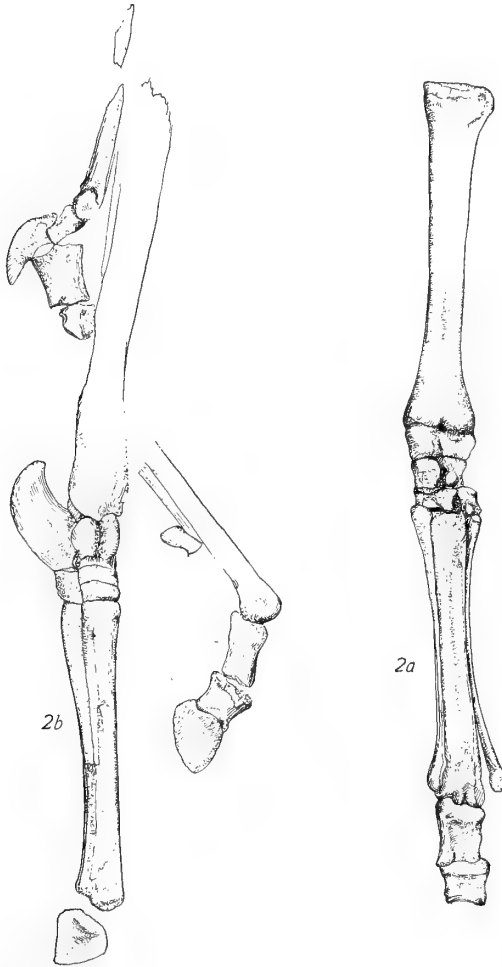
² Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, pp. 259 and 260, 1911.

The separation of metaloph and ectoloph as noted in the milk teeth of specimen no. 21056 is a matter of considerable interest in the classification of the Equidae. In *Mesohippus* the metaloph and ectoloph are separate, and a small transverse ridge or wrinkle may arise from the inner side of the ectoloph in the same situation as that in the milk teeth of the Nevada specimen, no. 21056. In *Miohippus*, as represented by specimens from the John Day series, the metaloph is usually separated from the ectoloph. In *Anchitherium*, *Hypohippus*, and *Archaeohippus* the metaloph is completely united with the ectoloph. The stage of advance of the cheek-teeth in the Nevada specimen, no. 21056, is near that of *Miohippus* so far as the relation of the metaloph to the ectoloph is concerned, and in this character it differs from the known forms of *Anchitherium*, *Archaeohippus*, and *Hypohippus*. In general form of the cheek-teeth and in the relation of protocone to protoconule, specimen no. 21056 is of the *Hypohippus* type. In *Mesohippus*, *Miohippus*, *Archaeohippus*, and *Anchitherium*, the protocone and protoconule are distinctly separated, in *Hypohippus* and in the Nevada specimen the protoconule is small, and is almost completely merged with the protocone.

As the teeth in specimen no. 21056 correspond so closely to the general type of cheek-teeth in *Hypohippus*, the hypothesis that the milk molars of typical *Hypohippus* might show the primitive character of the Nevada specimen naturally suggested itself. Leidy's type of *Hypohippus affinis*, the typical species of that genus, is a milk tooth, but the specimen shows no suggestion of separation of metaloph and ectoloph. It is slightly worn, but a corresponding degree of wear in Dm^4 of the Nevada form would not tend in any way to connect metaloph and ectoloph. Dr. W. D. Matthew, who has very kindly examined such milk teeth of *Hypohippus* as are present in the collections of the American Museum of Natural History, finds that in all of the specimens the metaloph and ectoloph are connected.

The Nevada form represented by specimen 21056 seems, therefore, to represent a type with dentition in general close to that of *Hypohippus*, but distinguished especially by the less advanced stage of evolution of the metaloph in the temporary molars.

Limbs.—Portions of both the anterior and posterior limbs (figs. 2a and 2b) exhibit some of the essential characters, but parts of each of the feet had been carried away before burial, or had been destroyed by weathering before the specimen was found. The general character and proportions of the parts of the extremities preserved are near those of *Hypohippus*. The



Figs. 2a, 2b, and other fragments. *Hypohippus* (*Drymohippus*) *nevadensis*, n. sub-gen. and n. sp. Portions of limbs. No. 21056, $\times \frac{1}{5}$. Fig. 2a, anterior limb; fig. 2b, posterior limb. Stewart Valley Beds, southwestern Nevada.

lateral digits and their ungual phalanges are relatively large, and were evidently functional. The first and second phalanges of the median digit are relatively shorter and wider than in the *Merychippus* forms of the Miocene. The ungual phalanx of the median digit is broad, and the lateral wings show a stage of development at least as advanced as in *Hypohippus*. Metacarpal three shows a distinctly oblique lateral facet for articulation with the unciform. In metatarsal three there seems to be a very small and quite oblique facet for the cuboid. In general the limb structure resembles that of *Hypohippus*.

MEASUREMENTS OF LIMB ELEMENTS

Radius, greatest length of shaft	241	mm.
Radius, least width of shaft	25	
Metacarpal II, greatest length	190	
Metacarpal III, greatest length	192	
Metacarpal III, width of distal end, approximate	28.5	
Phalanx I, digit III of anterior extremity, greatest length.....	40	
Phalanx I, digit III of anterior extremity, greatest width.....	30	
Phalanx II, digit III of anterior extremity, greatest length.....	30	
Phalanx II, digit III of anterior extremity, greatest width.....	31	
Metatarsal III, greatest length	203.	
Metatarsal IV, greatest width at proximal end	17	
Phalanx I, lateral digit (hind foot?) greatest length along superior side	23.5	
Phalanx III, lateral digit (hind foot?) length along superior side	35	

Relationships.—The form represented by the Nevada specimen, no. 21056, resembles *Hypohippus* in the characters of the limbs and in the general form of the cheek-teeth. It differs from *Hypohippus* in the separation of metaloph and ectoloph in the milk dentition. It is uncertain whether the permanent dentition of this species is represented in any of the collections from the Great Basin region. A difference in tooth characters comparable to that separating this species from typical *Hypohippus* is ordinarily considered as of generic value. In this particular case, the total characters, so far as known, indicate that the species is much nearer to *Hypohippus* than to any other group, and excepting the separation of metaloph and ectoloph is not

clearly distinguished from that genus. Viewed from the most unfavorable angle, the gap between this form and typical *Hypohippus* seems less than the spaces between other anchitheriine genera. The writer has therefore tentatively included this species in the *Hypohippus* group, with the suggestion of incipient separation indicated in the subgeneric distinction. The new subgenus, *Drymohippus*, proposed to include this form, bears the characters of *Hypohippus* excepting in the separation of metaloph and ectoloph in the milk dentition. Later investigations may add other distinctive characters.

PARAHIPPUS(?) MOURNINGI,³ n. sp.

Type specimen no. 19840, a portion of a maxillary with milk dentition and M¹. Paratype, a portion of a mandible, no. 19764, with dentition representing P₂ to M₂. Both specimens from the Mohave Miocene, Mohave Desert, California.

A portion of a lower jaw with dentition (figs. 5a and 5b) obtained by Mr. Baker in 1911 was recognized by the writer as representing a horse with characters near *Parahippus* and *Hypohippus*, but with size and stage of evolution suggesting *Archaeohippus*. The specimen differed, however, from the only lower jaw material referred to *Archaeohippus* in several characters, and especially in the absence of the strong internal cingulum shown on teeth referred to *Archaeohippus* by Gidley.⁴ In January, 1913, a second specimen, a maxillary (fig. 3) with Dm³ Dm⁴, and M¹, representing a very small brachyodont horse, was obtained in the Mohave region by Buwalda and Mourning, and again the resemblance to the genera *Parahippus*, *Hypohippus*, and *Archaeohippus* appeared. An approximation of the dimensions of the cheek-tooth series, as well as a comparison of individual teeth, shows that the upper and lower jaw specimens represent animals of very nearly the same size. The similarity of dimensions, considered with similarity of relationship to other forms and similarity of occurrence, leaves little room

³ This species is named in honor of Mr. H. S. Mourning, through whom the first specimens from the Mohave region came into the writer's hands.

⁴ Gidley, J. W., Bull. Amer. Mus. Nat. Hist., vol. 22, p. 385, 1906.

for doubt that the two jaws represent the same species.

The species represented by specimens 19840 and 19764 seems distinct from any form thus far described. In spite of its fragmentary nature, the upper jaw specimen is selected as the type, as the characters of the superior cheek-tooth series seem more significant in discussion of the relationships.

Upper Cheek-teeth.—In the specimen representing the upper jaw (fig. 3), the well-preserved, unworn, inner portion of M¹ offers good opportunity for examination of certain distinctive characters of this form. In this tooth the metaloph is fully united with the ectoloph. The protoconule is distinctly separate from the protocone, it is considerably elongated and flattened,

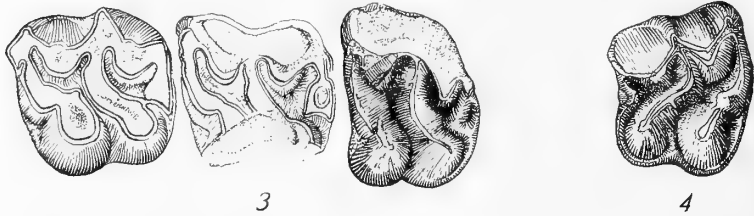


Fig. 3. *Parahippus(?) mourningi*, n. sp. Dm³, Dm⁴, and M¹. No. 19840, × 1½. Mohave Miocene, Barstow Syncline, Mohave Desert, California.

Fig. 4. *Archaeohippus ultimus* (Cope). Upper molar. No. 1689, × 1½. Middle Miocene, Mascall Beds, Eastern Oregon.

and its inner end slightly overlaps the protocone. The hypostyle is larger than in *Hypohippus* and *Archaeohippus*, and there is a more distinct cup-like depression behind it. There is no suggestion of a crochet, though several plate-like projections arise from the anterior side of the outer end of the metaloph. The cingulum is well developed on the posterior side, and less distinctly on the anterior side between protocone and protoconule. There is no shelf of the cingulum on the inner or lingual side of the tooth. The cusps or ridges of the crown are somewhat higher than in *Archaeohippus* or in *Hypohippus*. The surface shows a degree of rugosity more pronounced than seems characteristic of *Hypohippus* or of *Archaeohippus*. No trace of cement is evident upon the crown.

The crowns of the milk molars of the Mohave specimen were apparently somewhat shorter and slightly rougher than those of the permanent molars. As in the permanent dentition, the milk molars show the metaloph connected with the ectoloph, there is no internal or lingual shelf of the cingulum, and the hypostyle is large. On one of the milk molars there is a faint suggestion of crinkling of the anterior side of the outer end of the metaloph. A P² from the Mascall Miocene considered by Gidley to represent *Archaeohippus* differs from the milk molars of the Mohave specimen in showing much greater development of the longitudinal ribs on the outer side of the paracone and metacone. There is a very faint longitudinal rib on the outer face of the paracone in Dm³ of the Mohave specimen. A longitudinal rib is barely perceptible on the outer side of the metacone of this tooth.

MEASUREMENTS		Archaeo- hippus ultimus	Archaeo- hippus ultimus
	No. 19840	Type specimen	No. 1689
Dm ³ , greatest anteroposterior diameter	13 mm.	P ³ 12	.....
Dm ³ , transverse diameter	13.8	P ³ 16	.....
Dm ⁴ , greatest anteroposterior diameter.....	13.7	P ⁴ 13	.....
Dm ⁴ , transverse diameter	a 14.5	P ⁴ 17	.....
M ¹ , anteroposterior diameter measured along middle of crown	13.7	M ¹ 11	.....
M ¹ , approximate transverse diameter meas- ured along anterior border	a 16	M ¹ 15	.....
M ³ , anteroposterior diameter measured along middle of crown .....	.....	11	11
M ³ , transverse diameter along anterior border .....	.....	14	14.8

a, approximate.

The form of the cheek-teeth shown in the upper jaw of no. 19840 differs from *Hypohippus* in the greater height of the crown, larger protoconule and metaconule, larger hypostyle, and more abrupt inner wall of protocone and hypocone. From *Archaeohippus* no. 19840 differs in its somewhat higher, more rugose crown; larger, more compressed protoconule; much larger hypostyle with posterior cup; and absence of internal cingulum. From typical *Parahippus* the Mohave specimen differs in absence

of the crochet, and in its small size. The Mohave form seems to be distinguished from *Anchitherium* by relatively smaller size of the protocone and absence of internal cingulum.

Lower Cheek-teeth.—The lower jaw specimen, no. 19764, (figs. 5a and 5b) represents a form which in size is near *Miohippus*. The cheek-teeth are brachyodont, without evidence of cement covering. The crowns of the molars and premolars are slightly rugose, and tend to be somewhat higher than in the average *Hypohippus*.



5a



5b

Figs. 5a and 5b. *Parahippus(?) mourningi*, n. sp. P₃ to M₂. No. 19764, natural size. Fig. 5a, occlusal view; fig. 5b, outer side. Mohave Miocene, Barstow Syncline, Mohave Desert, California.

P₄ is considerably larger than M₁ in both anteroposterior and transverse diameter. The metaconid and metastylid show a distinct tendency to separate at the summit, the separation being more marked than in typical *Hypohippus*, and less advanced than in typical *Parahippus*. The entostylid is well developed. The cingulum is well shown on the anterior and posterior sides of the crown, but shows no distinct shelf on the outer and inner sides.

This specimen represents an anchitheriine horse smaller than any known to the writer from post-Oligocene horizons, excepting *Archaeohippus*. It is in some respects intermediate between *Hypohippus* and *Parahippus*. As *Archaeohippus* also represents a small form more advanced than *Hypohippus* and less advanced

than *Parahippus*, it might be suspected that the Mohave species is allied to it.

The only known material representing the lower jaw of *Archaeohippus* available for comparison consists of two fragmentary specimens from the Mascall Miocene, the typical horizon of that genus. This material was referred to *Archaeohippus* by Gidley.⁵ The principal specimen is a piece of a lower jaw with P³ and P⁴, and the roots of P¹ and P². The teeth present are unfortunately much worn, and the nature of the cusps cannot be determined. The important characters shown are the dimensions of the premolars, and the well-developed internal basal cingulum on the molariform teeth. It seems probable that Gidley's reference of the lower teeth from the Mascall to the genus *Archaeohippus* is correct, as these teeth resemble the typical upper teeth in the presence of a basal cingulum, just as the lower teeth from the Mohave Beds resemble the upper teeth from that region in the absence of cingula excepting at the anterior and posterior ends.

The dentition of specimen 19764 differs from the lower teeth referred to *Archaeohippus* by Gidley in the absence of external and internal cingula, and apparently also in the proportions of the premolars.

The form represented by the lower jaw, no. 19764, shows a general resemblance to *Hypohippus*, but differs in its slightly higher and more rugose crowns, more clearly marked incipient separation of metaconid and metastylid columns, and absence of external basal cingulum.

The lower jaw differs from typical *Parahippus* in the very weak separation of the metaconid and metastylid columns, and in the absence of cement from the crowns. The separation of metaconid and metastylid in no. 19764 shows but little advance beyond the stage seen in the dentition of a *Hypohippus* specimen from Virgin Valley.⁶ In none of the cheek-teeth of no. 19764 are metaconid and metastylid pillars separated on the inner side by more than a faint groove at the summit.

⁵ Gidley, J. W., Bull. Amer. Mus. Nat. Hist., vol. 22, p. 385, 1906.

⁶ See Gidley, J. W., Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 236, fig. 1, 1908.

The character of the dentition in the lower jaw specimen, no. 19764, does not agree fully with any of the described genera. It is intermediate between *Hypohippus* and *Parahippus*, and evidently approximates *Archaeohippus* in many respects. So far as the stage of evolution is concerned, the Mohave form would seem to come fairly near *Parahippus*. It shows elongation of the crown, the lateral cingulum is reduced, and there is clearly defined incipient division of the metaconid and metastylid pillars.

	MEASUREMENTS	Archaeo-hippus ultimus No. 1700
Length, anterior side of P ₃ to posterior side of M ₂	No. 19764 60 mm.	.....
P ₂ , approximate anteroposterior diameter	16	11.5
P ₃ , approximate anteroposterior diameter	15.8	12
P ₃ , transverse diameter across hypoconid	10.5	9.8
P ₄ , anteroposterior diameter	15	.....
P ₄ , transverse diameter across hypoconid	10.5	.....
M ₁ , greatest anteroposterior diameter	13.6	.....
M ₁ , transverse diameter across protoconid	9	.....
M ₂ , greatest anteroposterior diameter	13.6	.....
M ₂ , transverse diameter across protoconid	8.5	.....

Relationships.—The upper and lower jaw specimens (nos. 19840 and 19764) from the Mohave region resemble each other in a number of important particulars. Their similarity in structure, and their occurrence in the same region give a reasonable assurance that they represent the same type. The two specimens show similarity in the following characters: (1) height of tooth crowns; (2) rugosity of enamel; (3) absence of cingulum on the protocone side; (4) stage of development, as seen in separation of metaconid and metastylid, in increase of size and compression of the protoconule, in complication of the metaloph, and in increase of size in hypostyle. The stage of evolution in the two specimens shows about equal advance beyond the dentition of *Hypohippus*.

As has been suggested for the two specimens considered separately, the form represented by them shows resemblance to *Hypohippus*, *Archaeohippus*, *Parahippus*, and *Anchitherium*. It is in general more advanced than *Hypohippus*. Its habit and

stage of evolution are near *Archaeohippus*, from which it is distinguished in the upper molariform teeth by absence of cingula on the protocone side, by higher cusps, and by a slightly more advanced stage of development of the protocone and hypostyle, though the metaloph is not more advanced in the Mohave form. From the imperfectly known lower teeth of *Archaeohippus* it is distinguished by the absence of external cingula, and evidently also by proportions of the premolars. The absence of cingula on the protocone side of both upper and lower molars may have some significance in considering the stage of evolution, or may concern only the matter of immediate relationship.

The Mohave type represented by specimens no. 19840 and 19764 is evidently related to *Parahippus* in most characters, though distant from the typical form. The absence of a crochet in the upper teeth, and the very slight separation of metaconid and metastylid columns in the lower teeth, indicate a relatively undeveloped stage. Whether this form is too primitive to be included in *Parahippus* will be determined most clearly when better material is available for study.

Some significance may attach to the fact that this form, having a certain resemblance to *Parahippus*, but being relatively primitive, occurs in strata which were presumably deposited in a later period than the time of maximum development of the genus *Parahippus*. On the other hand, the Mohave form, being somewhat more advanced than *Archaeohippus* in most respects, and occurring in strata presumably younger, might be considered a product of modification from *Archaeohippus*. It is interesting to note that in the development of the crochet, in which one would expect advance, the Mohave form is more primitive than the Middle Miocene *Archaeohippus*.

The Mohave type strongly suggests *Anchitherium*, from which it seems to be separated by its slightly larger protoconule, separation of metaconid and metastylid columns of the lower teeth, and reduction of the cingulum on the outer side of the lower cheek-teeth and inner side of the upper cheek-teeth. *Anchitherium* is, moreover, doubtfully represented in America. *Anchitherium(?) zitteli* of China approaches the Mohave form in certain characters, but seems clearly separable.

The relationships of the interesting form from Mohave seem almost to require the establishment of a distinct group to give to this species such a position in the classification as will clearly indicate its true affinities. It could be assigned tentatively to a place with *Archaeohippus*, as an advanced stage with protoconule and hypostyle more progressive, cingulum of the protocone side absent, and complication of the metaloph not more advanced. It could be referred to *Parahippus*, as a primitive stage with crochet undeveloped, though the metaloph shows secondary folding, and with metaconid and metastylid in beginning separation. The reference of this form to one of the described genera depends somewhat upon the extent to which the limits of these groups may be expanded by later studies. A reference to *Parahippus* is apparently open to fewer definite objections than a reference to *Archaeohippus*.

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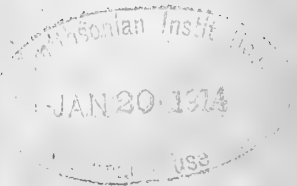
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NEW PROTOHIPPIE HORSES FROM
TERTIARY BEDS ON THE WESTERN
BORDER OF THE MOHAVE DESERT

BY

JOHN C. MERRIAM

UNIVERSITY OF CALIFORNIA PRESS
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INTRODUCTION

Investigation of the Tertiary mammal-bearing beds in the Mohave Desert, carried on by the Department of Palaeontology of the University of California within the past three years, has brought to light collections of unusual interest in two localities. One station is in the Barstow Syncline, north of Barstow, California, and near the middle of the desert. The other locality is in the El Paso Range on the extreme western border of the desert.

The greater part of the Tertiary mammal collection obtained in the Mohave region has come from exposures in the Barstow Syncline. The fauna obtained in these exposures has been reported by the writer¹ as evidently representing a stage near

¹ Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, p. 169, 1911.



Upper Miocene. The representatives of the horse group known from the Barstow Syncline include at least three forms: a *Merychippus* of advanced type, near *M. calamarius*; a large form near *Hypohippus*; and a recently described species near *Parahippus*.² The association of Equidae, now known from the typical Mohave Beds north of Barstow, seems to bear out the original suggestion that these strata are near Upper Miocene in age.

The fauna from the beds at El Paso Range contains some elements which are quite distinct from those of the Barstow region. Remains of horses are only fairly represented, but such forms as are present seem to represent a different fauna from that found in the Mohave Beds of the Barstow Syncline.

At least two types of horses are known from the beds in the El Paso Range. One group closely approaches the characters of the Old World *Hipparion*, and may include two species. The other type approximates *Protohippus*, and possibly includes two species. It is doubtful whether typical *Merychippus* is represented, and remains of *Hypohippus* and *Parahippus* have not been certainly recognized.

The general aspect of the representatives of the Equidae found in El Paso Range is that of a fauna distinctly later than that of the Barstow Syncline, and approximating very late Miocene or early Pliocene.

HIPPARION(?) MOHAVENSE, n. sp.

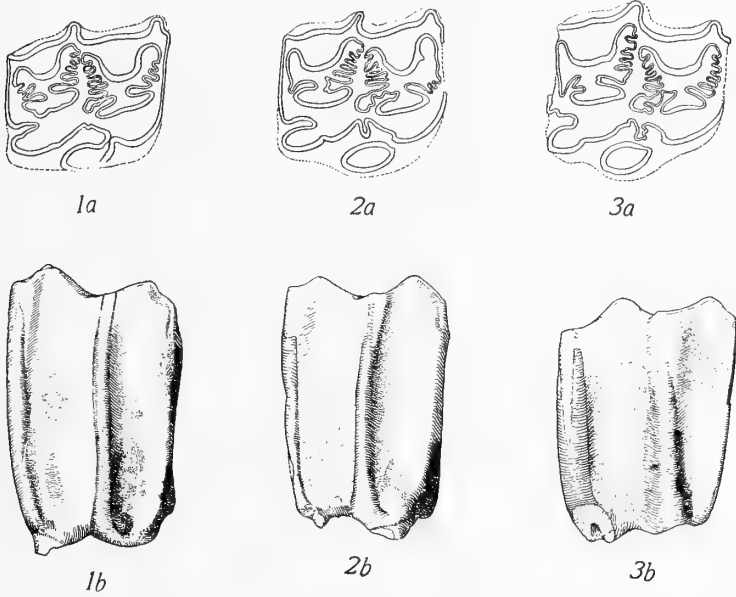
Type specimen no. 19787, an upper premolar three with two associated upper cheek-teeth, and several lower teeth presumably from the same individual. From the Ricardo Beds, in the El Paso Range, north of Mohave, California.

Crowns of upper molars nearly straight; protocone small, separate from protoconule and nearly circular in cross-section; enamel of the fossettes very strongly crinkled; mesostyle of nearly uniform width.

The crowns of the upper molars are nearly straight, or but slightly curved, and not greatly elongated. In the type material (figs. 1a to 3b), in which the enamel plications are very strong, the length of the crown measures about one and one-half times the transverse diameter. In other specimens, evidently but little worn,

² Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, p. 427, 1913.

the height of upper cheek-tooth crowns may equal about twice the transverse diameter. The transverse diameter of the anterior molars and posterior premolars about equals or slightly exceeds the anteroposterior diameter. The cement layer is well developed on the outer and inner sides. The parastyle and mesostyle are prominent. The external rib formed by the mesostyle is especi-



Figs. 1a to 3b. *Hipparion(?) mohavense*, n. sp. Upper cheek-teeth. No. 19787, natural size. Late Tertiary near Ricardo, California. Figs. 1a and 1b, M²; fig. 1a, occlusal view; fig. 1b, outer view. Figs. 2a and 2b, M¹; fig. 2a, occlusal view; fig. 2b, outer view. Figs. 3a and 3b, P³; fig. 3a, occlusal view; fig. 3b, outer view.

ally strong on the premolars. It narrows very gradually from the base. The middle region of the outer sides of the paracone and metacone crescents is flat, but may show a slight tendency to formation of a median rib.

The small protocone is free almost to the base in most specimens. In cross-section it is nearly circular or is slightly elongated anteroposteriorly. The walls of the anterior and posterior fossettes show unusually numerous plications. The posterior wall of the pefossette and the anterior wall of the

postfossette are each thrown into six or more short folds. The anterior wall of the prefossette also exhibits very marked plications. The posterior wall of the postfossette shows at least one strong fold.

The upper cheek-teeth do not closely resemble those of any West-American species known to the writer. In some respects they show more similarity to *Neohipparion plicatile* of the Florida Pliocene than to most of the western species. The general form of the teeth, the small, round protocone, the very complexly folded enamel of the fossettes, and to some extent the detailed pattern of the enamel folds in the Mohave form are strikingly similar to the expression of corresponding characters of the Old World *Hipparion* species. It may be noted in this connection that the American form *N. plicatile*, with which the Mohave form has been compared, is considered by Gidley³ as representing a group differing in some respects from other American species and possibly belonging to an American branch of the Old World *Hipparion*.

In dimensions and in general form the Mohave species is very near to *Hipparion richthofeni* of China and to the typical *H. gracile* of Europe. The Mohave form seems distinguishable from *H. gracile* by somewhat larger size, a more distinct tendency to lateral compression of the protocone, slightly wider mesostyle ribs, and possibly by very small differences in the folding of the enamel walls of the fossettes.

The resemblance of *H. mohavense* to *H. richthofeni*, as that species is figured by Schlosser,⁴ is very close. In the California form the dimensions, cross-section of protocone, and most details in the enamel pattern match closely the corresponding characters of the Chinese species. There are small differences suggesting separation; as in the tendency of the small fold of the inner enamel wall opposite the protocone to show two or more subdivisions in most specimens of *H. richthofeni*, while in the Mohave specimens the fold is commonly simple; and according

³ Gidley, J. W., Bull. Amer. Mus. Nat. Hist., vol. 23, p. 905, 1907.

⁴ Schlosser, M., Säugethiere Chinas, Abh. Munich Akad., Math-Ph. Classe, Bd. 22, Taf. 4, 1903-6.

to the measurements given by Schlosser there is a suggestion that the upper molars of *H. richthofeni* are slightly longer than in the Mohave species.

The Mohave form differs from *Hippodactylus antilopinum* of India in the more clearly rounded enamel folds, and the longer enamel fold on the inner wall opposite the protocone. It differs from *Hipparion theoboldi* in its smaller size.

Several lower cheek-teeth associated with the upper teeth constituting the type specimen of *Hipparion mohavense* are presumably a part of the type specimen. The lower teeth are long-crowned, but do not appear to have been unusually long previous to wear. The antero-internal column formed by the metaconid and metastylid is long anteroposteriorly, and is divided on the medial side by a deep, wide longitudinal furrow. The enamel folds show a tendency to form secondary plications, especially on the inner side of the parastylid ridge, and on the anterior side of the hypoconid pillar. The small, sharp fold common on the antero-external angle of the protoconid is seen in several specimens.

The form of the lower teeth is near that of certain of the specimens of *Hipparion richthofeni* figured by Schlosser⁵ and by Koken.⁶ The enamel folds in *H. richthofeni* are possibly a little more pronounced, and the crowns a little longer, but the discernible difference appears small.

An upper cheek-tooth closely resembling the Mohave species is known from the Coast Range region of California. This specimen was recently referred to *Hipparion* or *Neohipparion* by the writer.⁷ It is interesting to note that a suggestion of relationship of this tooth to *Hipparion richthofeni* was made by Gidley in correspondence in 1904. The tooth had, however, been labeled *Neohipparion*, and the recent reference to *Hipparion* by the writer was presumed at the time the determination was made to be at variance with that expressed by Gidley.

⁵ *Op. cit.*, Taf. 4.

⁶ Koken, E., *Palae. Abh.*, Bd. 3, Taf. 4, 1885.

⁷ Merriam, J. C., *Univ. Calif. Publ. Bull. Dept. Geol.*, vol. 7, p. 376, and figs. 3a and 3b, p. 375, 1913.

MEASUREMENTS OF No. 19787

	P ³	M ¹	M ²
Anteroposterior diameter	22 mm.	21.4	21.6
Transverse diameter	23	22	20
Height of crown	32+	32+	37

HIPPARION(?), sp.

Two moderately worn premolars (no. 19770) representing a *Hipparion* form somewhat larger than the type of *H. mohavense* show enamel folds bordering the fossettes in general like those of *H. mohavense*, but less pronounced and more simple. The difference does not appear to be due entirely to age, and this form may represent a species of *Hipparion* distinct from *H. mohavense*.

A P² (no. 19438) may be the same as *H. mohavense* or may be a distinct species. The enamel plications seem less complex than in *H. mohavense* and are more acute.

MEASUREMENTS

No. 19770

P ⁴ , anteroposterior diameter	25.5 mm.
P ⁴ , transverse diameter	24
P ⁴ , height of crown	30

No. 19438

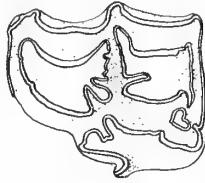
P ² , anteroposterior diameter	26
P ² , transverse diameter	20.7
P ² , height of crown	30

PROTOHIPPIUS(?) TANTALUS, n. sp.

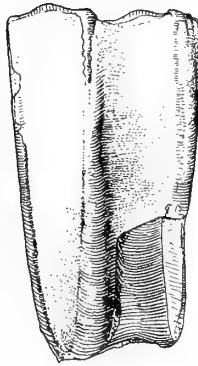
Two large upper cheek-teeth (nos. 19434 and 21221) from the El Paso Range differ from the *Hipparion* forms in the united protocone and protoconule, curved crown, and large wide fossettes with crinkling of the enamel limited to their adjacent borders. The outer styles are heavy and narrow noticeably above the base (figs. 4a and 4b).

These specimens seem certainly different from any referred to *Hipparion mohavense* or allied species. They possibly repre-

sent a type related to *Neohipparion*, but are probably to be included in *Protohippus* or *Pliohippus*. Several much worn upper molars from the Ricardo region seem clearly of an advanced *Protohippus* or *Pliohippus* type, and may represent the same species as the type of *P. tantalus*.



4a



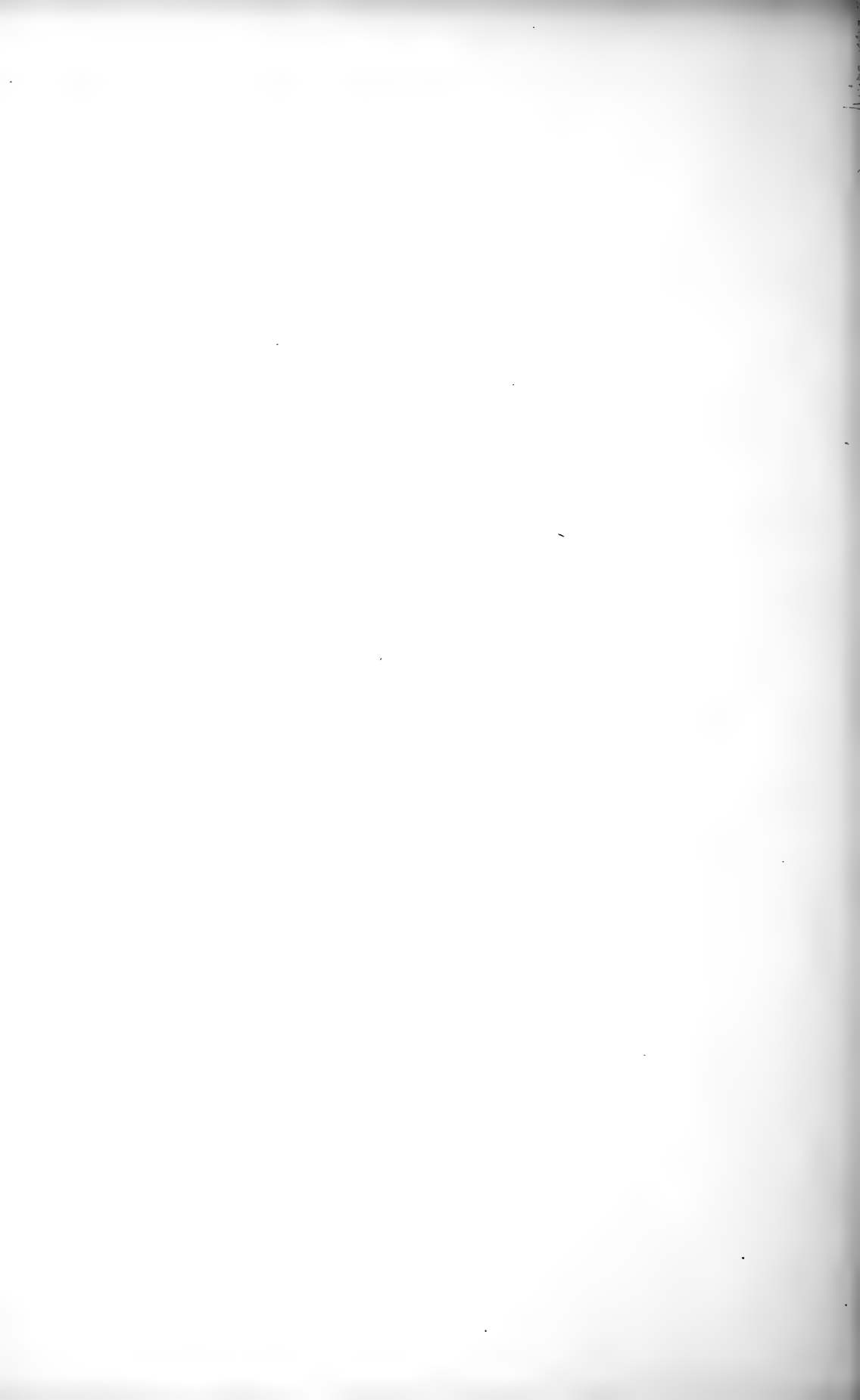
4b

Figs. 4a and 4b. *Protohippus(?) tantalus*, n. sp. · P⁴(?). No. 19434, natural size. Late Tertiary near Ricardo, California. Fig. 4a, oclusal view; fig. 4b, outer view.

MEASUREMENTS OF NO. 19434

P ⁴ ?, anteroposterior diameter	24.8 mm.
P ⁴ ?, transverse diameter	24
P ⁴ ?, height of crown	48

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PLEISTOCENE BEDS AT MANIX IN THE
EASTERN MOHAVE DESERT
REGION

BY

JOHN P. BUWALDA

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INTRODUCTION

While engaged in the collection of fossil vertebrate material in the eastern Mohave Desert region for the Department of Palaeontology of the University of California, the writer examined a series of Pleistocene mammal-bearing lake beds, which appear to have been deposited in the latest period of deformation in that region. Excellent exposures of the beds occur along



the Mohave River two miles southeast of Manix; the name *Manix Beds* is therefore proposed for them. The Pleistocene lake in which they were deposited will be referred to as Manix Lake.

The Manix Beds were brought to the attention of the writer by Mr. H. S. Mourning of Los Angeles, who had learned of the occurrence of vertebrate fossils in this formation from Mr. John T. Reed of San Bernardino. The writer is indebted to Professor John C. Merriam for the opportunity of engaging in the examination and for subsequent advice and criticism.

No reference to Pleistocene lake-beds in this region has been found in the literature. Some of the ranges surrounding the basin containing the Manix beds have, however, received some attention from geologists. Lindgren,¹ Storms,² Campbell,³ Keyes,⁴ Baker,⁵ and others have studied the geology of the Calico Mountains to the west, and Storms⁶ has published a brief account of the gold-bearing rocks of the Alvord Mountains to the north.

The geologic results offered in this paper are to be considered as of no more than reconnaissance value, inasmuch as a large part of the time spent in the region was occupied in searching for vertebrate fossils in the lacustral beds.

GENERAL GEOGRAPHIC AND GEOLOGIC FEATURES OF THE REGION

The Manix Lake basin lies about 120 miles northeast of Los Angeles, and twenty to forty miles east of Barstow, California. It is traversed by the lower course of the Mohave River, an intermittent stream which rises on the higher, less arid north slopes of the San Bernardino Mountains. After leaving the mountains

¹ Lindgren, Waldemar, The silver mines of Calico, California, *Trans. Am. Inst. Min. Engineers*, vol. 15, pp. 717-734, 1887.

² Storms, W. H., Report on San Bernardino County, in 11th Ann. (1st Biennial) Report of the State Mineralogist, Calif. State Min. Bureau, pp. 337-369, 1893.

³ Campbell, M. R., Reconnaissance of the Borax Deposits of Death Valley and Mohave Desert, U. S. Geol. Surv., Bull. no. 200, pp. 12-13, 1902.

⁴ Keyes, C. R., Borax deposits of the United States, *Trans. Am. Inst. Min. Engineers*, no. 34, pp. 867-903, 1909.

⁵ Baker, C. L., Notes on the later Cenozoic History of the Mohave Desert Region in Southeastern California, *Univ. Calif. Publ. Bull. Dept. Geol.*, vol. 6, no. 15, p. 349-353, 1911.

⁶ Storms, W. H., *loc. cit.*

the river runs northward along the eastern side of the relatively flat Mohave Desert for about forty miles to Barstow, and there turns eastward, entering a region of higher ranges. Its usually dry lower course reaches a point north of Scott on the Salt Lake railroad, fifty miles east of Barstow, where a playa lake receives and evaporates such of its flood waters as are not lost by evaporation en route in the extremely dry desert climate. This region of the lower Mohave River is an area of broad valleys and of rather bold ranges, which rise above the valleys one to three thousand feet. In its relief, climate, vegetation, and general physical aspect the region has the characteristics of the Great Basin, of which in reality it forms a part.

In the discussion of the rocks three divisions will for convenience be recognized: (1) the pre-Pleistocene rocks which form the floor and walls of the basin occupied by Manix Lake in Pleistocene time, (2) the Pleistocene fanglomerates underlying the Manix Beds, and (3) the Manix Beds of lacustral origin.

PRE-PLEISTOCENE GEOLOGY

The pre-Pleistocene formations are of diverse ages and characters.

West of the Manix Lake basin lie the Calico Mountains (pl. 22), formed in part of the Rosamond Series, which consists of upper Miocene tuff-breccias, tuffs, coarse land-laid granitic deposits, sandstones, limestones, and clays resting on rhyolite and overlaid unconformably by a later lava flow. The rhyolite is said to rest on granitic rocks.

To the north lie the Alvord Mountains, Dunn Mountain, and Cave Mountain. The core of the Alvord Mountains consists of coarse granitic rock, presumably Mesozoic or older, in which lie patches of limestone, marble, and schist; the mass is cut by numerous pegmatitic, aplitic, and basic dikes. On the eroded surface of the granite lies a series of basic lavas, presumably of middle Tertiary age. These are overlaid in turn, apparently conformably, by at least several hundred feet of very coarse, granitic detritus. The structure of the eastern end of the Alvord Mountains is anticlinal with an east-west axis, but farther west it is

possible that the south front represents a degraded fault scarp. East of the Alvord Mountains lies the well-rounded dome of Dunn Mountain, the mass of which appears to consist largely of schist. East of Dunn Mountain rises Cave Mountain. Through the south flank of this imposing granitic massif the Mohave River leaves the Manix Lake basin by a gorge cut in part in volcanics which overlie the granite. South of the Mohave River and east of the Manix Lake basin stand the Cady Mountains, of the geology of which little more was learned than that basic volcanics occur in the higher parts and that rhyolites with well-developed east-west slaty structure, probably of early Tertiary age, are present along the western flanks near Camp Cady. A patch of the older granite also is exposed in this vicinity. South of the Pleistocene basin the Kane Mountains rise abruptly. Lavas occur on their flanks and Campbell⁷ describes beds which are probably Rosamond extending eastward toward this locality from a point south of Daggett.

PLEISTOCENE FANGLOMERATES

The initial stage in the history of accumulation in the Manix Lake basin was the transportation of large quantities of coarse, more or less angular rock-waste from the surrounding ranges, to be deposited at lower levels. The character of these waste deposits indicates their alluvial-fan origin and therefore the term "fanglomerates" has been applied to them in accordance with the meaning of that term as defined by Professor Andrew C. Lawson.⁸

A fault near Field, and downcutting by the Mohave River, with consequent backcutting by side gulches, have been the principal means of exposing to view both the fanglomerates and the Manix Beds.

The fanglomerates were deposited on the lower range slopes as well as on the valley areas, and are of greater areal extent than the overlying horizontally deposited lacustral beds of Manix

⁷ Campbell, M. R., Reconnaissance of the Borax Deposits of Death Valley and Mohave Desert, U. S. Geol. Surv., Bull. no. 200, p. 12, 1902.

⁸ Lawson, A. C., The Petrographic Designation of Alluvial Fan Formations, Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, no. 15, pp. 325-334, 1913.

Lake. East of Afton the Mohave River has cut into what was the east rim of the Manix Lake basin to a depth of perhaps two hundred feet; the fanglomerates are there seen to arch over the core of older rocks of this anticlinal barrier and to dip down the east slope and disappear under the later fan deposits of the desert to the east.

The maximum thickness of the fanglomerates was not determined. From the sections exposed it is known to aggregate at least several hundred feet.

The fanglomerates are in general characterized by coarseness and variety of constituent materials and by lack of distinct bedding. The upper one or two hundred feet lying immediately below the lacustral beds is commonly of somewhat finer texture than the lowest visible strata. There is abundant and sudden variation in texture both horizontally and vertically throughout the section, as would be expected in an accumulation of waste-slope origin.

Along the north bank of the Mohave River, south of Field, the lowest visible fanglomerates are made up of coarse angular and subangular masses, commonly one to three feet in diameter, consisting of granite, basic lava, rhyolite, schist, limestone, and quartz, with little semblance of bedding. A part of the section at this point consists entirely of black lava fragments of large size.

In the upper part of the exposed section the fanglomerate consists of an abundance of angular and subangular fragments enclosed in a yellow matrix. The fragments are basic and acidic lavas and granite, ranging up to two or three inches in diameter. The matrix is made up largely of quartz and feldspar grains derived from the disintegration of granitic rocks. The whole deposit exhibits the indistinct and irregular bedding commonly seen in alluvial deposits. Some of the uppermost fine fanglomerate beds two miles south of Field can be traced laterally into the coarser materials of the alluvial fans which extend up the west slopes of the Cady Mountains. Some strata are composed almost entirely of pink feldspar and quartz; other thin layers are unevenly bedded sands, probably of wind-blown origin. Well-rounded river gravel is apparently absent from the fanglomerate

section, as are also fine materials similar to playa lake deposits. The very coarse fanglomerates lack matrix and are but little cemented. The more finely textured upper members are commonly sufficiently indurated to permit erosion into a gullied topography with steep fluted walls.

Where the fanglomerates can be observed lying on the older rocks—plutonics and pyroclastics—as east of Afton, the surface upon which they rest is one of erosion and often has considerable relief. It is not known what relation in time this erosion interval has to the development of the Ricardo erosion surface, which truncates the folded late Miocene strata of the Mohave Desert fifty to one hundred miles to the west, as described by Baker.⁹

PLEISTOCENE LACUSTRAL BEDS

Areal Extent.—The Manix Beds cover an area of irregular outline, measuring twenty to twenty-five miles in length, and of not less than two hundred, perhaps more than three hundred, square miles extent. (See pl. 22.)

The southeastern limits of the lake-beds are not definitely known. To the south they extend nearly to the flanks of the Kane Mountains. To the west the deposits reach almost to Kouns. To the northwest their limits are not certainly determinable, but beds of similar aspect and containing similar molluscan shells are reported by Mr. S. H. Gester to occur along the west flanks of the Alvord Mountains. To the north the Manix Beds are known to extend to the foot of the waste slopes stretching southward from the base of the Alvord Mountains; farther east the northern border of the beds bends around the south end of the ridge on which Field is located, and passes along the south front of Dunn Mountain and the west face of Cave Mountain.

The limits of the beds to the northeast are significant. The underlying fanglomerates, because of deformation, arch over the older rocks just east of Afton, but the lacustral beds are limited to the west side of the arch. The eastern edge of the deposits

⁹Baker, C. L., *Physiography and Structure of the Western El Paso Range and the Southern Sierra Nevada*, Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, no. 6, pp. 137-139, 1910.

rests for the most part on the gently sloping alluvial fans of the Cady Mountains. Near Camp Cady the Manix Beds rest against steep rhyolite slopes. It is improbable that the original area and thickness of the Manix Beds have been materially reduced by erosion.

Physical Characters.—Arenaceous clays and fine argillaceous sands constitute the bulk of the Manix Beds. Both are of light grayish green color. Quartz, feldspar and mica particles are the abundant coarser constituents; the particles are imperfectly rounded. In a part of the clays and sands there occur occasional grains of feldspar and quartz one-eighth to one-quarter inch in diameter, representing the little modified disintegration products of granitic rocks. Of equal persistence with the sand and clay strata are a few thin members which consist entirely of similar partially rounded grains. Such strata are decidedly cross-bedded. Excepting a little gypsum occurring locally as veins in the clays and sands, there is no trace of calcareous or other precipitates so commonly interstratified with Cenozoic lacustral deposits in the Great Basin region.

The most notable characteristic of the Manix Beds is the striking evenness, persistence, and parallelism of the individual strata. In such areas as that several miles southeast of Manix no irregularity of stratification is apparent in a view showing two to three miles of practically horizontal beds. The individual strata commonly show little lamination. The differences which distinguish different layers are principally those of slight variation in coarseness of materials or in shades of color. (See pl. 23.)

The upper part of the lake-beds is usually separated from the lower by several feet of relatively coarse material, presumably indicating a short period of contraction or dessication of the lake and fluvial deposition of coarser, more highly oxidized yellowish material. Except for this interruption the beds apparently record a period of continuous deposition.

Besides the evidence afforded by the remarkably even and persistent bedding, the fine texture, and the green deoxidized condition of the sediments, further proof of the lacustral origin of the Manix Beds lies in the abundance at more than one horizon of fresh-water organisms. Fish vertebrae and four species of

fresh-water mollusks occur at several horizons in the beds. Shallowness and the gradual lowering of the lake level probably explain the scarcity of marked features such as beaches, wave-cut terraces and sea cliffs. A well-defined pebbly beach is, however, reported by Mr. W. L. Moody to occur west of Cave Mountain.

The Manix Beds are but slightly consolidated, and the back-cutting from the Mohave River develops on them a subdued type of bad-land topography with smooth slopes. As exposed along the Mohave River between Kouns and Afton, they nowhere exceed about seventy-five feet in thickness. Their greatest thickness is between Field and Afton. The beds thin out gradually toward the west. (See fig. 1.)

Stratigraphic Relations.—The bedding planes of the uppermost fanglomerates and those of the Manix Beds are very nearly parallel. Since the former are alluvial deposits and the latter lacustral sediments, exact parallelism of bedding planes would hardly be expected. The approximate parallelism of the two sets of beds and the apparent evenness of the waste-slope surface on which the first lake deposits were laid down indicates that alluviation, and not erosion, was the dominant process on the fan surfaces at the beginning of deposition of the lake-beds, and therefore that the

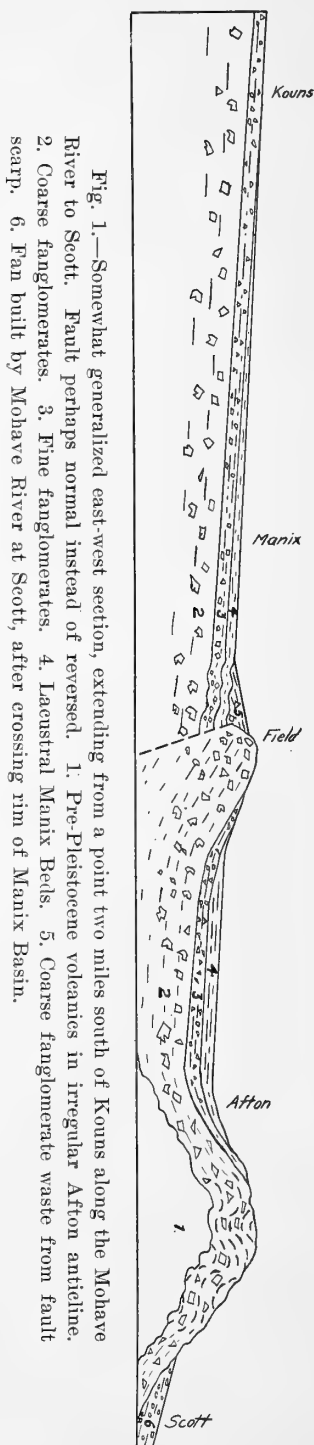


Fig. 1.—Somewhat generalized east-west section, extending from a point two miles south of the Mohave River to Scott. Fault perhaps normal instead of reversed. 1. Pre-Pleistocene volcanics in irregular Afton anticline. 2. Coarse fanglomerates. 3. Fine fanglomerates. 4. Lacustral Manix Beds. 5. Coarse fanglomerate waste from fault scarp. 6. Fan built by Mohave River at Scott, after crossing rim of Manix Basin.

youngest fanglomerates belong to a time immediately preceding that of lacustral deposition.

About seventy-five feet of coarse fanglomerate is reported by Messrs. Moody and W. F. Jones to overlie the Manix Beds on the flanks of the Cady Mountains south of Afton. Where the unflexed beds abut against the steep slopes of the Cady Mountains one to two miles east of Camp Cady, perhaps twenty-five feet of later fanglomerate overlies the beds. As Manix Lake was at few points bordered by steep slopes and the downcutting of the Mohave River in this region has influenced the tributaries to cut rather than to deposit, the accumulation of fan materials upon the Manix Beds has not been extensive.

Fauna.—The fossil material collected from the Manix Beds represents six species of mammals, one or more species of birds, four species of freshwater molluscs, and one or more species of fish. Of this fauna the mammals, because of their short range in geologic time, are the most important in age determinations. The six forms comprise a large horse quite certainly *Equus.*, a somewhat smaller horse, a large camel, a smaller camel, a mastodon or an elephant, and an antelope, the latter two each known by a single digital element. The fauna is considered by Professor J. C. Merriam to be of Pleistocene age. The stage of the Pleistocene represented by the fauna is, however, difficult to determine because of the paucity of species, and lack of knowledge regarding the dates of extinction of the forms represented. Because of the supposition that camels became extinct in North America before Glacial time, the fauna may represent an early stage of the Pleistocene.

DEFORMATION OF THE FANGLOMERATES AND LACUSTRAL BEDS

Deformative movements of considerable magnitude occurred in the Manix Lake region just before the appearance of Manix Lake, and again shortly after the deposition of the lake-beds.

The evidence of pre-lacustral folding is seen in the somewhat irregular anticlinal arching of the fanglomerates on a north-south axis passing through Cave Mountain and the Cady Moun-

tains. The fanglomerates are believed to be but slightly older than the Manix Beds. That this deformation was pre-lacustral in date is shown by the limitation of the lake-beds to the west side of this anticlinal divide. Further, the presence of beds of extremely coarse, unworn, undecomposed material, with little admixture of fine fragments, at some horizons in the fanglomerate series indicates that the slopes bordering the basin were steepened during the deposition of the fanglomerates. These coarse deposits are in sharp contrast with the deposits of gentle slopes, which are finer and contain only occasional large rock masses. The Manix Beds near Afton are tilted gently to the west and north, due apparently to continued arching along the north-south anticlinal axis mentioned above. The absence of embankments composed of well-rounded fluvial material within the narrow valley cut in the lake-beds by Mohave River above the point where it crosses the arched rim of the basin at Afton, probably indicates that no sudden uplift has occurred along this axis since the Mohave commenced cutting into the lake beds. Such an uplift across its path would suddenly lower the river gradient and cause the stream to deposit embankment materials in its valley for a certain distance above the barrier.

A bold east-west scarp which is traceable for about two miles rises along the north bank of the Mohave south of Field (pl. 24, fig. 2). While the most striking part of the scarp has been cut back and emboldened by the undercutting of the Mohave, its general extent marks a fault of perhaps one to two hundred feet displacement in the fanglomerates and Manix Beds. Near the west end of the escarpment the lake-beds and the fine fanglomerates immediately underlying them may be seen dipping northward at a low angle into the coarse older fanglomerates, which have been upthrown and likewise dip to the north (fig. 1). The lake-beds and underlying fanglomerates are gently contorted where they dip into the fault. Three-fourths of a mile eastward down the Mohave River there is exposed a nearly vertical plane of contact between the coarse older fanglomerate and the finer material; it is perhaps not the main fault-plane (pl. 24, fig. 1). Where the Mohave crosses the escarpment still farther down stream the coarse fanglomerates dip gently northward, with the

overlying finer fanglomerates on the north flanks dipping in the same direction and disappearing under the nearly horizontal lake-beds. The absence of remnants of the lake-beds on the upper back slopes of the upthrown block may indicate that some of the displacement occurred in pre-lacustral time, and that much of the upthrown block was not covered by the lake waters. The areal relations, dip, and folding of the lacustral beds at the west end of the scarp plainly indicate post-lacustral movement (pl. 25, fig. 1).

Whether the fault is of the normal or of the reversed type cannot be stated with certainty. The gentle contortion of the lake-beds and younger fanglomerates, where they dip into the fault at the west end of the scarp, suggests compression and faulting of the reversed type. The contact plane referred to above dips seventy-five degrees northward under the older fanglomerates, but whether its attitude is evidence as to the type of faulting is uncertain.

The degradation of the scarp and the wide breach cut across it by Mohave River indicate the lapse of considerable time since the faulting. While it is not possible to estimate accurately the length of time, the faulting perhaps occurred not long after the extinction of the lake. It may be that the faulting and the pre-lacustral folding represent a single deformative period beginning in pre-lacustral, and extending into post-lacustral, time.

The flat surface of the lake-beds about Manix is believed to represent nearly the top of the lacustral deposits except where slightly modified by one or two washes and by wind-blown sand. That this is not a flood plain developed by Mohave River below the upper surface of the lake beds is indicated by the absence of well-rounded fluvial material on the present surface, and the absence of terrace remnants of a higher surface about the sides of the basin. Railroad levels indicate that this plane surface has been tilted ten or twelve feet per mile to the east in the vicinity of Manix; in a north-south direction the surface is practically level. A thin accumulation of quartz and feldspar grains, left behind when the upper few inches of the soft containing lake-beds were blown or washed away, invariably covers this undissected surface.

No evidence of movement in Recent time was noted in the region. Three river terraces cut on the fanglomerates and extending along the Mohave near the fault south of Field are, to the eye, parallel with the present river bed. No accumulations of rounded gravels are found on these terraces. It is believed that their formation was due to inequalities in the rate of lowering of the local base level, controlled by the downcutting through the barrier below Afton. Terraces formed by accumulation of rounded gravels, which might indicate slackening of stream gradient through deformation, are apparently absent.

MODE OF ORIGIN AND CAUSE OF DISAPPEARANCE OF MANIX LAKE

Mode of Origin.—Manix Lake came into existence as the result of the ponding of waters furnished principally by Mohave River. Unless the climate of the region was much less arid in Manix Lake time than it is today, it required a stream of considerable size to support this lake during the entire year against the drain of two hundred or more square miles of evaporating surface and sufficient overflow to keep the lake water fresh. This stream must have headed in an area of much greater precipitation than occurs in this desert region. The attitude of the lake-beds indicates that, in this immediate region, topographic conditions have not changed so greatly since Manix time as to suggest the possibility that some stream other than the Mohave was the source of the water. Other than the Mohave there exists, moreover, no notable stream in the region.

If the absence of rounded gravel in the twenty-five-mile section of fanglomerates exposed by Mohave River in the Manix Lake basin indicates that this stream did not pass through the region in pre-lacustral time, it is quite possible that its entrance into the basin was effected simply by the lengthening of its lower course in a direction determined by the relief. The Mohave is a stream which derives its waters from the higher parts of the San Bernardino Mountains and wastes away in the dry desert. Such extension of this stream might be the result either of increased water supply due to uplift of the San Bernardino Mountains, or the extension may have been the result of the greater general

precipitation, which is supposed to have characterized the climate of glacial time. Regarding the latter possibility, it is of interest also that the Manix Lake deposits apparently record two periods of lake expansion with an intervening period of lake contraction or dessication. This is presumably caused by two periods of relatively abundant water supply separated by a period of relatively slight precipitation. These conditions are a parallel to the two periods of expansion and the intervening period of contraction or dessication believed by Russell to have obtained in Lake Lahontan; this lake is considered to have existed during the glacial period. Another possibility is that Manix Lake was formed by the turning of the Mohave River into this basin as a result of the deformation which the land surface underwent just previous to the Manix Lake time. The possibilities above considered, so far as they relate to Manix Lake, cannot in our lack of more detailed knowledge, be considered more than conjectures.

If the course of the Mohave River lay across this territory in pre-lacustral time, it seems probable that the initiation of lacustral conditions came about through the uplift across its path of such barriers as the irregular anticline east of Afton, through which the river has since cut a cañon.

Disappearance of the Lake.—At the point of outflow over the rim of the basin east of Afton the Mohave undoubtedly lowered its channel with comparative ease through the fanglomerates arching over the older rocks. Its downcutting in the underlying, more resistant rocks undoubtedly proceeded more slowly, however, and it is a notable fact that the lake-beds were deposited approximately up to the level of the top of the older rocks where these underlying formations are exposed in the section along the Mohave just east of Afton. In this locality the river has cut its channel downward at least seventy-five feet in these more resistant rocks (pl. 25, fig. 2).

During the existence of the lake its level gradually fell as its outlet was lowered by downcutting. Simultaneously the level of the accumulating sediments gradually rose. When the falling level of the lake and the rising level of the sediments met, the lake became extinct. Further downcutting has slowly lowered the local base level of the Mohave and enabled it to trench the

lake deposits for twenty-five to thirty miles above the resistant rim. The stream is undoubtedly still cutting in its narrow vertical-walled gorge through the hard rocks, and meanwhile it has locally widened its trench in the unresistant lacustral beds and fanglomerates above the gorge to a width of a half mile or more, as at Camp Cady.

EVIDENCE OF CLIMATIC CHANGE IN THE MANIX REGION IN PLEISTOCENE TIME

The quantity of water brought to the Manix region by the Mohave River of today is in striking contrast to the supply furnished by that stream during Manix Lake time. The present-day Mohave River is dry throughout much of its lower course during most of the year, and its spasmodic floods yield only sufficient water to fill temporarily a playa lake of small area compared to that occupied by Manix Lake deposits. The playa lake is reported to be dry all but a few days or weeks of each year. The Mohave River of Manix Lake time afforded water for the two hundred or more square miles of continually evaporating surface of Manix Lake, with sufficient overflow for the lake to retain its freshness. The mean annual flow of the Mohave River has apparently greatly decreased.

It is improbable that such causes as diversion of headwater tributaries of the Mohave or decrease of altitude influencing precipitation of the San Bernardino Mountains watershed brought about the lessened flow. The decreased flow apparently indicates a decrease in the general precipitation of this and adjoining regions since Manix Lake time. What relation such change of climate may have had to possible Pleistocene uplift in the San Bernardino and other high mountain ranges to the west, or to post-glacial changes of climate, cannot be stated in the absence of more complete knowledge.

SUMMARY

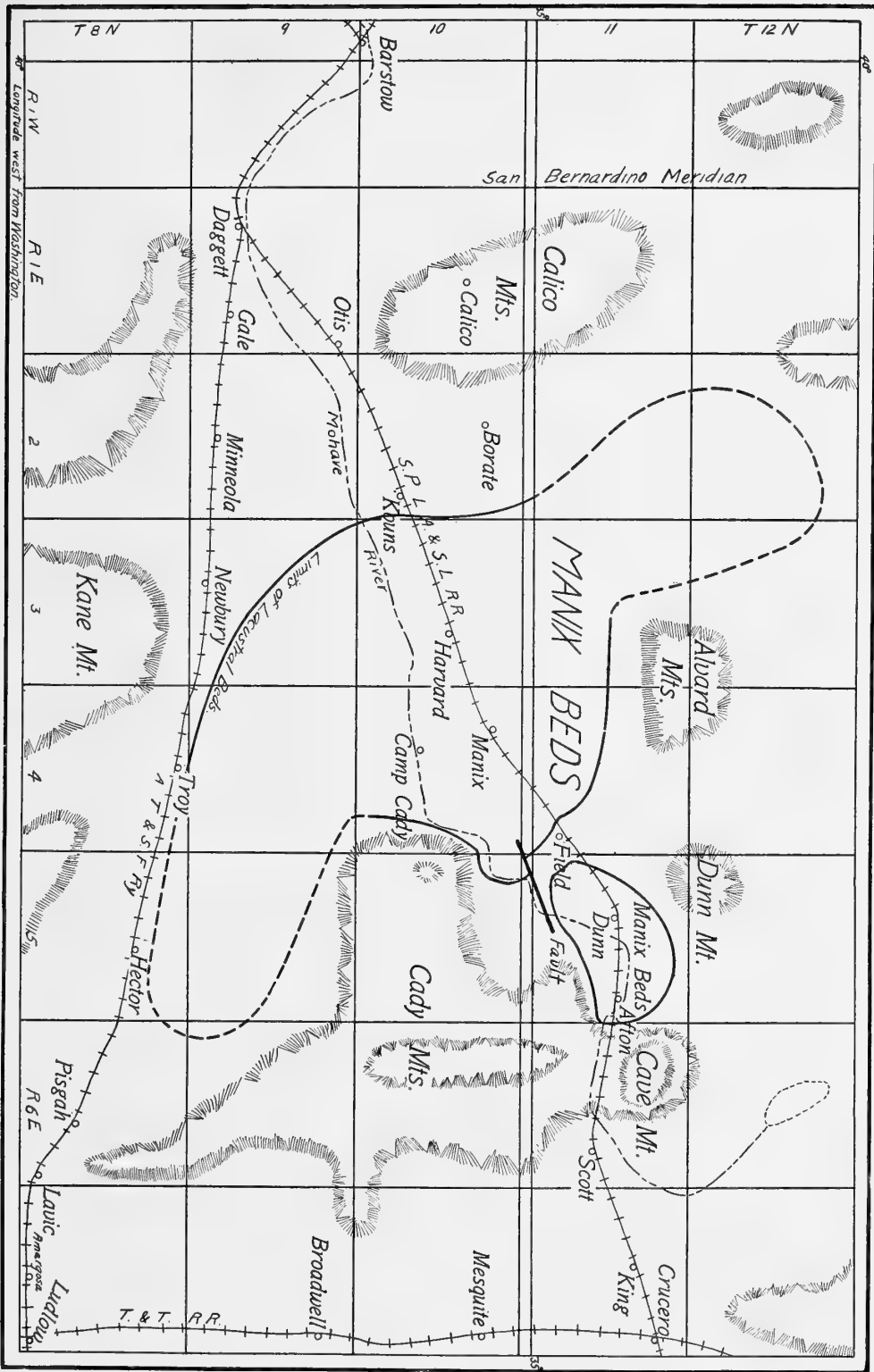
In Pleistocene time the waters of the Mohave River were ponded in a basin in the eastern Mohave Desert region. In the lake thus formed there was deposited a series of clays and

sands. The writer has termed these deposits the Manix Beds, and has referred to the lake as Manix Lake. Fossil remains of six species of mammals, of several birds, molluses, and fish were obtained from the lake-beds. The mammals indicate a Pleistocene age for the formation, but with out present knowledge it is not possible to determine definitely the particular stage of Pleistocene time. Deformation of the region occurred not long before the origin of the lake, and to a less extent after the lake's extinction. No evidence was noted indicating disturbance in very recent times. It is evident that the lake owed its origin to changes of climate in the direction of greater precipitation over large areas and to deformation in this or adjoining regions. The disappearance of the lake was the joint result of the partial filling of its basin with sediments and the downcutting of its outlet. The evidence obtained indicates that the climate in this region and in that to the west has become more arid since the deposition of the Manix Lake Beds in Pleistocene time.

Transmitted June 9, 1913.

EXPLANATION OF PLATE 22

Sketch map showing approximate limits of Manix Beds.



EXPLANATION OF PLATE 23

Fig. 1. Manix beds two miles south of Field, dissected by the back-cutting of gulches tributary to the Mohave River. View shows evenness and persistence of bedding, the type of topography developed by erosion, and the original lake-bed surface at the skyline.

Fig. 2. Manix beds three miles south of Field. Course of Mohave River is cut down forty to fifty feet. On left are Cady Mountains.



Fig. 1



Fig. 2



EXPLANATION OF PLATE 24

Fig. 1. North bank of Mohave River one mile southeast of Field. Coarse older fanglomerates on the left are brought up by post-lacustral fault. Finer fanglomerates on the right are horizontal. The contact is a plane movement, but perhaps not the main fault-plane. Note lack of bedding in coarse materials. Mohave River in foreground (February, 1913).

Fig. 2. Looking west and up Mohave River, one mile southeast of Field. Scarp of post-lacustral fault as emboldened by backcutting of the Mohave into the coarse older fanglomerates. In foreground recent waste from coarse fanglomerates above overlies the fine fanglomerates.



Fig. 1



Fig. 2

EXPLANATION OF PLATE 25

Fig. 1. One mile south of Field. Fine younger downthrown fanglomerates in right middle distance dip northward into coarse older fanglomerates composing upthrown hill to the left. Downthrown strata unconformably overlain by dark-colored southward-dipping Recent fanglomerates derived from hill above.

Fig. 2. Three or four miles east of Afton. Showing depth of cañon cut across the anticlinal rim of Manix Lake basin by Mohave River in Pleistocene and Recent time. Irregularly arched older fanglomerates in middle distance, lying on older rocks of Cave Mountain exposed in foreground. Cady Mountains in far distance.



Fig. 1



Fig. 2

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THE PROBLEM OF AQUATIC ADAPTATION
IN THE CARNIVORA, AS ILLUSTRATED
IN THE OSTEOLOGY AND EVOLUTION
OF THE SEA-OTTER

BY

WALTER P. TAYLOR

UNIVERSITY OF CALIFORNIA PRESS
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INTRODUCTION

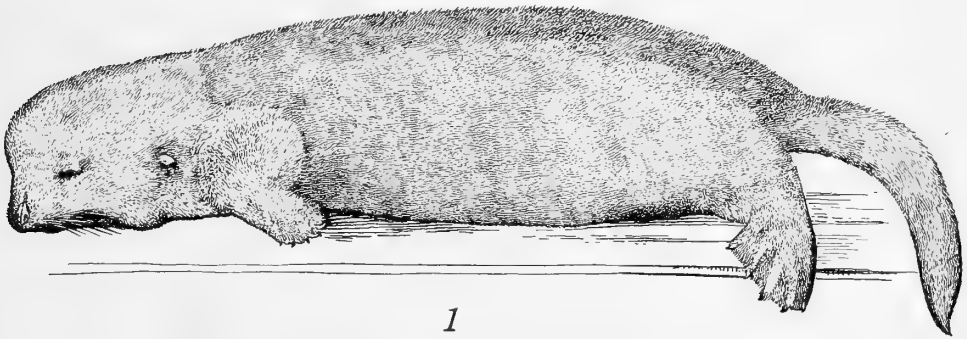
Adaptation to life in the water presents many possibilities in connection with studies of variation of form, since the influence of the factor of environment is so nearly a constant, and the nature and direction of the variation may be clearly seen. This is especially true of animals which have been adapted to life on land, and have later entered upon an aquatic existence. In such cases one should be able, from a consideration of their present form and palaeontologic history, to follow the course of evolution with more than usual certainty. Under these circumstances, when the nature and significance of the changes are so clearly shown, there should also appear to be a greater probability of gaining some insight into the process by which these changes are effected. Unfortunately, this ideal is in few if any cases attainable, partly because ancestry often can not be traced, owing to lack of the necessary palaeontologic material.

The aquatic Mammalia, the Cetacea, Sirenia and Pinnipedia, are groups already far advanced in adaptation. Since they are at present almost exclusively marine, they offer an especially wide field for investigation of this kind. Work upon these highly specialized groups, however, does not to any extent reveal data on the beginning stages of adaptation to aquatic life, and the early structural changes are, in many respects, the most significant, especially from the point of view of an enquirer into the nature of the processes involved.

A study of the sea-otter (*Latax lutris*) might presumably be of value in this connection, since the animal is one exhibiting variations which are probably, in some degree, analogous to those shown by the ancestors of the groups above mentioned not

long after they took to the water. The ancestry of this species is at least roughly traceable, as its structure shows it to be closely related to the river otter (*Lutra canadensis*). At the same time, *Latax* possesses characters which are certainly to be interpreted as incipient adaptations to an exclusively aquatic life.

The present paper is the result of a study carried forward in continuation of work done by Professor John C. Merriam¹ on the problem of aquatic adaptation as illustrated in the history of certain of the marine reptiles of the Mesozoic, especially the Thalattosauria and Ichthyosauria.



1

Fig. 1. *Latax lutris nereis* (no. 6956. Univ. Calif. Mus. Vert. Zool).
Drawn from the skin.

It is intended in this paper (*a*) to present a detailed discussion of the osteological and dental peculiarities of *Latax*; (*b*) to submit conclusions from a study of the palaeontologic history of the group; (*c*) to analyze the characters of *Latax*, so far as possible, and to consider them in the light of aquatic adaptation; and (*d*) to discuss the bearing of the material presented on current theories of species formation.

MATERIAL AND ACKNOWLEDGMENTS

Through the interest and generosity of Miss Annie M. Alexander a complete specimen of the southern sea-otter, *Latax lutris nereis* Merriam, C. H., (no. 6956, Univ. Calif. Mus. Vert. Zool.,

¹ Merriam, J. C., "Triassic Ichthyosauria, with special reference to the American forms," Mem. Univ. Calif., vol. 1 (1908), no. 1; and "The Thalattosauria, a group of marine reptiles from the Triassic of California," Mem. Calif. Acad. Sci., vol. 5 (1905), no. 1.

data: ♀ adult; Point Sur, Monterey County, California; March 10, 1908; collected by J. Rowley) now a very rare animal off the coast of California, has been added to the collection of the Museum of Vertebrate Zoology of the University of California, and makes possible the present study. Additional material at hand consists of a skull of *Latax lutris lutris* (Linnaeus) (no. 8124) from the collection of the Department of Palaeontology of the University of California, as well as a number of skulls and skeletons of *Lutra canadensis* (Schreber), *Taxidea taxus* (Schreber) and *Phoca vitulina* Linnaeus, contained in the collection of the Museum of Vertebrate Zoology and in that of the Department of Palaeontology of the University of California.

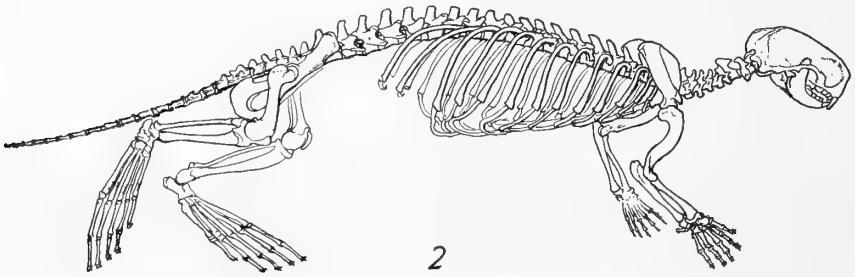


Fig. 2. Camera lucida drawing of skeleton of *Latax lutris nereis* (no. 6956. Univ. Calif. Mus. Vert. Zool.).

The sex of the specimen of *Latax lutris lutris* is unknown, but the size of the skull and the degree of development of the processes for muscle attachment, together with the degree of wear of the teeth and ankylosis of the bones, might indicate that it is an old male.

Through the kindness of Professor Edwin Chapin Starks of Stanford University, the writer has been enabled to examine a mounted skeleton of an adult *Latax lutris nereis* in the museum of that institution.

Grateful acknowledgment is made to Professor John C. Merriam, head of the Department of Palaeontology of the University of California, for generous criticism and suggestion.

The writer was assisted in many ways by Dr. Joseph Grinnell, director, and by Dr. H. C. Bryant and Mr. F. H. Holden, members of the staff, of the Museum of Vertebrate Zoology of the same institution, and desires to express to them his appreciation.

The drawings were made by Mrs. Louise Nash.

HISTORY OF THE LITERATURE

The osteology of the sea-otter has been discussed by Home,² who notes several points with regard to skull (two plates of the skull and lower jaw are given), skeleton, and external characters, but considers internal anatomy at greater length; Lichtenstein, who is said to have figured the skull; Martin,³ who described the skeleton of the sea-otter in some detail; Baird⁴ who, in characterizing the sea-otter, incidentally mentions skull characters; Gervais,⁵ who worked out the osteology and discussed the systematic position of *Latax*, and by Coues,⁶ who discusses quite comprehensively the habits, characters and systematic status of the animal, and gives the leading references to the sea-otter.

Many naturalists, explorers, and traders, as well as a number of both the earlier and later historians, refer, at least casually, to the sea-otter. The fact of its former great abundance on the shores of the North Pacific is recorded in many places.⁷ The progress of civilization has witnessed the steady increase in the efficiency of man as a hunter, and a corresponding diminution in numbers of this intrinsically interesting and economically important animal, until now, from all accounts, it has become so rare an animal as to be approaching extinction everywhere.

² Home, E., "A description of the anatomy of the sea-otter." Phil. Trans. R. Soc., London, 1796, p. 385.

³ Martin, W. C. L., "On the Osteology of the *Sea Otter Enhydra marina* Flem." Proc. Zool. Soc., London, pt. 4 (1836), pp. 59-62.

⁴ Baird, S. F., "General report upon the mammals of the several Pacific railroad routes," pt. 1 (1857), p. 189, in *Mammals of North America*. (Philadelphia, J. B. Lippincott and Company, 1859).

⁵ Gervais, Journ. de Zool., vol. 4 (1875), pp. 200-206.

⁶ Coues, E., "Fur-bearing animals." U. S. Geol. and Geog. Surv. Terr. Misc. Pub. 8 (Washington, Government Printing Office, 1877), p. 325.

⁷ For example, see Smythe, W. E., *History of San Diego* (San Diego, The History Company, 1907), pp. 68, 88, 107.

DISTRIBUTION AND CLASSIFICATION OF LATAX

DISTRIBUTION

The northern sea-otter, *Latax lutris lutris* (Linnaeus), inhabits the coast and islands of the North Pacific Ocean. In 1904 C. H. Merriam⁸ described a southern subspecies from the Santa Barbara Islands (*Latax lutris nereis*, type from San Miguel Island). Coues⁹ gives the range of the sea-otter as south to Lower California. The limits of the range of the two subspecies are not determined.

CLASSIFICATION AND RELATIONSHIPS

Many early writers observed the resemblance of the sea-otter to the seal. Pennant¹⁰ noted the resemblance of the two in tooth formula. He also called attention to their likeness in habits. Referring to sea-otter, he states: "These animals partake very much of the nature of seals in their almost constant residence in the water, their manner of swimming, finlike legs, and number of fore teeth." In the same account he says: "They are seen very remote from land, sometimes even at the distance of a hundred leagues." Pallas,¹¹ as noted above, referred the animal to the genus *Phoca*. Martin, with reference to the close resemblance between the two, states¹² that between the seals and the otters the *Enhydra* forms a palpable link of union, approximating, in some portion of its osseous structure, even more to the former than to the latter. Baird (1857) practically repeats this statement. "The sea-otter, the sole representative of the genus so far as known, is an exceedingly remarkable animal, with perhaps more resemblance to a seal than to the common otters."¹³ Scammon¹⁴ includes the sea otter in the Pinnipedia. Coues is

⁸ Merriam, C. H., "A new sea-otter from southern California," Proc. Biol. Soc., Wash., vol. 17 (1904), p. 159.

⁹ Coues, E., *op. cit.*, p. 327.

¹⁰ Pennant, T., *Arctic Zoology* (London, Henry Hughs, 1784), p. 91.

¹¹ Pallas, P., *Zoographia rosso-asiatica* (Petropoli ex officina Caes. Academiae Scientiarum MDCCCXI), p. 100.

¹² Martin, W. C. L., *op. cit.*, p. 59.

¹³ Baird, S. F., *op. cit.*, p. 189.

¹⁴ Scammon, C. M., *Marine mammals* (San Francisco, John H. Carmany & Co.; New York, G. P. Putnam's Sons; 1874), pp. 168-174.

much more conservative, remarking¹⁵ that the hind limbs are developed into flipper-like organs, similar to those of some seals. He notes the general likeness of the skulls of the seal and sea-otter, and says: "In general superficial aspects, the Sea Otter is not unlike a Seal, a resemblance increased by the flipper-like hind feet." Coues is apparently the first author who clearly discriminates between superficial resemblances to the seal and the real and close affinities with the rest of the otters.

Gill¹⁶ divides the subfamilies of the Mustelidae into two groups, the first including the Mustelinae, Mellivorinae, Melinae, Helectidinae, Zorillinae, and Mephitinae, and the second including the Lutrinae and Enhydrinae.

His characterization of the two groups follows:

"1.—Skull with the cerebral portion comparatively compressed backwards; and with the rostral portion comparatively produced, attenuated and transversally convex above; anteorbital foramen small, and opening forwards. Feet with little-developed or no interdigital membrane.

"2.—Skull with the cerebral portion swollen backwards and outwards; and with the rostral portion abbreviated, high and truncated forwards, and widened and depressed above; anteorbital foramen enlarged, and produced downwards and backwards. Feet with well-developed interdigital membrane, and adapted for swimming."

It will be noted that the fundamental resemblances of the sea and river otters are presented in the characters of group 2.

According to Gill's classification, the Enhydrinae are separated from the Lutrinae on the basis of the tooth formula and the elongation of the digits of the posterior feet.

The characters mentioned above under the second group serve to hold Gill's two subfamilies (Lutrinae and Enhydrinae) together in a broad way. Other common characters are (and these, of course, are more intangible) the general similarity in shape of body, length of tail, and habits.

With the possible exception of the digits of the hind feet, every part of the skeleton of *Latax* clearly resembles in general form and shape the corresponding part of *Lutra*. The differences elaborated below rest on close scrutiny and comparison.

¹⁵ Coues, E., *op. cit.*, pp. 325, 327.

¹⁶ Gill, T., "Synoptical tables of characters of the sub-divisions of mammals, with a catalogue of the genera." Smithsonian Inst., Misc. Collect., vol. 11 (1871), pp. 64, 65.

Although the divergencies are expressed in nearly every part of the skeletal structure, they are, in most instances, small in amount.

With regard to the tooth formula, Coues states: "It is said that the *young* Sea Otter has I $\frac{3-3}{3-3}$ like all other *Mustelidae*. . . ." ¹⁷ Unfortunately, he omits the authority for this assertion. If the young *Latax* does possess three incisors below on each side, the different incisor formula of the genus would be clearly shown to be not in any way a profound or fundamental distinction. It may be questioned further whether the loss by the sea-otter of P¹ is a difference any more deep-seated than the loss of the middle pair of lower incisors. The loss of certain anterior premolars is well known to be comparatively frequent in fissipedian carnivores, while incisor loss is comparatively rare.

The modification of the digits of the hind foot, though striking, would not seem to the writer to be of sufficient importance to warrant the reference of the sea-otter to a subfamily distinct from the Lutrinae.

If *Latax* is left in the subfamily Lutrinae, the classification in a measure fails to show the differences existing between the two genera. If, on the other hand, the sea-otter is referred to a distinct subfamily, the classification certainly does not indicate the fundamental resemblances of the two genera. Apparently the question is one of whether the differences or the resemblances seem to the individual author of most significance. Baird,¹⁸ Osborn,¹⁹ Trouessart,²⁰ Elliot,²¹ and Stephens²² refer the sea-otter to the subfamily Lutrinae, while Gill²³ and Coues²⁴ make it the sole genus in the subfamily Enhydrinae.

¹⁷ Coues, E., *op. cit.*, p. 326.

¹⁸ Baird, S. F., *op. cit.*, p. 189.

¹⁹ Osborn, H. F., *The age of mammals* (New York, the Macmillan Co., 1910), p. 531.

²⁰ Trouessart, E. L., *Catalogus mammalium* (Berolini, R. Friedländer & Sohn, 1898, 1899), vol. 1, p. 281.

²¹ Elliot, D. G., "Synopsis of the mammals of North America," *Pub. Field Columb. Mus., Zool. Ser.*, vol. 2 (1901), p. 351; and "Check list of North American mammals," same series, vol. 6 (1905), p. 433.

²² Stephens, F., *California mammals* (San Diego, West Coast Pub. Co. 1906), p. 232.

²³ Gill, T., *op. cit.*, p. 65.

²⁴ Coues, E., *op. cit.*, p. 325.

The facts of relationship seem to the writer to be somewhat more adequately shown by the former course, and consequently the sea-otter is here referred to the Lutrinae.

NATURE OF THE CHARACTERS SEPARATING LATAX AND LUTRA

Although, as previously suggested, a superficial examination of the skeleton of *Latax* reveals no very emphatic modifications in the form of the bones, except in the hind foot, such as might be expected to occur in response to an aquatic environment, a closer scrutiny brings to light the fact that adaptations of this nature affect almost every bone in the body, and indicates that, outside the Pinnipedia, *Latax* is the most highly specialized for life in the water of all the carnivores.

Reference to the following table shows further that many of the characters distinguishing *Latax lutris nereis* from *Lutra canadensis* may be ascribed to the effect of natatory modification.

DIFFERENTIAL CHARACTERS, OSTEOLOGICAL AND DENTAL, APPARENTLY RELATED TO AQUATIC ADAPTATION

<i>Lutra canadensis</i>	<i>Latax lutris nereis</i>
1 Skull relatively not enlarged in proportion to length of trunk.	1 Skull heavy, massive, relatively much enlarged in proportion to length of trunk.
2 Brain-case relatively not inflated.	2 Brain-case inflated.
3. Orbit small relative to length of skull.	3 Orbit large relative to length of skull.
4 Lambdoidal ridge and sagittal crest little developed.	4 Lambdoidal ridge and sagittal crest highly developed.
5 Anterior ends of nasals a short distance posterior of anterior ends of premaxillaries.	5 Anterior ends of nasals almost directly above anterior ends of premaxillaries.
6 Interorbital constriction narrow.	6. Interorbital constriction broad.
7 Tooth formula $\frac{3}{3}, \frac{1}{1}, \frac{4}{3}, \frac{1}{2} \times 2 = 36$	7 Tooth formula $\frac{3}{2}, \frac{1}{1}, \frac{3}{3}, \frac{1}{2} \times 2 = 32$
8 Cheek-teeth with a cutting function.	8 Cheek-teeth with a crushing function.
9 Lower carnassial with paracoid large.	9 Lower carnassial with paracoid much reduced.

Lutra canadensis

- 10 Foramen lacerum posterius small.
- 11 Neck long, nearly $3/10$ length of trunk.
- 12 Tail with about 24 vertebrae.
- 13 Intervertebral foramina small.
- 14 Zygapophyses comparatively highly developed.
- 15 Anapophyses present on all the lumbar vertebrae but the fifth and sixth.
- 16 Vertebral centra long antero-posteriorly, dorso-ventral measurement relatively small.
- 17 Epiphyses less developed.
- 18 Vertebrarterial foramen of atlas small, round; transverse process plate-like, thin, expanded; dorsal arch broad antero-posteriorly.
- 19 Spine of axis long antero-posteriorly.
- 20 Vertebrarterial canal of sixth cervical vertebra small; transverse process divided into three parts, one lateral peglike, and two ventrolateral platelike processes.
- 21 Transverse process of third lumbar vertebra platelike; metapophyses wide; anapophyses highly developed.
- 22 Sacrum with zygapophyses indicated; transverse process on posterior sacral.
- 23 Chevron present on fourth caudal vertebra.
- 24 Ribs light.
- 25 Pelvis comparatively light; obturator foramen bounded by light bars.
- 26 Pelvis forming slight angle with vertebral column.
- 27 Ilia not markedly flaring anteriorly.
- 28 Fore limb comparatively large.
- 29 Olecranon of ulna slightly larger than in *Latax*.

Latax lutris nereis

- 10 Foramen lacerum posterius large.
- 11 Neck short, less than $2/10$ length of trunk.
- 12 Tail with number of vertebrae reduced, varying from 18 to 21.
- 13 Intervertebral foramina large.
- 14 Zygapophyses not so highly developed.
- 15 Anapophyses present on first three lumbar vertebrae only.
- 16 Vertebral centra short antero-posteriorly, dorso-ventral measurement relatively large.
- 17 Epiphyses greatly developed.
- 18 Vertebrarterial foramen of atlas large, round; transverse process heavy; dorsal arch narrow antero-posteriorly.
- 19 Spine of axis short antero-posteriorly.
- 20 Vertebrarterial canal of sixth cervical vertebra large; transverse process divided into three peglike processes.
- 21 Transverse process of third lumbar vertebra short and peglike; metapophyses narrow; anapophyses indicated merely.
- 22 Sacrum with no zygapophyses indicated; small transverse process on posterior sacral.
- 23 Chevron absent from fourth caudal vertebra.
- 24 Ribs heavy.
- 25 Pelvis comparatively heavy; obturator foramen bounded by heavy bars.
- 26 Pelvis more nearly parallel to vertebral column.
- 27 Ilia markedly flaring anteriorly.
- 28 Fore limb comparatively small.
- 29 Olecranon of ulna slightly smaller than in *Lutra*.

<i>Lutra canadensis</i>	<i>Lutra lutris nereis</i>
30 Hind limb not specialized for use as a paddle.	30 Hind limb specialized for use as a paddle.
31 Head of femur with pit for <i>ligamentum teres</i> .	31 Head of femur without pit for <i>ligamentum teres</i> .
32 Tibia and fibula long and light.	32 Tibia and fibula comparatively heavy.
33 Pes not expanded.	33 Pes expanded.
34 Metatarsals and phalanges not noticeably elongated or flattened.	34 Metatarsals and phalanges noticeably elongated and flattened.
35 Fifth digit not the longest.	35 Fifth digit the longest.
36 Hind limb not markedly backward extending.	36 Hind limb markedly backward-extending.

CHARACTERS APPARENTLY NOT RELATED TO AQUATIC
ADAPTATION

<i>Lutra canadensis</i>	<i>Lutra lutris nereis</i>
1 Infraorbital foramen large but not so elongate as in <i>Lutra</i> .	1 Infraorbital foramen large and elongate.
2 Zygomatic process of frontal prominent.	2 Zygomatic process of frontal less prominent.
3 Angular process represented by a hook and internal shelf.	3 Angular process indicated by tubercle.
4 Zygomatic arches fairly wide-spreading.	4 Zygomatic arches not so wide-spreading.
5 Coronoid process rounded and bent forward.	5 Coronoid process rounded and bent backward.
6 Incisive foramen oval.	6 Incisive foramen more nearly round.
7 A large condylar vacuity present 3.17 mm. from foramen lacerum posterius.	7 A minute foramen present near condyle 7.3 mm. from foramen lacerum posterius.
8 Spine of fifth thoracic vertebra platelike, rounded posteriorly; ending in knob.	8 Spine of fifth thoracic vertebra thicker, straight, not rounded posteriorly; not ending in knob.
9 Suprascapular border of scapula having a dip in the curve.	9 Suprascapular border of scapula having an even curve, no dip.
10 Deltoid ridge of humerus somewhat expanded, indefinite.	10 Deltoid ridge of humerus a definite single ridge.
11 Entepicondylar foramen bounded by light bar; elongate.	11 Entepicondylar foramen bounded by heavy bar; small.

From these tables it develops that 36 characters, or 69.6 per cent, are apparently related to aquatic adaptation, while 11 characters, or 30.4 per cent, are apparently not so related. Although

this classification of the characters is subject to modification, and the statistical statement not all that could be desired, since account cannot well be taken of the relative importance of the characters, still it is believed that in the main what seems to be shown is very near the truth.

OSTEOLOGY AND DENTITION OF LATAK

SKULL

The comparative size of three skulls examined is shown by the following measurements, all in millimeters:

	<i>Lutra canadensis</i>	<i>Latax lutris</i> nereis (no. 6956)	<i>Latax lutris</i> lutris (no. 8124)
Greatest length of skull—most posterior surface occipital condyle to most anterior surface of premaxillary	106.8	114.1	132.9
Height of skull at auditory bulla—taken perpendicularly to basiscranial axis of skull.....	36.9	60.2	63.7
Greatest breadth of skull at mastoid process, measured exteriorly	63.2	83.1	97.7

These dimensions indicate the heavy and massive character of the cranium of the sea-otter, and clearly show that as compared with the skull of *Lutra canadensis* that of *Latax lutris nereis* is larger relatively to length of trunk.

The brain-case is more bulky in the southern sea-otter (no. 6956) than it is in the river otter, the skull of *Latax l. lutris* (no. 8124) having this bulkiness still more emphasized.

The latter skull (no. 8124) evidently belonged to an old animal (possibly a male), as the sutures are discernible in only a few places, and the sagittal crest and lambdoidal ridge, as well as other processes for muscle attachment, are very highly developed.

The lateral boundary of the anterior nares, formed by the premaxillaries, is in the sea-otter more nearly perpendicular than in the river otter. Consequently, the skull may be described as being high anteriorly, the nasals being more above the incisors.

The orbit in the two skulls of the sea-otter is relatively (to the length of the skull) larger than in the *Lutra canadensis*. This enlargement may be due to an increase in size of the visual organ to adapt the animal for sight under water, paralleling the conditions in this respect observed by J. C. Merriam²⁵ and others in ichthyosaurs, in which group the orbits of the later Jurassic forms are larger than in the earlier Triassic reptiles. The relative enlargement of the skull of *Latax lutris* may also be definitely

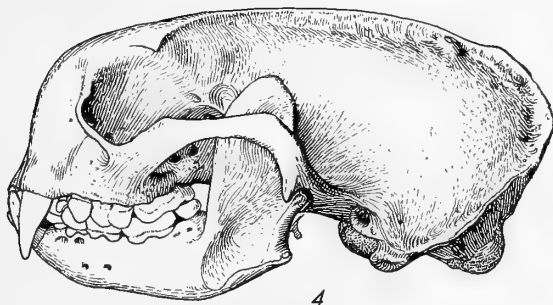
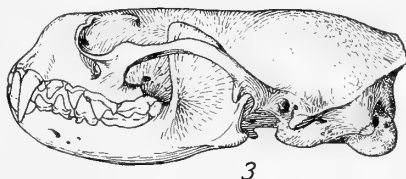


Fig. 3. Skull of *Lutra canadensis* (Univ. Calif. Col. Palae.) $\times\frac{1}{2}$.

Fig. 4. Skull of *Latax lutris* (no. 8124, Univ. Calif. Col. Palae.) $\times\frac{1}{2}$.

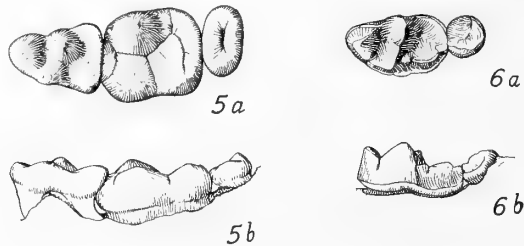
related to aquatic adaptation. The later ichthyosaurs, those which had lived longest in the water, had larger skulls relatively to the length of the trunk than those of earlier periods. As an extreme example of this kind of skull modification, the whales, in which the proportionate size of the skull is tremendous, may be cited.

²⁵ Merriam, J. C., "Triassic ichthyosauria, with special reference to the American forms," Mem. Univ. Calif., vol. 1 (1908), p. 74.

The general rounding of the profile of the sea-otter skull and the increased width of the interorbital constriction result respectively from the increased mass of the brain-case and the enlargement of the skull as a whole. The lesser prominence of the zygomatic process of the frontal and the reduction of the angular process of the mandible may be related to aquatic adaptation in that they signify a general reduction in the angular tuberosities for muscle attachment, which has been found by Raymond Osburn²⁶ to be indicative of natatory modification. There might theoretically be a reduction in certain angular tuberosities for muscle attachment (those to which the supporting muscles are attached) as an animal became adapted to life in water. The medium does not require the development of such heavy muscles as are required on land for support and locomotion, and so would not necessitate the production of large processes for their attachment.

DENTITION

General Characters.—Upon comparing the teeth of *Lutra* and *Latax* one is impressed immediately by the broader and more rounded character of the cheek-teeth of the latter. Coues expresses it well in saying: “If the teeth of ordinary carnivorous



Figs. 5-6. Teeth of *Latax* and *Lutra* (natural size).

Figs. 5a and 5b. Milk carnassial, true lower carnassial and second lower molar of *Latax lutris nereis*. Fig. 5a, superior view; 5b, lateral view.

Figs. 6a and 6b. Lower carnassial and second lower molar of *Lutra canadensis*; Fig. 6a, superior view; 6b, lateral view.

²⁶ Osburn, R. C., “Adaptive modifications of the limb skeleton in aquatic reptiles and mammals,” *Ann. Acad. Sci. New York*, vol. 16 (1906), p. 449.

quadrupeds be likened to fresh-chipped, sharp and angular bits of rock, those of the Enhydrinae are comparable to water-worn pebbles.²⁷ Evidently the cheek-teeth have entirely lost their sectorial and prehensile functions.

The tooth formula of *Latax* ($\frac{3}{2}, \frac{1}{1}, \frac{3}{3}, \frac{1}{2} \times 2 = 32$) is somewhat reduced as compared with that of *Lutra* ($\frac{3}{3}, \frac{1}{1}, \frac{4}{3}, \frac{1}{2} \times 2 = 36$).

The loss of a pair of lower incisors is a modification analogous to the case in seals, which, as is well known, have only two pairs of these teeth. This is one of the points which seemingly indicates that, from an evolutionary standpoint, the sea-otter is traveling in the general direction of the pinnipedian carnivores.

Carnassials.—One specimen (no. 6956) retains the milk carnassial in the lower jaw. This tooth was evidently about to be shed. Immediately behind it is the permanent carnassial. The tuberculation of the milk carnassial resembles that in the lower carnassial of *Lutra canadensis*, which has well-developed protoconid, paraconid and metaconid, with a heel made up of hypoconid and entoconid. These facts probably indicate that the ancestral form from which *Latax* is descended possessed a carnassial in form resembling that of *Lutra canadensis*. Another item confirming this view is that the milk carnassial is not so flattened and rounded in appearance as the true lower carnassial, but the ridges and tubercles are more acute. Of course if the food of the young sea-otter after the animal is weaned is different from that of the adult there might be adequate reason for the differences in the form of the carnassial here noted, which differences would then have no phylogenetic significance. There is no evidence, however, that there is any difference in food between adult and weaned juvenal.

The permanent carnassial exhibits a very great reduction of the paraconid. Reduction and ultimate loss of the paraconid are generally correlated with the assumption of a crushing function. In the case of the sea-otter, the acquisition of a more purely crushing function seems to be associated with aquatic adaptation.

²⁷ Coues, E., *op. cit.*, p. 325.

Tentative Suggestions as to Evolution of Dentition.—According to H. W. Elliott,²⁸ C. M. Scammon²⁹ and others, the sea-otter feeds to some extent on fish, but for the most part on sea-urchins, crabs, mussels, and clams. This would seem to account for its highly specialized crushing dentition. It is of interest to note in this connection that a primitive ichthyosaur from the middle Triassic (*Phalarodon fraasi*)³⁰ has a crushing dentition, the teeth being of a thick, low-crowned type. This is in marked contrast with the dentition of later Jurassic ichthyosaurs³¹ which have teeth of a simple subconical type. It would seem possible that in ichthyosaurs the crushing dentition was one of the early steps in aquatic adaptation.

In the course of the evolution of any pelagic mammal which is descended from a land-living species, there may be three habitat stages, namely, (1) one in which the animal is terrestrial only (and would ordinarily possess molars with conical or with compressed tubercles for securing and killing active land animals); (2) one in which the animal preys upon organisms of the littoral zone (and might have a crushing dentition); (3) one in which the animal depends upon pelagic forms and fishes which it does not crush or masticate (and might have slender teeth).

It might be expected that when a terrestrial species takes to aquatic life it would first become gradually accustomed to feeding on animals of the littoral zone, probably using a few land or river forms at the same time. As it progressed in adaptation to life in the water and became more specialized, it would depend to a continually greater degree on littoral animals for food. At this stage of evolution such a species would best be served by a

²⁸ Elliott, H. W., "Report upon the condition of affairs in the Territory of Alaska." House Exec. Doc. 83, 44th Congress, 1st Session (Washington, Government Printing Office, 1875), pp. 54-62.

²⁹ Scammon, C. M., *Marine mammals* (1874), pp. 168-174. Snow (In forbidden seas, London, Edward Arnold), 1910, pp. 279-280, asserts that remains of clams, limpets or mussels were not found in a single one of hundreds of stomachs examined by him, the food consisting principally of crabs, sea-urchins, sea-squirts, and what looked like fish-spawn (see p. 481).

³⁰ Merriam, J. C., "The skull and dentition of a primitive ichthyosaurian from the middle Triassic," Univ. Calif. Publ. Bull. Dept. Geol., vol. 5 (1910), p. 383.

³¹ Merriam, J. C., "Triassic ichthyosauria," etc., Mem. Univ. Calif., vol. 1 (1908), p. 74.

crushing dentition, for its food would consist of crustaceans, echinoderms and similar animals. Recent *Latax* represents a genus presumably specialized to this extent, although the exact status of the animal in this respect is not now certainly determined. A recent writer (Snow),³² whose twenty years of experience hunting the sea-otter lend authority to his statement, asserts that the animal dives to get its food, ordinarily in water of from 10 to 25 fathoms depth. As to the nature of the food, Snow states that the examination of hundreds of sea-otter stomachs reveals the fact that crabs, sea-urchins, sea-squirts, and a substance that looked like fish-spawn, are chiefly fed upon. He found no trace of seaweed, clams, limpets or mussels, and very seldom of fish. The crabs and similar animals were chewed up and swallowed shell and all. He says further that the sea-otter is very shy and sensitive, and nowadays rarely comes on shore, though according to accounts given by Steller and others it was formerly in the habit of "hauling out" on the rocks and beaches in large numbers.

Further adaptation of our hypothetical species might imply independence of shore animals, and the ability to make use of pelagic forms for food. A simple, subconical type of dentition to serve a prehensile function would be the most advantageous at this stage, for the food would consist of such animals as cephalopods and fish. The later Jurassic ichthyosaurs and the modern *Phoca* approximate this degree of adaptation, although this does not imply that phylogenetically the teeth of these forms have passed through a thick, low-crowned stage.

NECK AND TRUNK

The neck of the animal is very much shorter relatively to length of trunk than in *Lutra canadensis*. In this it resembles the seal, which has a proportionately very short neck. In the porpoise (*Phocaena*) the shortening has advanced to such a degree that the anterior cervical vertebrae are completely fused, and the posterior ones are indicated by thin spines only. In the sea-otter the centra and dorsal arches of the cervical vertebrae

³² Snow, H. J., In forbidden seas (London, Edward Arnold, 1910), pp. 278-280.

are much shortened anteroposteriorly. Actual numerical proportions in the sea and river forms follow:

	<i>Lutax lutris nereis</i>	<i>Lutra canadensis</i>
Length of trunk measured around curve, from posterior side neural arch of 7th cervical to anterior edge of sacrum, near the median line	412 mm.	390
Length of neck measured around curve, from anterior side neural arch of atlas to posterior edge neural arch 7th cervical vertebra (near median line)	69	110
Ratio length of neck to length of trunk.....	16.74	28.20

This very materially reduced ratio is even less than that of the seal (*Phoca vitulina*) which, in a specimen at hand, is nearer that of the river otter. There is in the sea-otter no evident elongation of the trunk as is sometimes noted in aquatic animals.

TAIL

The tail shows a tendency toward reduction in the number of elements, having in our specimen twenty-one vertebrae instead of the twenty-four which are present in *Lutra*. Coues asserts³³ that Gerrard gives the number of caudal vertebrae as eighteen, which indicates a still further reduction in the specimen or specimens examined by him. The Stanford University example studied by the writer has nineteen caudal vertebrae. The reduction in the number of tail elements would not be unexpected, as the sea-otter uses its hind feet largely for propulsion. In this respect progression in aquatic adaptation in the sea-otter tends to parallel that of the seal, which possesses only twelve caudal elements. Martin notes³⁴ the fact that in swimming the hinder extremities are placed far back, exceeding the tail when stretched out in the act of swimming. The tail is said to appear placed between them almost as much as it is in the seals.

The flatness of the tail of *Lutax* when viewed from above suggests that the organ is used as a means of elevation and depression of the head while swimming, and as a directive organ. Probably it assists also in diving. Snow (*loc. cit.*) says that

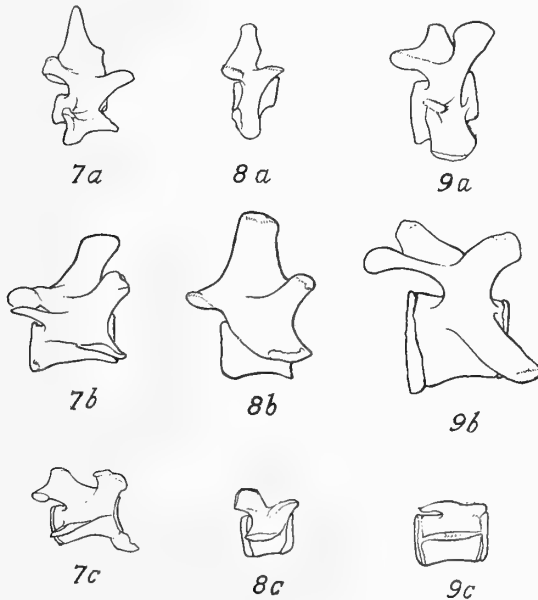
³³ Coues, E., *op. cit.*, p. 331.

³⁴ Martin, W. C. L., *op. cit.*, p. 59.

the tail is used as a rudder. The shape of the tail and the presence of the so-called flanges upon it laterally have led to the suggestion by Lull³⁵ that they are homologous to the expanded flukes on the tails of certain of the Cetacea and Sirenia, the posterior position of the flukes in these groups being a mechanical adaptation which has been accelerated in its appearance so as to be embryonic.

VERTEBRAE

General Characters.—The form of the vertebrae in the sea-otter is different from that in the river otter, in that the intervertebral foramina are larger, especially posteriorly, the zyga-



Figs. 7-9. Lateral views of selected vertebrae of river otter, sea-otter, and seal. $\times\frac{1}{2}$.

Figs. 7a, 7b and 7c. Vertebrae of river otter (*Lutra canadensis*). Fig. 7a, fifth cervical; 7b, third lumbar; 7c, fourth caudal.

Figs. 8a, 8b and 8c. Vertebrae of sea-otter (*Lutra lutris nereis*). Fig. 8a, fifth cervical; 8b, third lumbar; 8c, fourth caudal.

Figs. 9a, 9b and 9c. Vertebrae of seal (*Phoca vitulina*). Fig. 9a, fifth cervical; 9b, third lumbar; 9c, fourth caudal.

³⁵ Lull, R. S., "Relation of embryology and vertebrate paleontology," Popular Science Monthly, vol. 77 (1910), p. 153.

pophyses are nowhere developed to the extent that they are in the river otter, and the anapophyses are much reduced. The anapophyses are present on the first lumbar vertebra, indicated in the second, but practically obsolete in the third. The same elements are indicated as rudiments even on the third, fourth and fifth lumbar vertebrae in the mounted skeleton at Stanford University.

In *Lutra* the anapophyses are well developed on every lumbar vertebra but the fifth and sixth. Posteriorly in the sea-otter the metapophyses are reduced. The bodies or centra of all the vertebrae are, as compared with those of the river otter, shorter anteroposteriorly relatively to length of trunk, and relatively higher. The zygapophysial facets are much reduced, and the epiphyses are developed much more highly; to such a degree, in fact, that the heads of the anterior eleven pairs of ribs articulate, not on the bodies of the vertebrae proper, but on the epiphyses between them.

There is apparently much greater flexibility in the vertebral column of the sea-otter, the vertebrae being not nearly so firmly locked together. The vertebrae show considerable resemblance to those of the seal, in which the zygapophyses are much reduced, the intervertebral foramina are large, there are no anapophyses, the bodies of the vertebrae are short anteroposteriorly, the spinous processes are very much reduced, and the epiphyses are prominent (a similar though lesser tendency to have the anterior pairs of ribs articulating on the epiphyses alone being apparent).

Sacrum.—Zygapophyses are not noticeable upon the sacrum of the sea-otter, while on the river otter they are indicated. The transverse process on the posterior sacral is much reduced in *Lutra*.

Chevron.—There is no chevron in the sea-otter. Its position is indicated by two knobs diminishing gradually in size distally, first appearing ventrally on the seventh caudal vertebra and disappearing as such about the eighteenth. In the river otter the chevron first appears on the fourth caudal, where it forms a complete or nearly complete ring. It is definitely arched upon the next two or three vertebrae, and then gives place to two knobs, gradually diminishing in relative size toward the distal end of the tail.

Relation of Vertebral Characters to Aquatic Adaptation.—Reduction of interlocking processes, shortening and heightening of the centra, enlargement of the intervertebral foramina, and thickening of the epiphyses seem all to be correlated with an increased flexibility of the vertebral column, which is an adaptation to life in water. Other aquatic animals, as the pinnipeds and ichthyosaurs, exhibit modifications of the same kind.

Reduction of vertebral processes for muscle attachment may also be an adaptation to aquatic life, in that an animal living in water depends largely on flotation for support, as elsewhere expressed. This would lead to a weakening of muscles otherwise needed for support and of the processes for their attachment.

The absence of the chevron in the sea-otter may be related to the shape of its tail, which is flattish dorsoventrally, and to the reduction in importance of the tail. The tail of the seal presents no haemal elements. The evolution of the tail of the sea-otter apparently is following the same direction as that already taken by the seal.

The porpoise (*Phocaena*) shows tail development in another direction. In this genus the tail is short, but there are lateral flukes. There are prominent chevrons on the caudal vertebrae, which doubtless have a supporting function through their serving as places of muscle attachment.

In the sea-otter the *loss* of the chevron seems to be related to aquatic adaptation through its correlation with the shape of the tail and its reduction in length. In the porpoise the *retention* of the chevron and even its further development is apparently an adaptation to aquatic life, through its correlation with the probable continued increase in importance of the tail as a propelling organ.

SCAPULA

The scapula in *Latax lutris nereis* (no. 6956) is relatively smaller than in the river otter, and not so long anteroposteriorly. The distal narrowing is more marked. The spine is not so prominent, and the acromion is less expanded. The Stanford University specimen has the acromion and spine more developed than in no. 6956. The spine of the scapula in the seal is reduced, and the acromion is still less developed than in the sea-otter.

These modifications are indicative of adaptation to life in the water, in that an animal living in the water does not depend so much upon its fore limbs as upon flotation for support. This lack of need of a supporting function allows a weakening to take place first in the muscles of the fore limbs, and then in the processes for their attachment. J. C. Merriam³⁶ found the scapula in the later Jurassic ichthyosaurs to be narrowed distally, and suggests that this character may be ascribed to the effect of aquatic adaptation.

RIBS

The ribs are heavy as compared with those of *Lutra*. This may be an adaptation to life in the water, since it may be desirable for the ribs to have increased weight so as better to resist the pressure of the denser medium.

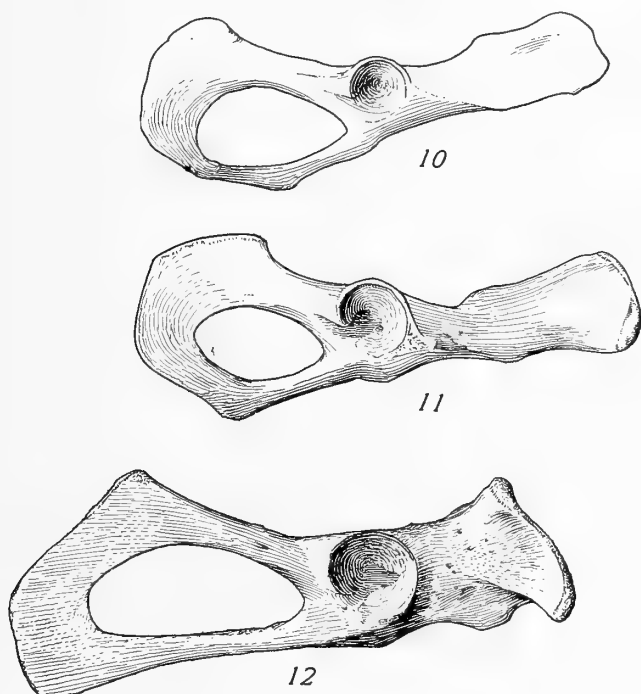
PELVIS

The pelvis is elevated somewhat so as to lie more nearly parallel to the vertebral column than in the river otter. The ilia are very markedly turned outward anteriorly. Their superior borders or crests serve as places of attachment, at least partially, for the following muscles of the hind limb: the *gluteus medius*, *gluteus minimus*, and *sartorius*. The *sartorius* is the largest and probably the most important of these muscles. Its action is the adduction and rotation of the femur and the extension of the tibia. It is noteworthy that the proximal portion of the crest of the tibia, to which the *sartorius* is fastened, is more roughened in the sea-otter than in the river otter. The pubic bones are not (in no. 6956) joined along the symphyseal line, except by cartilage, but they would possibly become somewhat more intimately united as the age of the animal increased. The Stanford University specimen, although a middle-aged adult, still shows the pubic bones not ankylosed. This fact would indicate that this is the normal condition in *Latax*.

In the seal the pelvis is approximately parallel to the vertebral column, the ilia flare outward anteriorly, so as to be nearly

³⁶ Merriam, J. C., "Triassic ichthyosauria, etc.," Mem. Univ. Calif., vol. 1 (1908), p. 75.

at right angles to the rest of the innominate, the pelvis is rather loosely connected to the sacrum, and the pubic bones (in the adult animal) are not united except by cartilage, the symphyseal line being extremely short.



Figs. 10-12. Pelves of river otter, sea-otter, and seal. $\times \frac{1}{2}$.
 Fig. 10. Lateral view pelvis of *Lutra canadensis*.
 Fig. 11. Lateral view pelvis of *Lutra lutris nereis*.
 Fig. 12. Lateral view pelvis of *Phoca vitulina*.

Relation of Characters of Pelvis to Aquatic Adaptation.—
 With the increase in importance of the hind limb as a paddle, the muscles for the adduction and rotation of the femur and extension of the tibia would augment in size. Several of the muscles, as above indicated, are attached to the superior border of the ilium; so the flare of this part of the bone may be readily accounted for as being a natatory modification.

In aquatic animals increased flexibility of the vertebral column is associated with a pelvis having a position more nearly parallel to the vertebral column than in land forms. The pelvis is also more extended posteriorly, and has a looser connection with the sacrum and weaker pubic symphysis. The sea-otter shows all these characters to a small extent.

The characters of the pelvis which serve to differentiate it from that of the river otter are thus clearly related to aquatic adaptation.

FORE LIMBS

The fore limbs in *Latax* are proportionately smaller than in the fluviatile form of otter. The humerus is not so compressed laterally. The space between the radius and ulna is slightly greater than in the river form. The metacarpals and phalanges are reduced. The tuberosities for muscle attachment, while not prominent, would probably become more so as the animal grew older, and so are probably not significant from the standpoint of aquatic adaptation. The head of the humerus is pushed back with reference to the shaft of the bone, so that the fore limb has a slightly more posterior position than in the river otter. In the seal the humerus, radius and ulna are much shortened, and the head of the humerus is pushed still farther back, the articular surface, instead of being at right angles approximately to the shaft of the bone, being more nearly parallel to it, giving the limb a still more posterior position. The olecranon of the ulna is, in the sea-otter, slightly less prominent than in the river animal, which modification is associated with the general reduction in the size of the limb. The metacarpals resemble the phalanges. In *Latax* as in *Lutra*, the fifth digit of the forefoot is longer than the first.

In the seal the forefeet serve mainly as paddles, while in the sea-otter the almost unanimous testimony of observers is that they serve as organs of prehension as, for example, holding food or the young.

The principal organs used by aquatic groups for locomotion through the water are (1) posterior paddles, as in the seals, or (2) a sculling tail, as in whales. The sea-otter evidently makes

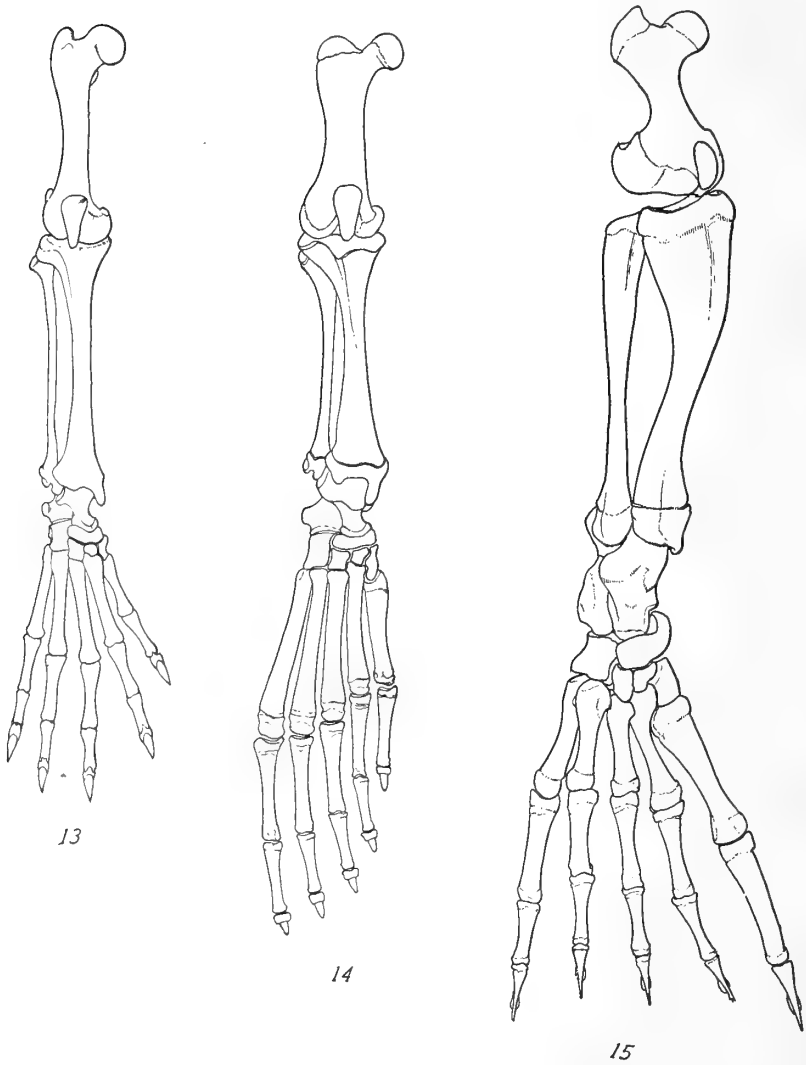
use of the former. Apparently the uses to which the sea-otter puts its forefeet do not require a large hand. If, as the available evidence seems to indicate, the fore limbs are little used in propulsion, a certain reduction in size would be beneficial to the species, and this reduction would be in the nature of an aquatic adaptation.

HIND LIMBS

The hind limbs present more evident adaptations than any other part of the skeleton. These adaptations may be set down as follows: (1) Proportional abbreviation of the propodial and epipodial portions of the limb; (2) curvature or backward extension of the limb; (3) distal dilation of the limb; and (4) elongation of digits. Under the first head it should be noted that the femur, tibia and fibula are relatively short. The anterior surface of the femur is longer than in *Lutra*, causing the distal articular surface to face more posteriorly. This implies a greater backward extension of the limb. As an evidence of distal dilation, it may be noted that the feet are lengthened and widened to form oars, or paddles. This dilation is brought about largely by the elongation and spreading of the digits. The abbreviation and backward extension of the limb shows a tendency in the development of the hind limb to parallel that of the fore limb, though the disposition toward a distal dilation opposes this tendency.

There is no *ligamentum teres* in the sea-otter, and consequently no pit in the head of the femur for its reception. This is another evidence in the parallelism of the development between the sea-otter and the seal, in which there is likewise no *ligamentum teres* or pit in the femur for its attachment. The environmental medium is of such a nature that apparently it does not require so strong a connection between pelvis and femur as does the medium of the atmosphere. Increased freedom of movement may be subserved by this looser connection, and it is probable that this would be an advantage. Flexibility of the vertebral column, as has already been mentioned, is an aquatic adaptation.

In the hind limb of the seal modifications analogous to those in the sea-otter are apparent. Two opposing tendencies seem to



Figs. 13-15. Posterior limbs of river otter, sea-otter and seal. $\times\frac{1}{3}$.

Fig. 13. Posterior limb of *Lutra canadensis*.

Fig. 14. Posterior limb of *Lutra lutris nereis*.

Fig. 15. Posterior limb of *Phoca vitulina*.

have existed in its evolution, namely, that toward shortening of the limb, and that toward backward extension of the limb. The first tendency has brought about the shortening of the femur, but the second has resulted in the epipodials remaining rather long. Distal dilation has resulted from an elongation and lateral spreading of the digits.

Elongation and distal dilation of the hind foot is differently brought about in the sea-otter and seal. In the former the fifth digit is the longest, the first being the shortest, and those between grading regularly from one to the other. In the latter the first digit is the longest, the fifth being next, followed by the second, third and fourth. The region in which expansion would be expected to occur is the outside of the foot, that is, on its posterior margin, the region of the fifth digit. In those aquatic animals which exhibit hyperdactyly, it is often the fifth digit which is split. The extension of the swimming membrane calls for the extra support on the posterior margin.³⁷

The foot of the sea-otter is of such a form that this extra support is furnished through the fifth digit being longest. In this connection the following facts might be regarded as indicating that *Latax* is derived from a form near the existing river otter. *Lutra canadensis* has the first digit shortest, second and fifth about equal, the fifth a little the longer, and the third and fourth about equal. A considerable elongation of the fifth, and a slight lengthening of the fourth, would bring about the relations existent in the hind foot of the sea-otter.

STAGE OF EVOLUTION OF LATAX

Latax has probably already attained to as great a degree of structural adaptation to life in the water as is possible without some modification in function of some of the various parts. This change in function would be conditioned by a change in habits. Following out the suggestions already presented it is conceivable that, by coming to feed on fish and pelagic cephalopods, thus attaining greater independence of shore animals, the sea-otter might, in time, become entirely pelagic in habitat. In such an

³⁷ Osburn, R. C., "Adaptive modifications," Ann. N. Y. Acad. Sci., vol. 16 (1906), p. 456.

event its teeth might attain a form more like those of a seal (i.e., approach the conical type), its cranium might increase still further in size, its neck become shorter, the tail be reduced, and other changes in the skeleton take place.

Phoca evidently represents a considerably more advanced stage of adaptation to aquatic life than *Latax*, for it has developed the habits and corresponding adaptive characters whereby it may live at times in the open seas independent of shore forms. As has been suggested, there is some evidence that *Latax* also has the ability to live far from land.

The following characters are illustrative of the sort of modification which is shown particularly well by the seal, adaptation of its teeth to a piscivorous diet, modification of its fore and hind feet to serve as paddles, abbreviation of the tail, and flexibility of the vertebral column. Modification in form of almost every bone in the skeleton has taken place so as to carry on with greater efficiency some new function in the new environmental medium. The same statement is true of the sea-otter, though, of course, the modification is less in amount.

PALAEOLOGIC EVIDENCE BEARING ON PROBLEM OF ORIGIN OF SEA-OTTER

Our knowledge of the history of the Mustelidae in general and the Lutrinae in particular is so limited that it is impossible to point out at this time where the sea-otter first appeared.

Lydekker has remarked³⁸ that the distribution of fossil Mustelinae accords well with present-day distribution of the living species. So far as is known to the writer, this may be said of the lutrine division of the Mustelidae also. It is therefore not improbable that *Latax* is descended from some primitive form that lived in North America or Asia, since *Latax* is found at present in the waters of the Pacific Ocean only.

The evident agreement in skeleton between *Latax* and *Lutra* suggests that the sea-otter is an offshoot from the lutrine stock after it had become differentiated as such. The fundamental consonance of characters, as illustrated especially in the denti-

³⁸ Lydekker, R., "Siwalik and Narbada carnivora." *Palae. Ind., Calcutta*, series 10, vol. 2 (1884), p. 179.

tion, militates against the idea that *Latax* is of independent origin. If the sea-otter is derived from some form of otter immediately ancestral to the Recent *Lutra*, it would presumably not date back earlier than Pliocene or late Miocene time. As the genus *Lutra* is known to have occurred in North America as early as the Miocene, it may easily be the parent stock.

*Enhydridon*³⁹ or *Enhydriondon* from the Lower Pliocene of Asia (Siwalik beds, India) possesses teeth which are intermediate in their crowns between *Lutra* and *Latax*. The superior-tooth formula is the same as in *Latax*. *Enhydriondon* may lie somewhere near the line of ancestry of this genus, although its geographic location might argue against its actually being ancestral to the sea-otter. It may represent a form which, in another part of the world, had started to specialize in the same direction as that followed by the sea-otter.

VARIATION IN LATAX

Under this head two conclusions seem obvious: (1) The variation in the sea-otter has been away from *Lutra*; (2) The variation in the sea-otter is intimately related to aquatic adaptation.

It will be remembered that 69.6 per cent of the most important differences between *Latax* and *Lutra* are shown to be related to aquatic adaptation. Doubtless, if our knowledge were greater, other characters would be seen to be so related also.

In general a slow change through continuous variations is seemingly indicated both by the nature of the characters separating the sea-otter from the terrestrial form, and by probable analogies with the development of other species of mammals as apprehended through a contemplation of certain palaeontologic phyla. The differently shaped skull in *Latax*, such that the anterior ends of the nasals are almost directly above the anterior ends of the premaxillaries, the different degree of development of the paracoid of the lower carnassial, the modification in the form of the zygapophyses, and the slightly different size of the olecranon, are some of the characters which would seem to indicate this

³⁹ Beddard, F. E., "Mammalia," in Cambridge Natural History (New York and London, The Macmillan Company, 1902), vol. 10, p. 439.

slow change through continuous variations. On the other hand, the differences in tooth formula and in the number of caudal vertebrae may indicate meristic variation, integral, and so discontinuous.

According to Darwin: "A strictly terrestrial animal, by occasionally hunting for food in shallow water, then in streams or lakes, might at last be converted into an animal so thoroughly aquatic as to brave the open ocean."⁴⁰ We look at the highly specialized sirenian and cetacean, and it is difficult to realize how its present form could have been reached through gradual transition from a primitive land-living to a highly specialized aquatic form. Darwin⁴¹ realized, of course, the difficulties for his own natural selection hypothesis involved. Nevertheless he believed that, although the end product of the evolutionary process might be widely different from its parent land form, still each stage in the transition of the organs involved might be useful to its possessor. This study of the sea-otter surely does not conflict with at least this much of Darwin's view.

It may further be stated that many of the facts as brought out in this study might indicate that the evolution has resulted from a combination of methods, and that Whitman's suggestion⁴² as to the probabilities of the reconciliation of natural selection, orthogenesis and mutation may be as near the truth as it is possible to come at this time.

The imperfection of the geological record will probably always be an obstacle to the tracing through of all stages of aquatic adaptation in a single mammalian phylum. We may consider ourselves fortunate if we are able to approximate these stages in different groups. This we seem to be able, in a measure, to do. Within the Mustelidae we have examples of animals entirely terrestrial (as *Gulo*, *Martes*, and *Mephitis*); one genus which lives a terrestrial and river life (*Lutra*); and one which is almost exclusively marine (*Latax*). In the reptilian order Ichthyosauria,

⁴⁰ Darwin, C., *Origin of species* (ed. 6 reprint; New York, Peter Eckler, 1859), p. 200.

⁴¹ Darwin, C., *ibid.*, p. 155.

⁴² Whitman, C. O., "The problem of the origin of species." Congress of Arts and Science, Universal Exposition, St. Louis (Boston and New York, Houghton, Mifflin & Co.), vol. 5 (1904), p. 44.

there are illustrated several stages in the adaptive process, ranging from the less specialized genera *Phalaradon* and *Micosaurus* to the more specialized *Cymbospondylus* and the most specialized *Baptanodon*. Thus we are able to contemplate a series of beginning stages of aquatic adaptation, in a terrestrial to littoral-marine group, on the one hand, and a series of advanced stages in a group exclusively marine, on the other. Although the gap which intervenes is considerable, the pinnipedian carnivore *Phoca* exemplifies a stage of adaptation probably somewhere between the two series, and as palaeontological exploration is carried forward it is not unlikely that more intermediate stages will be discovered.

SUMMARY

The following points covered in this paper may be broadly recapitulated:

1. The detailed consideration of the osteology of *Latax* and *Lutra* emphasizes, first, the close relationship of the two, in that both are fundamentally alike, having probably descended from a common ancestral form; and second, the fact of the divergence of the former from the latter, the bulk of the modifications in skeletal structure being clearly and intimately related to adaptation to life in the water.

2. The facts pertinent to the palaeontologic history of *Latax* indicate its descent from a lutrine ancestor, probably near the genus *Lutra*.

3. The consideration of this concrete case of a species apparently in a stage of evolution transitional between a form of terrestrial and one of marine habit cannot be shown to favor one of the proposed methods of evolution to the exclusion of others.

4. This study suggests a most significant possibility, namely that in mammals, during the transition between a land and water habitat, a crushing type of dentition is likely to be found. A broad dentition, fitted only for crushing, may, in other words, be intermediate between the more compressed and acutely tuberculated cheek-teeth of land-dwelling forms in which a dental armature fitted for cutting and tearing is a necessity, and the more nearly isodont cheek-teeth of marine-dwelling forms in which the dentition serves no other function than that of catching and holding.

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* Univ. Calif. Publ. Bull. Dept. Geol., vol. 7.

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- Page 39. *For Felix read Felis.*
Page 54. *For Platydon read Platyodon.*
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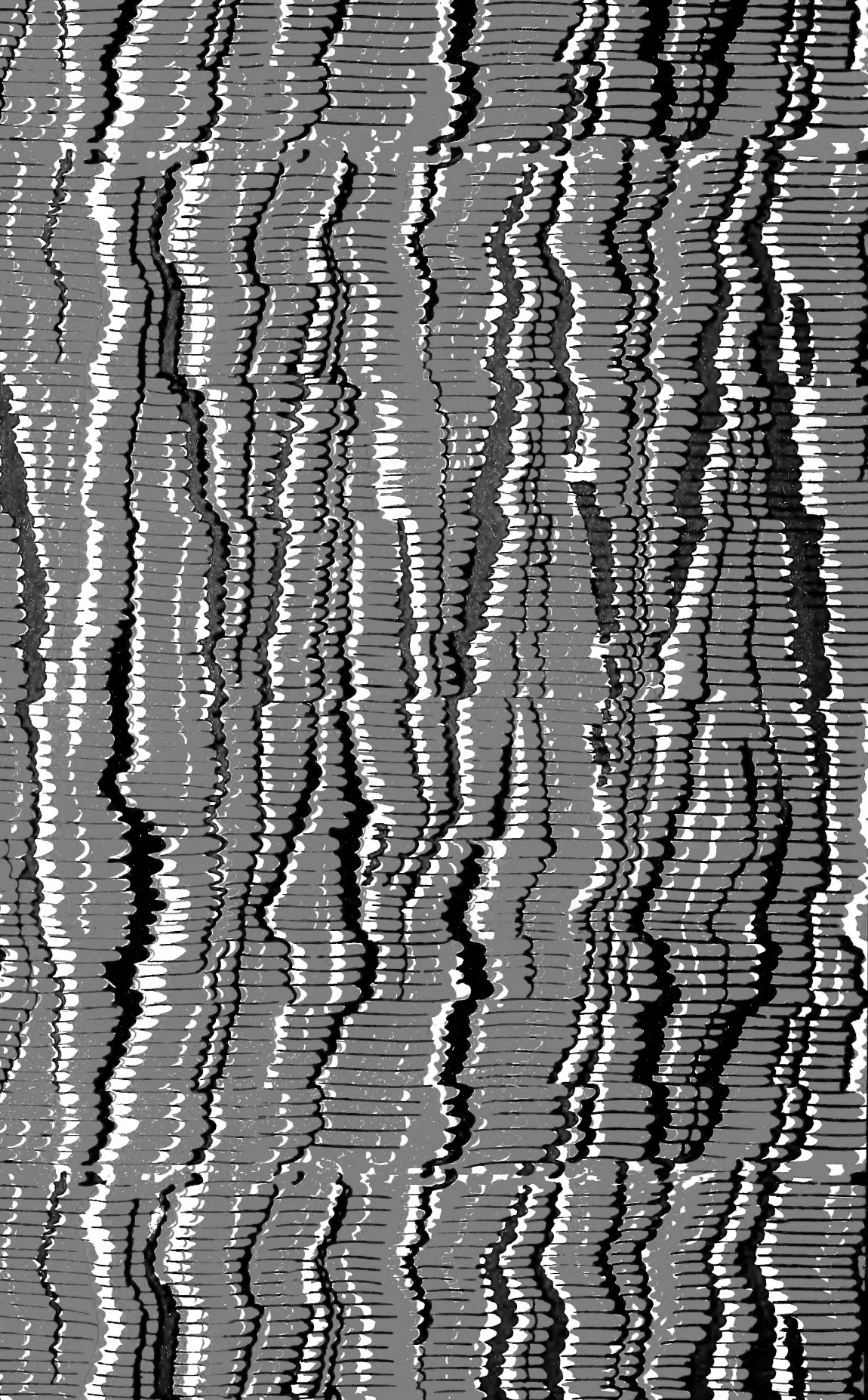
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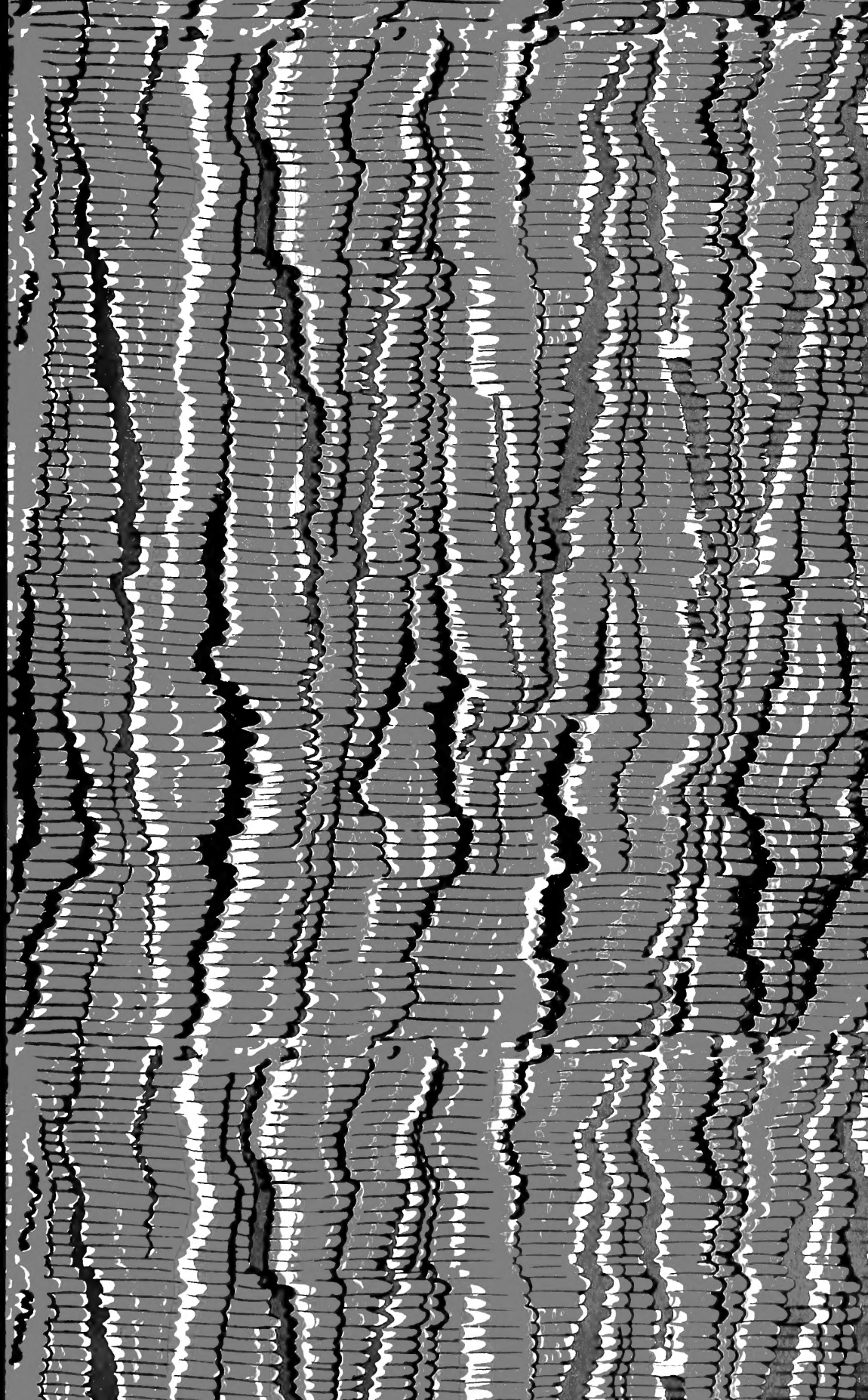
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