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CONTENTS.

the igneous rocks themselves. Perhaps the earliest hint of the possibility of such a connection is found in Le Verrier's suggestion ('88) that basic rocks were developed at periods of terrestrial calm, and acid rocks in times of great crust-disturbance. Harker ('96), followed by Prior ('03), Becke ('03), and later by Suess ('09), held that in periods and regions in which the crust was in a state of tension, producing block-faulting, rocks of a generally alkaline facies were produced, while in regions of compression and folding the much more abundant rocks of the gabbro, diorite, and granite series were produced.

Steinmann ('05) urged that "under the depths of the sea magmas of extreme basicity collect and are injected or poured out during the folding of the abyssal regions, while in the basements of the continents and under shallow seas acid magmas are brought forth * * *. In wearisome uniformity appear serpentine (and peridotite) and gabbro, generally in stocklike masses, spilite, variolite, certain diabases and diabase-porphyrites, as dike-forming rocks in certain zones of the younger folded mountains, while a typical effusive facies is seldom seen." The conditions of injection of the basic rocks he thought to be essentially different from that of the granitic and dioritic rocks. It is the alpine (overthrusting) type of injection as distinct from the cordilleran. Instances are cited of intrusions of the alpine type, in Ordovician, Carboniferous, and Mesozoic times in many regions.

Sacco ('05) attempted to show that the Cretaceous period was the epoch of greatest development of ultrabasic and basic rocks, but he considered together a number of rock types that do not seem to be genetically closely related to one another, either tectonically or petrographically.

Daly ('06, '14) introduced the conception of abyssal injection and assimilation as a cause of orogenic movement, and the consequent injection into higher portions of the crust or extrusion of magma. In this view the bulk of extrusive rocks consist of more or less undifferentiated basalt, the primitive magma, while the intrusive masses have assimilated the invaded and more acid crust-materials, and have become gravitationally differentiated. In his later statement the summary given of the field-occurrence of the basic and ultrabasic rocks emphasizes the importance of the gravitative separation, so that instances in which it may possibly be exemplified have a prominence above the greater number of occurrences where no such separation seems apparent. The reason for such partiality in statement is, however, clear from the very interesting and stimulative discussion given.

Suess's ('09) generalization concerning the green-rocks has been quoted above. The intrusion is held to have taken place during a period of movement and into planes of differential movement, or of bedding in the invaded rock. Thus, is explained the very frequent occurrence of peridotite or serpentine in long, narrow, sill-like masses parallel to the general strike of the structure lines of the surrounding region. A group of rocks have been classed by Suess under the single name of the green-rocks ("*pietre verdi*") which have rather diverse characters and must be specially considered.

Dewey and Flett ('11) have urged that a special group of rocks should be recognized, the spilitic suite, which range from picrites and dolerites to quartz-keratophyres, and are characterized by the abundance of albite. These were erupted as flows or sills in offshore regions in which crust-subsidence was proceeding unaccompanied by folding and faulting. They are thus considered to be distinct from Steinmann's ophiolitic rocks in their mode of origin.

Harker ('11) has accepted this group (omitting the quartz-dolerites) as a special subdivision of the alkaline branch of the igneous rocks both on tectonic and petrographic grounds, but Daly ('14), carrying to a further application a conception of Bowen's ('10), believes that their high content of albite is merely the result of the concentration of soda in the upper portion of an intrusive magma, by resurgent water derived from the wet sediments it has invaded, and he sees nothing especially alkaline about the rock-masses as a whole. They are merely flows and shallow intrusions formed during the sedimentation in a subsiding geosyncline, that preceded the main orogenic movement and plutonic intrusions.

C. H. Smyth ('13) also invoked gaseous transfer (but as the result of the action of juvenile, not resurgent, gases, chiefly water) by which alkalies and the elements especially present in pegmatites would be concentrated, and he concluded that alkaline rocks could be formed in this manner as the last consolidation products of a subalkaline magma. While not of the opinion that a regional differentiation occurred as the result of tectonic forces, he suggested that it might be possible that under the conditions of comparative tranquillity associated with plateau-block faulting, alkaline differentiates might be produced that could not be formed under conditions of lateral thrusting and folding. He accords no place to the absorption of sediments by the magma.

Bowen ('15), while considering that there is a comparatively slight alteration of magmatic composition by such absorption of sediment, and thus abandoning a characteristic feature of Daly's doctrine, concurs with him in putting a very great importance upon gravitational differentiation by the sinking of crystals forming in magmas originally of basaltic composition, believing that by this process together with the separation of liquid from crystals brought about by the deformation of a crystallizing magma even alkaline magmas may be developed as the latest products of magmatic differentiation, though possibly granitic, dioritic, gabbroid and ultrabasic rocks had previously been derived from the initial magma. Peridotites on this view are merely the aggregates of subsided crystals of ferromagnesian minerals, though it is held possible that they may have been re-fused in part, or mixed with residual magma to allow them to be independently injected into neighboring rocks. In common with perhaps the majority of American petrologists, he rejected the view that there is any provincial causal connection between the type of igneous rocks produced and the tectonic conditions existing before and during their crystallization, holding that the alkaline and alkali-calcic rocks are too closely associated to permit of such a tectonico-petrological connection, but he has since recognized the possibility of such a connection (Bowen '20, p. 162). This association is, however, recognized by Harker ('16), who also believes the alkaline rocks to be derived ultimately from the same magmas as the subalkaline, but urges that lateral pressure, is an efficient cause of spatial differentiation, no less than gravitative sinking, in that it causes the molten residuum of a magma to move into the regions of lesser compression, so that orogenic forces bring about a distribution of such fractions drawn from the parent magmas as to produce broad distinctions between petrographic provinces, when operating for a long period of time and over extensive areas, and local complexes of diversified types when acting within more limited areas. Indeed, he holds, as also does Cross ('15), that exposures of gravitationally differentiated masses of igneous rocks are far less common than Daly or Bowen believe. We may also suggest that in regions in which there are intimate associations of the more alkaline with the alkali-calcic igneous rocks, upon which some petrologists have laid much stress, e. g., Cross ('10, '15), local and gravitational (or gaseous) differentiation may have had a greater effect than regional lateral pressure, while in the regions where lateral pressure was strongly effective, leading to provincial specialization, it is still possible for a magma remaining unconsolidated after the great lateral pressure had diminished to be differentiated in the ways Bowen and Smyth described (for these by no means seem to be mutually exclusive), leading possibly to the production of nepheline-syenite, intrusive among the alkali-calcic rocks, as occurs in western Canada (Daly '12, pp. 448–454) and the Ural Mountains. The occurrence, therefore, of provinces of incomplete petrographic specialization appears to the writer not to be a negation of Harker's generalization, but rather as exemplifying a reasonable deduction from it.

The papers of Smyth and Bowen are of great value in that they suggest definite mechanical concepts for the process of differentiation within the magma, and the latter is especially noteworthy in that it deduces from a long experience of experimental research the probable physico-chemical conditions and compounds present in a cooling magma, which make possible the separation of fractions of the magma such as the field evidence indicates to have been successively differentiated in the production of igneous complexes. They give reason for the belief that very diversified types of rock have been produced from a single magma, probably of basaltic composition, and, as we have suggested, such differentiation may have occurred in a horizontal or in a vertical direction according to the tectonic conditions, and these may thus affect the type of rocks produced as well as the form of the complex.

Moreover, since both discussions show how small a proportion of the initial magmas can become concentratedly alkaline, they accord with Daly's demonstration ('14) of the exceedingly small bulk of the alkaline rocks compared with the alkali-calcic types, and lead us to infer that the individual rocks of a subalkaline complex, from which concentratedly alkaline rocks have been removed by differentiation, will not be noticeably poorer in alkalies than those which have suffered but little differentiation. The practical uniformity of the characters of, e. g., felspar-basalt from alkaline and calcic complexes, (Flett's ('12) instance of a "diphylitic rock type") may perhaps be explained in this manner.[1]

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[1] Holtedahl's discussion ('19) of "Sal and Sima" rocks has not been accessible to the writer.

Chapter II.

A PROVISIONAL TECTONICO-PETROGRAPHIC CLASSIFICATION OF INTRUSIVE COMPLEXES OF BASIC IGNEOUS ROCKS.

From the various considerations already adduced it will be quite clear that no general philosophy of petrogenesis should be based upon a study of a portion of the igneous rocks alone, however complete it might be in regard to geological, petrographical, and physico-chemical circumstances; and therefore, since no study of the intermediate and acid types of normal and alkaline igneous rocks has been made by the writer comparable in detail with those upon basic igneous rocks here given, it must be recognized that the generalizations which follow are derived perhaps too exclusively from the study of basic rocks. If, however, they are found to be an adequate statement of the modes of occurrence of such rocks, they may then be combined with the results of similar studies upon the other types of rocks into a general petrogenetic theory.

While no invariable rules for mode of occurrence of basic intrusive rocks seem yet discoverable, there emerge from the studies which follow the conception of several modes of occurrence, so frequently represented that they seem to result from fundamental principles of petrogenesis, while the exceptions to these are especially worthy of study, since in all probability they will throw most light upon the nature of the controlling conditions and the relationships to one another of apparently distinct modes of occurrence.

A frequent association of basic intrusive rocks is in a series of masses ranging from peridotites to granites, the relative size of the individual masses as mapped being often an inverse function of their basicity. In these there may be a gradual variation between the apparently laccolitic type of complex to that of a sill-and-batholitic phase. In the former the basic rocks appear as more or less of a marginal zone, and are commonly supposed to indicate either gravitational differentiation *in situ*, productive of a stratiform arrangement, the strata merging more or less completely into one another, or they may result from differentiation as a result of crystallization with active diffusion in the magma in the manner suggested by Harker's ('94) study of Carrock Fell, or the alternative explanation, viz, that as a result of chilling the margin crystallized without much differentiation, but the central portion consolidated only after much gravitative differentiation (cf. Daly '14, p. 358). In the sill-and-batholitic complexes the several portions of the complexes have been separated, and more or less stratiform or sill-like masses of peridotites and gabbros were formed, which were invaded subsequently by less regular batholiths of diorite, granite, etc., of which, however, the longer axes may still be parallel to the structure lines of the country. The complexes of the Bushveld [1] and of the Southern Urals may illustrate the former type; those of Garabal Hill and the Harz Mountains tend rather to the latter type. While the latter are always formed during a period of great lateral pressure, this does not appear to have been very noticeable during the formation of the first type of complex. Complexes of the latter type we may therefore conveniently class as of the cordilleran type (cf. Steinmann's usage of the term); for the former the phrase laccomorphic type may perhaps be suggested, though the term lopolith has been applied by Grout ('18) to certain instances of this type, notably the Duluth complex.[2] Between the two extremes there are a number of intermediate forms, as may be inferred from Bowen's comment ('15) on the varying extent of lateral separation of the fractions of a gravitationally differentiated complex.

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[1] The work of Brouwer and Humphrey now permits us to doubt the relationship of the Pilandsberg nepheline rocks with the Bushveld complex, though it seems still just possible that the two may be genetically connected.

[2] The convenient term "stromatolith" has been preoccupied for a very different significance (Foye '16) and for the name of a sedimentary rock (Kalkowsky).

In considering these two groups we must carefully distinguish between two types of ultrabasic rocks. Normally the more abundant are the earliest ultrabasic and basic intrusions of a complex, the subordinate type are the petrographically very similar dikes commonly termed "picrite,"[3] and these form the latest differentiates in the "phase of minor intrusions," which follows that of the major intrusions in a cordilleran complex. Harker ('04) has emphasized this distinction in Skye. The well-known hornblende-peridotite of Schriesheim is a further example of these intrusions. Analogous to them, though not so basic, are the dolerite-dikes which form the final products of the "phase of minor intrusions" in many normal cordilleran complexes. No petrographic distinction can generally be drawn between the basic rocks of the major intrusions of the laccomorphic and cordilleran type, in spite of the apparent difference in the extent to which they have been subjected to lateral pressure.

Some of the members of the cordilleran group, particularly the Ivrea rocks (see p. 26) were included among the "green-rocks" in Suess's generalization.

In the third group of occurrences, which we may term the alpine type, are comprised the majority of the "green-rocks" as considered by Suess. These are also the "ophiolitic rocks" as defined by Steinmann ('05), in which serpentines and gabbros are intimately associated with amphibolites and diabases, sometimes showing the ellipsoidal form of pillow lavas. They occur in regions that have been intensely disturbed by overthrusting and alpine orogeny. The conditions under which they may have been formed are far from being obvious. We must leave this group aside for the present as one requiring further analysis and endeavor to discuss it subsequently (p. 68). With the possible exception of certain of the diabasic members, the chemical features of the rocks of this group are those of the more basic members of the cordilleran group.

In addition to these, there is a fourth mode of occurrence of ultrabasic and basic rocks, namely, in the form of lenticular masses generally conforming to the structure lines or schistosity of the gneissic, or schistose complexes in which they occur. It is not always possible in such cases to state the conditions under which these masses were injected, though it is not improbable that many are essentially intrusions of the alpine or cordilleran types and were erupted during orogenic movement. The ultrabasic and basic igneous rocks of the Caledonian series in Norway afford good examples.

A very uniform group comprises the sills of dolerite, and especially quartz-dolerite, which invade approximately horizontal but not folded strata, underlying very broad areas, but sometimes rising obliquely through the invaded strata. Rarely they are associated with apparently indubitable examples of gravitationally differentiated laccolites. The mechanism of their intrusion is somewhat obscure, but its action must have been rapid to permit the extension without chilling of such widespread but narrow intrusive sheets. It is evident that it was not accompanied by marked lateral pressure. The dolerites—and the associated laccolitic masses with basal differentiates when these are present as in Natal (p. 49)—have much the same range of chemical characters as occur in basic members of the cordilleran group of rocks. The Whin Sill of England, the Palisades on the Hudson River, the dolerites of the Karroo, of Tasmania, and of Antarctica are typical members of this group. The average composition of these rocks has probably undergone comparatively little differentiation from the parent magma though relative differentiation may be present.

The occurrences of basic intrusive rocks with alkaline features may be classed in two further divisions, the first of which being that specially considered by Becke ('03) and typified by the Tertiary complex of the Bohemian Mittelgebirge and the late Palaeozoic rocks of Scotland, (Tyrrell '12). We may term them the alkaline plateau-group, thus distinguishing them from those last considered. They comprise rocks which were not classed under the green-rocks by Suess, the essexites, theralites, teschenites and picrites in the original sense of the term.

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[3] The inclusion of these rocks under the term "picrite" is an extension of the significance given to it by the originator Tschermak ('67) who applied it to the melanocratic phase of teschenites, formed under completely different conditions from the rocks considered here (see p. 7). This usage, therefore, seems disadvantageous in many respects and has been abandoned by Dr. Harker. See also Bailey's discussion ('10).

On the one hand they are associated with strongly alkaline phonolites, nephelinites, basanites, and other felspathoid-bearing rocks, while on the other hand they are also accompanied by felspar-basalts often indistinguishable from those accompanying the subalkaline andesites, but they are not commonly associated with gabbros, diorites, etc. These alkaline plateau-rocks occur in regions of vertical block-faulting, with perhaps some tilting but not strong lateral thrust, and consequent folding. They are, however, sometimes found in areas adjacent to regions of central compression, and development of subalkaline rocks, as for example in the case of the occurrence of ouachitites near Mull. It is usually stated that the rocks of this group have been erupted under conditions of crust-tension, but perhaps it would be more in accord with modern views (e. g. of the origin of the Great Rift Valley) to state that the tectonic conditions accompanying intrusion were those of relatively slight lateral pressure, or even tension.

A special subdivision of this group is probably indicated by the perofskite-bearing mica-peridotites, sometimes erroneously termed "kimberlite." These are absolutely distinct from the mica-peridotite of the Harz as indicated by Rosenbusch ('07) (see p. 20), and from the bulk of "formations ophitofères" of Sacco ('05), though included by him in that series. They form thin dikes and (rarely) sills in almost horizontal but often faulted sediments in Eastern United States, South Africa, and India. They contain melilite in several instances, and are apparently related to the material of the kimberlite-breccia type of South Africa and the melilite-basalt, and alnoitic breccia of the volcanic necks of southern Bavaria (Schwarz '05). It will be convenient to employ for these the term "alkaline peridotite-dikes."

Finally, we have a much more varied group comprising the majority of the spilitic suite of Dewey and Flett ('11). They are stated to be characteristic of those offshore regions which have undergone steady subsidence unaccompanied by folding or faulting. We may therefore consider these as forming on the margin of geosynclines. They comprise sills and flows very closely associated, of picrite, albitic diabase (or dolerite) of several types, spilites,[4] keratophyres, etc. Harker has recognized these as a division of the alkaline branch of igneous rocks, with well-marked tectonic and petrographic characters ('11), while Erdmannsdoerfer ('07) and Weber ('10) have shown some petrographical analogy between the essexite, theralite series (our alkaline plateau series) and the diabases and keratophyres of Germany. Rosenbusch's hesitation concerning the affinities of the keratophyres is significant in this connection. Intrusion of the one series into subaerial rock masses, and of the other into silty subaqueous sediments may have accounted for some structural differences, and Daly ('14, p. 340) urges the later is the cause of the concentration by the action of vapors ("gaseous transfer") of the soda into the rocks of the spilitic suite in which he was formerly supported by Bowen ('10). How far this last may be true or not (and the writer's observations in New South Wales do not support it)[5] the conditions of origin of the spilitic suite of rocks, and those of alkaline plateau rocks are alike in the absence of effective lateral compression at the time of eruption, but unlike in the fact that the essexite-theralite group generally were formed in continental regions that have not been folded to any degree subsequent to their eruption,[6] while the spilitic rocks were formed during the slow subsidences in geosynclinal areas that preceded orogenic movements with intense lateral compression, and they are therefore generally greatly disturbed. Daly ('18, p. 112) has objected to a distinction somewhat analogous to this made by Harker ('16) on the ground that it is unsafe to infer the conditions accompanying an act of intrusion by the subsequent history of the region in which it occurred. But, while recognizing that there is no necessary coincidence of tectonic provinces of different ages, some degree of correspondence may

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[4] These spilites are soda-rich albitic rocks occuring in definite tectonic and petrographic association. There are many non-albitic spilites (e. g. perhaps those of Bohemia described by Slavik '08) which lack these features and can not be included in the "spilitic suite" as defined by Dewey and Flett, though even in these Algonkian pillow-lavas, the origin of the associated chert is assigned to a "post-volcanic effect of the spilitic cruptions!" (Von Purkyně '09).

[5] Compare the statements on page 71, and Sundius observations ('15) in regard to the bearing of Termier's hypothesis ('98) on this point.

[6] Note the exceptional cases mentioned in northwestern Germany.

be looked for, "inasmuch as there is a certain tendency for successive systems of crust-movements, even at wide intervals of time, to follow in some measure the same general lines." (Harker '09, p. 105.) In the contrast between the conditions of the Tertiary alkaline rocks of the Bohemian Mittlegebirge, almost undisturbed save for block-faulting, with the roughly coeval green-rocks of the Apennines, which have suffered intense dislocation, we see that the difference in their history subsequent to their eruption accords with the difference in the tectonic conditions, plateau as against geosyncline, of their place of development, and may notice a corresponding difference in the original petrographical character of the rocks themselves.

Chapter III.

THE BASIC AND ULTRABASIC INTRUSIVE ROCKS IN NORTHERN EUROPE.

THE BRITISH ISLES.

Probably there is no country of similar area with a more lengthy and complex record of igneous activity than that of the British Isles, or one which has been studied more intensively from the tectonico-petrographic standpoint. The facts have recently been summarized in Harker's comprehensive address ('17), to which the writer is much indebted, and also to Sir A. Geikie's "Ancient Volcanoes of Great Britain" ('97). We here consider very briefly those portions only which bear upon the basic rocks.

Pre-Cambrian.—According to the views of Barrow ('12) the oldest formation of the Scotch Highland, the Dalradian series, though very highly metamorphosed, indicates the association of a series of lava flows, in part pillow-lavas, with intrusive contemporaneous sills of dolerite, albite-dolerite, keratophyre, and soda granite, interstratified in a series of quartzites, shales and limestones. In Aberdeenshire they are now mostly amphibolites, but in Banffshire and Argyllshire their affinities with the spilitic rocks are indicated (Peach '04, '09). Their development was followed by orogenic movements and igneous intrusions which produced the majority of the gneissic and igneous rocks of the Scotch Highlands, the older igneous rocks of the Highlands. The earliest of these were of stratiform masses of hypersthene-gabbros, and occasionally pyroxenite or peridotites in narrow sills.[1] All of these suffered intense folding and were subsequently invaded by granitic gneisses. Barrow ('12) considers that the great period of folding separates these two series of intrusions, and that the former basic intrusions were injected into the Highland sediments and lavas before they had been much disturbed. Harker ('17), on the other hand, thinks that the intrusion of the basic rocks accompanied the main folding in which their sill-form was determined, while the granitic masses of more irregular outline formed during the times which directly followed the main period of orogenic movement. (See also Read '19 and fig. 1.) More clearly laccolitic types of igneous complex occur occasionally, such as at Carn Chinneag, where the granite has a differentiated margin of diorite and gabbroid rocks. Here the division of the plutonic action into two sharply defined phases is not apparent. Similar pre-Cambrian albitic pillow-lavas occur in the Lleyn Peninsula and Bardsey Island of North Wales and in Anglesey, where their eruption seems to have occurred under exactly the conditions specified for the development of the "spilitic suite." The ancient sediments and intercalated volcanic rocks were subsequently intensely folded and invaded by a series of probably late pre-Cambrian plutonic rocks ranging from peridotite, mostly dunite, to a rather sodic granite, the latest of the series. (Greenley '19.)

The Lizard region is different from these. The oldest series of rocks, the Lizard Head schists and granulites were interstratified with basic sills and lava-flows and ashes. They were invaded by tonalitic rocks and cut by dolerite-dikes. Great crust-movements followed, after which were injected coarse dolerites or gabbros (now hornblendites), which were immediately followed by the intrusion of a roughly circular, probably laccolitic mass of peridotite, within which is lherzolite and harzbergite. Fluxion-banding is a marked feature of these rocks. "The zoned structure is clear evidence that the serpentine is an intrusive stock that welled upward and forced outward the surrounding schists. The fine 'flinty-looking' serpentine of the margin was the earliest, and the coarse bastite-serpentine the latest portion of the intrusion." (Flett and

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[1] The ultrabasic rocks of Connemarra probably belong to this series, but little is known definitely about them.

Hill, '12, p. 21.) This series of intrusions was followed by the injection of troctolite and later of gabbro, with flaser or massive structure, forming innumerables dikes in the serpentine, and a large mass extending beyond the limits of the visible serpentine. After a considerable period of cooling there came the intrusion of olivine-diabase, and a set of composite intrusions of partially mixed doleritic and granitic magma forming the streaky masses known as the Kennack gneisses, followed immediately by small laccolitic masses of granite. The extremely metamorphosed character of many of these rocks is explained as the result of the orogenic pressure suffered while still hot.[2]

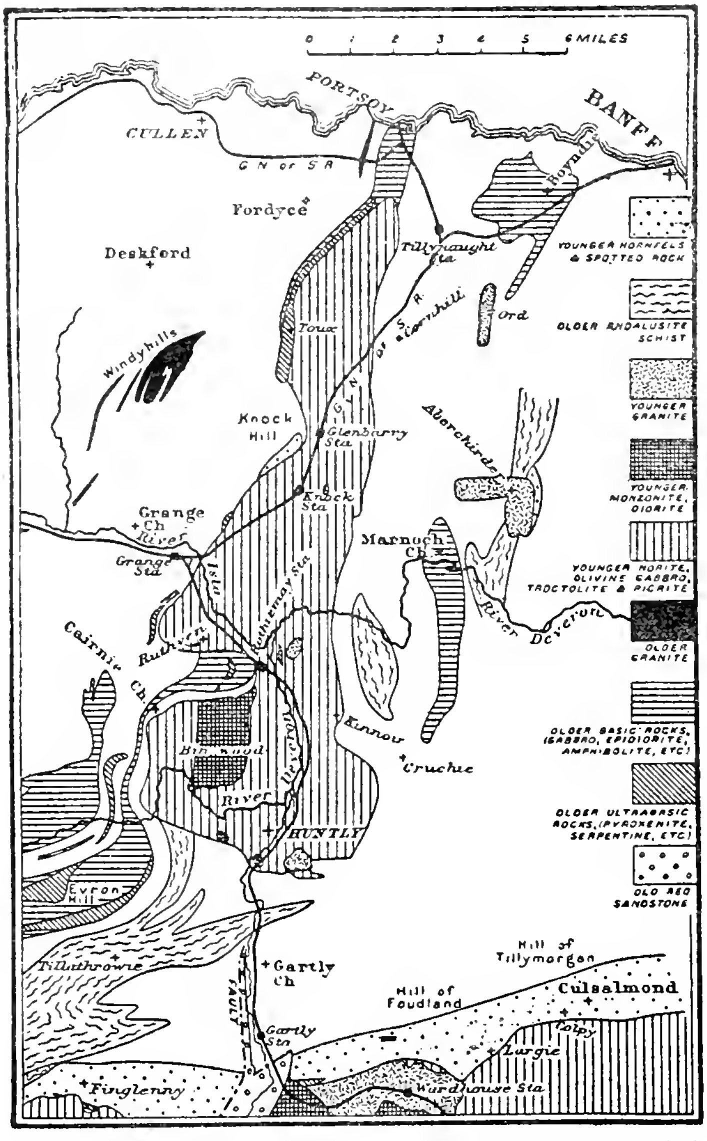

FIG. 1.—Sketch-map, showing distribution of Older and Younger Igneous Rocks in Strathbogie and Lower Banffshire. (After Read.)

Early Paleozoic.—The chief epoch of igneous activity in this era was that commencing in late Cambrian times and extending into the early Silurian. Rocks of the spilitic suite, both flows and intrusions, were developed during the steady deposition of radiolarian sediments in a geosyncline. These now appear along each side of the Central Valley of Scotland. The northern series stretching from Stonehaven to Arran appear to be, in part at least, of Upper Cambrian age (Campbell, '13), while those to the south stretching from Ballantrae to Peeblesshire are Arenig (Peach and Horne '97). Jehu and Campbell ('17) have described the northern series at Aberfoyle. Here there are Upper Cambrian or passage-beds into the Ordovician, consisting of black shales and cherts containing radiolaria, graptolites, and brachiopods, with interbedded spilites, and intrusive albite-dolerites, "serpentinized albite-gabbros," and dunite serpentine, more or less changed to a ferruginous dolomite. The serpentine shows evidence of intense shearing and has apparently shared in the movements which induced the foliation in the rocks to the north. In the region immediately north of Ballantrae there is a marked unconformity between the Ordovician and Silurian rocks, though only 12 miles to the south of Ballantrae they are quite conformable. During the crust movement indicated by this unconformity, approximately stratiform masses of peridotite and gabbro were thrust into the Arenig rocks. The intrusive character of these was first proved by Professor Bonney ('78), and they are sharply distinct from the associated spilitic rocks; the gabbros and serpentines are in separated masses, the latter being the older. The pre-Silurian age of

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[2] In the above account the opinions of Dr. Flett, who guided the writer over the region, have been adopted, as was done in Dr. Harker's address ('17). Nevertheless attention should be directed to the divergent views urged by Prof. Bonney ('14).

these plutonic rocks can be inferred from the occurrence of pebbles of serpentine and gabbro in the Silurian rocks. The same zone of Ordovician sediments with intercalated basic rocks may be traced into Ireland, where pillow-lavas occur with chert in Tyrone (Geikie '97), Mayo, and Galway (Reynolds and Gardiner '09, '10, '14). The sediments and igneous rocks are here of Bala age, and were thus formed at a period nearer to the epoch of folding than the Arenig rocks. The occurrence of conglomerates among the sediments, and lamprophyre among the intrusive rocks, are features not recognized in Flett's conception of a typical development of the spilitic suite. Another instance of the association of somewhat diverse types of igneous rocks lies in the interdigitation of normal basaltic lavas with those of a spilitic facies rich in acid plagioclase, skomerites, etc., in south Wales—Skomer, Haverfordwest, Llangynog, and Fishguard. These are variously of Arenig, Llanvirn, and Llandeilo age. (Thomas and Cantrill '06, Thomas '11, '14, Cox and Jones '13, Cox '15.) On the other hand, the Ordovician greenstones of Cornwall, like those of Scotland, are thoroughly representative of the spilitic petrographical characters, and their occurrence affords the typical examples of the association of these with radiolarian sediment, as Dewey and Flett ('11) and others have shown.

In north Wales, the Ordovician rocks are usually of Llandeilo age, and are generally free from any alkaline features. There occur several sill-like masses of basic rocks, some of which are so constantly associated with the arches or troughs of folds as to be probably phacolites rather than laccolites, and to have been injected during the late Ordovician folding. The most interesting is that of Mynyth Penarfynydd, which is perhaps in part gravitationally differentiated, the mass of hornblende-diabase having a thick layer of olivine-dolerite near its base. Although there is no very gradual transition between the two rocks they are evidently in close connection, and indeed have segregation-veins passing from one to the other. (Harker '89.) The minor intrusions which invaded the older Paleozoic rocks of Anglesey during the late Silurian folding, though partly felsites, have for their latest members dikes of dolerite and sills of hornblende-picrite, which, though affected by the later stages of the orogeny, lie concordantly within the cleavage but not the bedding planes of the invaded formations. (Greenley '19.)

Completely different from these are the rocks described by Shand ('10) at Loch Borolan in northwest Scotland, though they are possibly of the same age. Here are a very remarkable series of garnetiferous ultrabasic rocks associated with alkaline types. In places the differentiation appears due to gravitational separation; in other places sharp lines of division appear between the rock types. The relationship is obscured by imperfect exposure and crushing subsequent to consolidation and cooling, and it is not clear what tectonic conditions accompanied their intrusion.

The middle and late Paleozoic intrusions.—The folding which followed Silurian times was accompanied by the intrusion of the newer granites of Scotland which with one exception are entirely subalkaline. In occasional occurrences as at Garabal Hill (Teall and Daykins '92, Wylie and Scott '13), at Glen Doll, and the Coyles (Barrow '12), basic and ultrabasic rocks are developed. In the first of these a rock, which is a hybrid of acid and basic types, has been noted by Wylie and Scott, and in the Glen Doll complex a hornblendic rock occurs of probably similar nature.[3] Generally, however, the successive intrusions are sharply defined. The boundaries of the ultrabasic masses follow the structure lines of the invaded formation much more strongly than do those of the acid types, which are generally transgressive. The kentellanites (olivine-monzonites) of Argyllshire, though of a somewhat alkaline nature, have a fairly stratiform habit, and exhibit a distinct gravitiatonal separation. They are associated with an augite-diorite marginal facies of the granite boss of Ben Cruachan (Hill and Kynaston '00, '08). Further kentellanites and still more basic cortlandites near Ballachulish are similarly related to the granites of Ben Nevis (Bailey and Maufe '16), and quartz-syenites, monzonite, "picrite," and hornblendite occur together on Colonsay (Bailey and Wright '11). The basic plutonic rocks of Huntly in Aberdeenshire, described by Watt ('14), perhaps afford a further instance of a

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[3] The writer had the privilege of seeing this area with Dr. Harker and Mr. Barrow.

gravitationally stratified laccolite of norite with gabbro, banded troctolite, and "picrite," but Read ('19) points out that there are no gradual passages from one rock to another, and the individual rock-types are well marked. "It seems more probable that the differentiation of the gabbroic magma took place in a lower chamber, and that the picrite was intruded as a small sill followed by increasingly acid derivatives, each of which slid roughly on the top of its forerunner. After the intrusion of the composite picrite-norite set had finished, there were intruded a few small bosses of diorite, followed by monzonites, granites, and pegmatites." (Op. cit.)

The date of intrusion of all these masses is rather vague. The inclusion of pebbles of granite in the lower Old Red Sandstone, and the invasion of this sandstone by the granites of Glencoe would suggest a long, continuous period of plutonic activity with recrudescence of intrusion through the interval between late Silurian and Middle Devonian times.[4]

The close of the Highland-folding, and the deposition with continued subsidence in the lowlands of Scotland of Devonian and Carboniferous sediments was accompanied by intrusions which, commencing in Lower Carboniferous times, reached their maximum in Upper Carboniferous and Permian times. The rocks developed are dolerites, essexites, theralites, teschenites, and true picrites, with basalt and limburgite. They occur especially near Edinburgh and Glasgow (Bailey and others '10). The remarkable sills of picrite of Inchholm (Campbell and Stenhouse '07) and Lugar Water[5] (Tyrrell '09, '12, '17) and the analcite-rocks discussed by Tyrrell (op. cit.) and Scott ('16) are the most noteworthy members of this group of rocks, which are clearly alkaline in character, and very analogous to the Bohemian prototypes of Becke's "Atlantische Sippe." They clearly fall into the alkaline plateau group of eruptions in our classification and owing to the abundance of magmatic water, have been greatly differentiated, the subsidence of the heavier crystals being facilitated by the abnormal fluidity of the magma.

While, however, the early Devonian conditions ot crust folding and igneous intrusion of the orogenic type were waning in Scotland and passing into the Carboniferous conditions of plateau-subsidence and eruptions, geosynclinal conditions of sedimentation with typical spilitic eruptions had recommenced in the southwest of England, and extended from the Devonian into Carboniferous times. The extension of this geosyncline, the Hercyniau trough, passed through Germany, where somewhat similar conditions occurred. In England, the shape of the igneous masses formed at this time has been more or less obscured by later folding and crushing, but the presence of tuffs and pillow-lava, often reduced to the condition of schistose greenstone, intercalated among phyllites and radiolarian sediments, of clearly intrusive albitised dolerites, minverites, palaeo-picrites, and keratophyres, typify the features of the spilitic suite of which this area has been taken as the type by Flett and Dewey ('11). The subsequent folding and overthrusting in later Carboniferous times, of the geosyncline in which these rocks were developed, is the most marked feature (Dewey '09), and this overthrusting was followed by the intrusion of the Hercynian granites of Devon and Cornwall.[6]

It was perhaps during the latter part of the Carboniferous period that the Whin Sill was formed, a sheet of dolerite which extended probably continuously over an area of more than a thousand square miles. It is on the average about a hundred feet in thickness, but diminishes toward the west; rarely it splits into two portions. It is not quite concordant, but lies with a very slight obliquity to the bedding planes of the inclosing Carboniferous limestone, as in different districts it appears in different horizons in the Carboniferous succession. No trace of any boss or neck which might be supposed to mark a funnel of ascent for the material of the Whin Sill has been detected (Geikie '97, Harker '17). The intrusion of Carrock Fell (Fig. 2) may also be of this age, though possibly it should be referred to the Tertiary period (Harker, '94, '09, '17). It is interesting as being the example chosen by Harker to illustrate differentiation by crystallization with active diffusion in the magma. Bowen ('15) has urged

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[4] There is a long dike of serpentine believed to invade the Old Red Sandstone near Kinnordy in Forfarshire. No modern data concerning it are yet available.

[5] The writer was guided over this region by Mr. Tyrrell.

[6] The writer is indebted to Mr. Dewey for guidance through this region.

objections to this process, and holds that the basic marginal facies of laccolitic complexes are the portions of the magma that were cooled and crystallized quickly with but little differentiation. At Carrock Fell these marginal rocks about the central mass of quartz-gabbro contain as much as 22 per cent of iron ores, so that if this explanation be true, the original magma must either have been very abnormal, of which there is not other evidence, or a considerable segregation of iron-ore to both the floor and roof of the sheet of laccolite must have occurred, as Daly recognizes ('14 p. 359).

The Tertiary intrusions.—No further development of ultrabasic or basic plutonic rocks occurred till Tertiary times, when igneous activity again centered in the northwestern areas. Sir A. Geikie ('97) and Harker have shown that the plateau basalts of the Brito-Icelandic petrographic province as recognized first by Judd ('86) were formed by a series of fissure eruptions of which merely the horsts remain above sea level. They have a slightly alkaline facies, indicated by the occasional abundance of sodic zeolites (Harker '11), and the presence of definitely alkaline rocks, such as the nepheline-rock of Shiant, the ouachitite of Mull, and the rockallite of Rockall. About centers of tangential pressure (from which the abundant dikes tend to radiate), such as the Cuillins in Skye, St. Kilda, Eigg, Rum, Muck, Mull, Ardnamurchan, Arran, and Carlingford, there appear laccolitic complexes of peridotite and gabbro invading the basalts and invaded by granite. That of Skye (Fig. 3) has become classic through the investgiations of Harker ('04). Only a brief summary can be given of the varied features of this complex. The overlapping of the older formations around it shows that it was long a center of elevation. The volcanic phase was followed by the intrusion through fissures of varied peridotitic rocks, in alternating bands or in masses in which a later rock veins an earlier one, or is crowded with débris of it They were succeeded by much larger intrusions of gabbro, the western portion being laccolitic, and the eastern boss-like, the latter being the region of most narrowly localized and intense strain. The gabbro-laccolite was built up of a multitude of distinct intrusions which differ somewhat in composition and structure, and often visibly cut one another. In some places no interval of quiescence separated the period of intrusion of the gabbro from that of the succeeding granite, as is shown by their extreme interaction, but in one place the granite has been so chilled against the gabbro that its margin and apophyses have assumed the structure of spherulitic rhyolite. The granite has also assumed the laccolitic habit in the west and the boss-form in the east. In the former it was intruded partly beneath and into the gabbro. The granite-boss rises from the dome of an old anticline which has been a center of uplift since Paleozoic times, and the upward thrust was renewed after the injection of the granite. The laccolitic gabbro-granite mass, on the other hand, has a synclinal structure, due perhaps to subsidence into the region from which the magma was extravasated. A series of minor intrusions were formed after this, dolerite-sills in the plateau-basalts, dolerite-sheets in the gabbro, and a few ultra-basic dikes near thereto, while composite sills and granophyres formed about the boss of granite. The complexity of these relations are held by Harker ('16) completely to exclude the possibility that the complex could have formed by gravitative differentiation of a laccolite with a general easterly dip formed as the result of "a single principal act of intrusion of magma" as suggested by Bowen ('15).

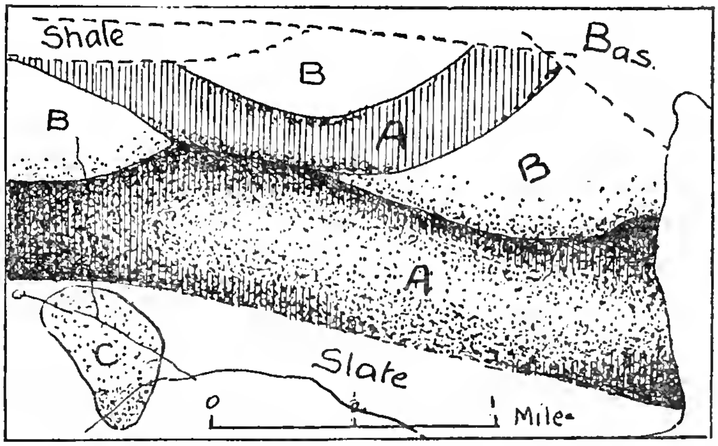

FIG. 2.—Geological map of Carrock Fell, Cumberland. (After Harker.)
A. Gabbro increasingly basic toward margin.
B. Granophyre rendered basic on margin by absorption of Gabbro. C. Greisen.
Invaded formations: Slates, shales, and old basalts.

In Rum, also (Harker '08) (Fig. 4) the Tertiary basalts have been invaded by plutonic masses. The ultrabasic rocks occupy the highest position in the complex; their lower anothite-bearing member (harrisite) is clearly the younger, and its junction with the overlying peridotite is an intrusion-brecci. The eucrite-gabbro invades the ultrabasic rocks but lies for the most part beneath them. The junction between these two masses is a zone of fragmental peridotite inclosed in veins of gabbro, which is sometimes a hundred yards in width. The granite in turn invades the gabbro, but lies for the most part beneath it. In several regions their mutual reaction has produced hybrid rocks, which solidified with a primary gneissis structure, owing

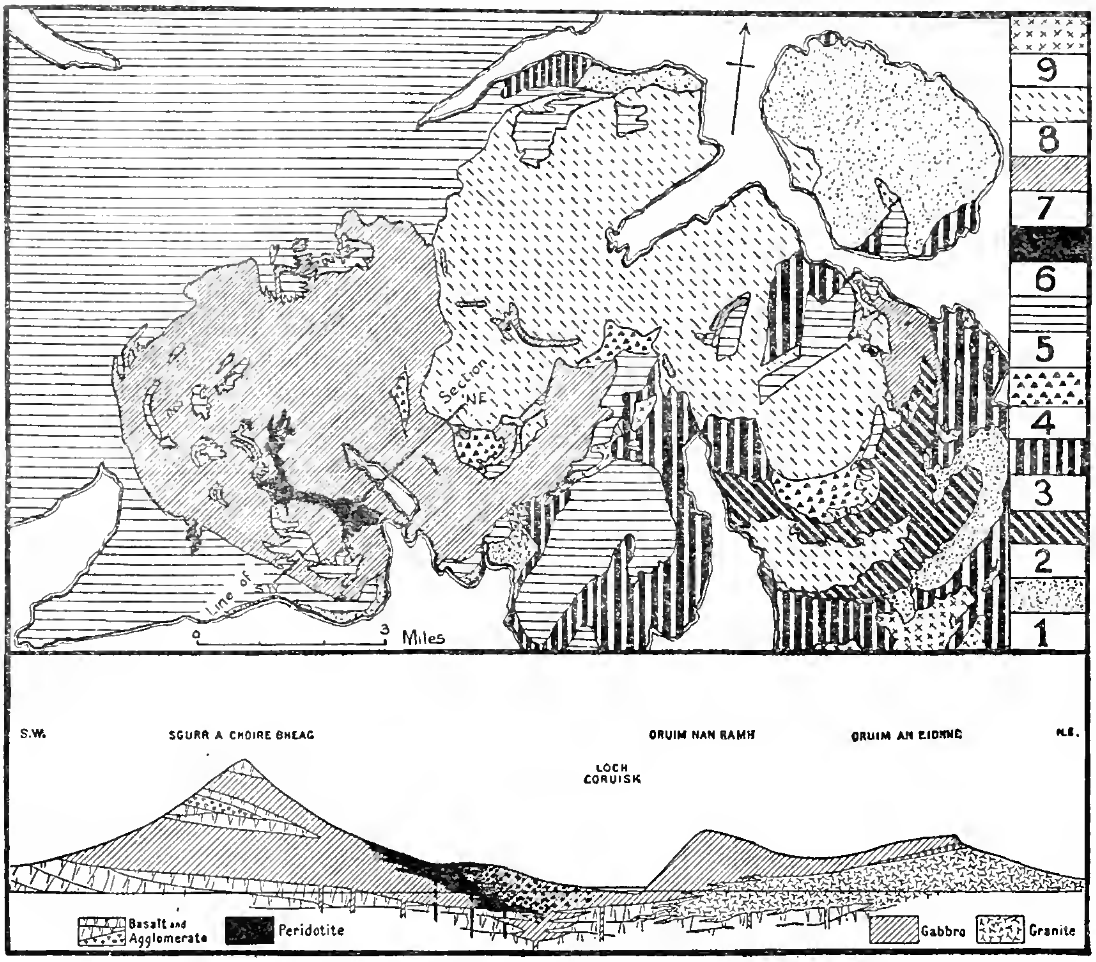

FIG. 3.—Geological map (somewhat simplified) and section of Skye. (After Harker.)
1. Torridonian sediments. 2. Cambrian limestone. 3. Mesozoic sediments. 4. Tertiary agglomerate.
5. Basalt with some dolerite-sills. 6. Peridotite. 7. Gabbro. 8. Granite. 9. Granophyre.

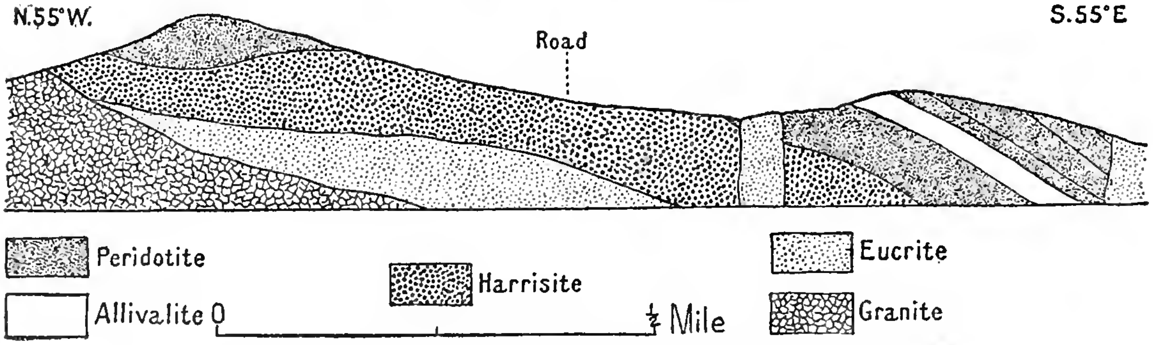

FIG. 4.—Geological section showing the relations of the plutonic rocks in Rum. (After Harker.)

to the effect of movements during crystallization. These relations are clearly the reverse of those which the hypothesis of gravitative differentiation *in situ* would lead one to expect.

In Mull the complexity of the record is increased by the repetition of the cycle of igneous activity, but as the publication of the detailed account of this region is expected before long, no summary will here be given of the progress-reports that have been issued.[7]

The features in Arran and Carlingford do not call for special mention in this place. The latter is classical for the evidence therein of the relation of granophyre to quartz-gabbro. (Sollas '94.)

FINLAND AND SCANDINAVIA.

The basic rocks of this area are mostly of pre-Cambrian or early Palaeozoic age. The former are very abundant, but can not be discussed fully as yet from a tectonico-petrographic standpoint. The later pre-Cambrian (Jotnian) rocks of Finland are invaded by differentiated laccolites, sometimes gravitationally arranged, at times showing hybrids allied to the marscoite of Skye. Occasionally the gabbroid rocks are associated with granites. Many of the occurrences of gabbro and peridotite in this Jotnian complex have a marked stratiform arrangement suggestive of intrusion during folding (Sederholm '03).

The Caledonian period of crust-folding produced huge overthrusting with which was associated the development of the great masses of basic igneous rocks of Norway, consisting of gabbro, rich in titanium, norite, anorthosite, and peridotite. These have a stratiform appearance, as noted by Vogt ('02) and Kolderup ('03). With these basic rocks are associated monzonitic granites and syenites, which become notably sodic in the Bergen region, an association which seems an extension of a feature already noted in the presence of kentallanites with the Caledonian basic rocks of Scotland. The order of intrusion of these plutonic rocks in Norway is not always from basic to acid but sometimes intermediate, basic, acid (Högbom '13).

Goldschmidt ('16) has summarized and extended the studies of these rocks in southern Norway. They are referable to three series or "stems." That of the green lavas and intrusive rocks is comparable with the series of Ordovician igneous rocks of Scotland and the *pietre verdi.* It consists of tuffs, variolitic spilites and diabases (associated with radiolarian jasper) paleopicrite, and sills and laccolites of gabbro, periodotite and pyroxenite. The igneous activity extended from late Ordovician times into the period of Caledonian orogeny, for dynamically metamorphosed gabbros lie concordantly in the planes of schistosity of the invaded formations. These rocks have a normal calcic composition except for a rather sodic diabase, the analysis of which is cited by Falkenberg ('14). The occurrence of sulphide-ores in connection with the gabbros of this stem has long been studied by Vogt and others.

The opdalite-trondhjemite stem is probably cognate with these. It contains as its earliest members pyroxenite and peridotite, but only as large inclusions in dynamically altered gabbros and norites, and also diorites and trondhjemite (a sodic grano-diorite). The rocks form steeply inclined laccolitic masses concordant with the schistosity of the invaded formations. They were erupted after the rocks of the first-mentioned stem, but before the conclusion of the Caledonian orogeny, and were exposed to erosion in Devonian times. "It is quite probable that a geological connection exists here between the orogeny and the plutonic intrusion." The rocks are comparable with the later plutonic rocks of Scotland, the East Alpine tonalites, etc., and the American granodioritic series.

The stem of the Bergen-Jotun rocks is probably, but not clearly, related to these two stems. It has been studied chiefly by Kolderup ('03, '11, '14, '15), who showed its affinity to the charnockite-anorthosite group of Rosenbusch. It comprises peridotites and pyroxenites in small lenticular or rounded masses inclosed in the gabbros and orthoclase-bearing norites. With these are labradorite-rocks with cataclastic structure, in which a single dike of peridotite has been recorded. The latest members of the stem are hypersthene-syenites and alkaline granites. The close association between the intrusion of these rocks and orogenic movement is shown by

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[7] The writer had the privilege of studying Carrock Fell and Skye with field directions given by Dr. Harker, and of examining part of Mull in company with Dr. Thomas and other officers of the Geological Survey then investigating the island.

their clastic (sometimes protoclastic) structure and sill-like habit. It is not clear, however, whether this was a pre-Cambrian or early Caledonian orogeny, though the latter appears more probable.

Interesting observations have been made also in northern Norway by Foslie ('21). "Outside the real roots of the mountain-chain, all eruptives seem to have been intruded parallel to the schists, the moving force being induced by the orogeny folding itself, and lateral pressure existed throughout the crystallizing period." Where the marginal meshwork of crystals was able to protect the central residue of uncrystallized magma, a complex was produced by differentiation *in situ*, consisting of marginal norites including scattered masses of peridotite, and a sharply distinct central body of quartz-norite, with aplite-dikes. There is here no effective gravity-control of the differentiation. Where the lateral pressure was excessive, there are sill-like masses of rather sodic amphibolite with albitized plagioclase, and small lenticular masses of altered peridotite, together with sodic granite or granodiorite, and rarely schlieric types of diorite.

While there is thus in Norway an association of alkali-calcic rocks with alkaline granites, Goldschmidt ('16) holds that one "would be going too far in generalizing from such always rare associations if one denied the essential difference between most alkaline stems and alkali-calcic stems. Direct comparison between the alkali-calcic stems of the Caledonian folded mountains and the *completely* alkaline stem of the neighbouring fault-graben of Christiania affords an instance of this." Brogger ('94) showed that the latter rocks, some of which are basic, were erupted during the Devonian block-faulting, and they may therefore be classed in our alkaline plateau-group.

RUSSIA.

The great chain of the Ural Mountains contains almost throughout its length a discontinuous series of broadly lenticular masses of basic rocks (as shown by the International Geological Map 1892), but the writer has not been able to obtain much information concerning its geological history and tectonics. Suess (Vol. III, p. 400) considers that it resulted from the posthumous folding of the Eurasian nucleus, and that the main movement occurred in Carboniferous times, and was a thrusting toward the west. Haug groups the range as a geosynclinal area ('08); Duparc and Pearce ('03) remark on the evidence of several periods of folding; but the present ranges result from a re-elevation in Tertiary times of an ancient folded region (Cole '14). It was in connection with the Carboniferous folding, however, that the development of the great intrusive masses occurred. The sedimentary succession as displayed on the eastern flank of the range near Ekaterinburg shows Middle Devonian limestone and radiolarian rocks associated therewith. With these are basic rocks possibly of a spilitic nature, "andesites," vesicular porphyrites, diabase-porphyrites, and tuff with breccia (Lagorio and Karpinsky '97, Tschernychew '87). Upper Devonian limestone and slates are followed conformably by Carboniferous conglomerates. Recently Wyssotsky ('13) has given an exceptionally interesting description of the whole structure of the northwest and southwest of Ekaterinburg, which, combined with the above information, gives a comprehensive account of the later palaeozoic history of the Ural Mountains in the region lying between 57° 30′ and 59° 4′ north latitude. Here the Urals are zonal mountains, asymmetrically folded, and dipping isoclinally westwards. The geological history of this region, so far as we are concerned, commences with the eruption of basic magma into the clayey sediment at the commencement of the Devonian period. On the western flanks of the range these have become albitic green-schists and schalsteins; while those erupted in Lower and Middle Devonian times on the eastern slopes appear as diabase and porphyrite, tholeitic and vitrophyric andesites, with acid plagioclase and a large amount of keratophyre. In other words, the rocks of the spilitic suite are developed in a fairly typical manner. In other parts of the Ural Mountains these volcanic eruptions continued into early Carboniferous times. Their relations are obscured by later folding which has sometimes converted the keratophyre into a sericitic schist. They were at first submarine flows, which directly followed the depositions of the Lower Devonian limestone, vesicular lavas occurring with normal marine sediments, tuffs, limestones, and chert. A noteworthy feature of these lavas is the presence of phenocrysts of albite, oligoclase and andesine, the later Upper Middle and Upper Devonian volcanic rocks being more gabbroid in composition. These eruptions were succeeded before the close of Devonian times, by the first severe dislocation with the formation of a series of anticlinal and synclinal folds, later broken by a series of transverse

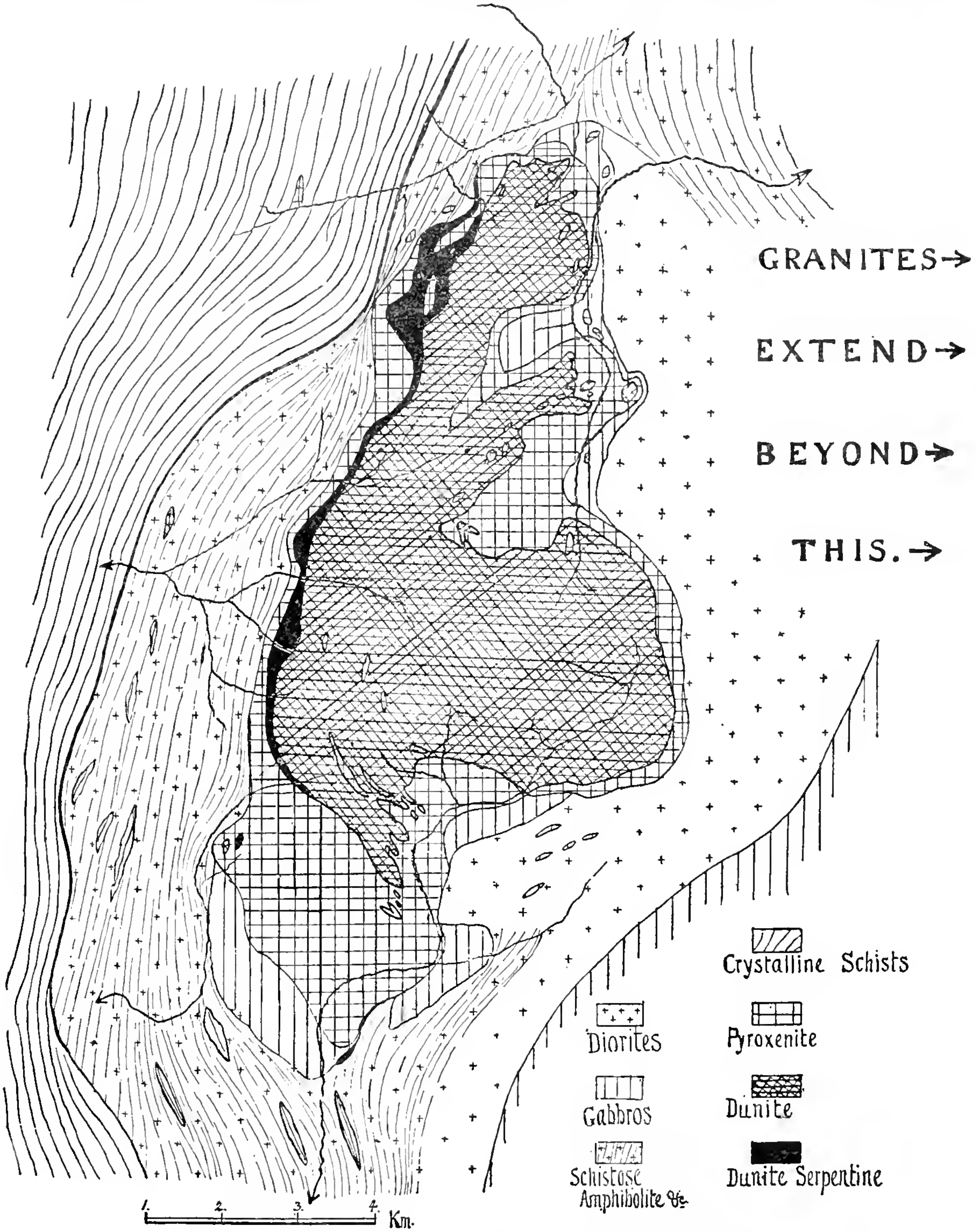

FIG. 5.—Geological map of the Tagil District, Ural Mountains. (After Wyssotsky.)

and longitudinal fissures, accompanied by energetic eruptions of porphyrite, partly as dikes, partly as widespread subaerial flows of pyroxene-andesite, and labradorite-porphyry and diabase, of generally gabbroidal composition.

Orogenic and eruptive activity recommenced in about the middle of Carboniferous times. The region was now dry land, and there was built up a mass of igneous rocks, tuffs at first largely acidic with keratophyric and aplitic types, followed by a mass of pyroxene-and labradorite-porphyrites, and diabases, and small intrusive masses of diorite, syenite, and granite. The folding and metamorphism of the western portion of the Urals occurred about this time, and was apparently accompanied by the immense plutonic intrusions which have the form of lenticular and probably essentially laccolitic masses, consisting of peridotite, pyroxenites, gabbros, diorites, and granites. There are two chief types of complexes; in the one the olivinic rocks predominate, and about it are a series of shells of rocks, the acidity increasing towards the periphery, which consists of gneissic hornblende-gabbros showing secondary dynamometamorphism. The ultrabasic rocks of the interior are free from dykes of the gabbro or diorite. (Fig. 5). In the second type of occurrences, pyroxenites predominate over olivinites, which occur merely as narrow schlieren-bands, the gabbros are proportionately more abundant and the whole series is less regularly arranged. In both types of occurrence the diorites may pass into granites and finally gneissic albite-granites, the marginal portions being always strongly banded or schistose. The intrusion of acid rock appears generally to have followed that of the basic rocks, among which, however, the sequence is less constant, and some repetition of ultrabasic intrusions seem to have occurred. In general, however, the sequence is one of increasing acidity from below upward, from within outwards, and usually from the west eastwards. The separation between the various types of rocks is sometimes sharp; at other times there are all gradations between them.

According to Bowen's view this complex suggests a sheet-like mass dipping eastwards with the peridotite and pyroxenite near its base, and passing eastward (and upward), successively less basic rocks. The pyroxenite-bodies occurring as borders about the dunites (collected olivine-crystals) are considered to be huge reaction-rims. The size of these bodies, however, would seem to demand very efficient diffusion in the magma, were they formed in this manner.

This complex illustrates the general nature of the occurrences of ultrabasic rocks in the southern Urals. According to Duparc ('14, '16) they form an enormous band stretching for hundreds of kilometers along the Eurasiatic divide. The individual occurrences consist usually of elliptical masses of homogeneous dunite, surrounded by a continuous or interrupted band of olivine-bearing pyroxenite passing into koswite. This varies greatly in amount, and is in turn surrounded by a zone of gabbro, which is the most abundant of the three rocks. Generally the mass of dunite occurs eccentrically in the pyroxenite and gabbro. One instance has been described in which it is in direct contact with the gabbro-diorite and schists, and only a small amount of pyroxenite-tilaite and olivine-gabbro occurs in association with this mass. Contrary to Wyssotsky's statement, Duparc declares that in all cases observed in detail the separation of the three main types of rock is sharp, without any lateral passage.

In the regions of the Ural Mountains further to the north somewhat similar conditions occur as has been shown by Duparc and Tikanowitch ('14) in the region of the Wagran and Kakwa rivers. Here the sedimentary sequence is much less complete, being chiefly composed of infra-Devonian quartzites and schists. There are intrusive into these large masses of gabbro, in comparison with which the pyroxenites play a very secondary rôle. They also occur in distinct masses surrounding the dunite-serpentines intrusive into the green schists. Near Lake Turgojak, the serpentines and amphibolites of the Urals are invaded by alkaline syenite-porphyries (Viscont-'13) and large masses of alkali-syenites, etc., occur elsewhere in the range.

GERMANY, BOHEMIA, AND NORTHERN HUNGARY.

The present state of uncertainty as to the age of the crystalline masses of Saxony and south Germany prevents a satisfactory consecutive treatment of the earlier igneous action and tectonic history of this land. The definitely Palaeozoic complex consists of Cambrian, Ordovician, and

Silurian rocks, followed, usually after a break of varying importance, by Devonian and lower Carboniferous rocks, all very disturbed and much metamorphosed in the neighborhood of the crystalline massifs. Lepsius ('87–'10), Gabert ('07), Dull ('02), Zeigler ('14), and others consider that much of the gneiss of these crystalline areas may be profoundly metamorphosed Palaeozoic rocks. Lepsius sees in the amphibolites, eclogites, and serpentines of the gneissic series, or the gabbros with the granulites, the metamorphosed equivalents of the Devonian diabases and picrites, a view with which their petrographic character seems hardly to accord [8] as Uhlig ('07) has shown. On the other hand Credner, Sauer ('03), and others affirm the pre-Cambrian age of the crystalline series. Hence most of the occurrences of basic and ultrabasic rocks such as the serpentine in the schists at the Rauenthal, in the Vosges, that in the gneiss at Zöblitz, and the gabbro of Penig both in Saxony, or the serpentine and gabbro of Münchberg in northeastern Bavaria, can not be discussed from our tectonico-petrographic standpoint.

In the crystalline foundation of Bohemia the basic and ultra-bassic rocks form numerous lenticular masses, the elongation of which is generally independent of the structure planes of the invaded rock, though locally they may accord with the schistosity. They generally consist of eclogite, garnet-amphibolite, or serpentine. Bergt ('03) has claimed a Carboniferous age for some of these, and Hinterlechner and von John ('09) have thought a similar age to be not impossible for certain gabbroid masses with peridotites and diabase intruding into gneisses and granites. They seem to be certainly post-Silurian. A frequent location of serpentine is lying between granulite or gneiss. Near Krems serpentine and granulite alternate in sharply distinct bands (F. E. Suess '03; Becke '13).

In northwestern Germany the tectonic history is less obscured. Here and there appear fine-grained and cherty Silurian rocks deposited during steady geosynclinal subsidence, which had commenced with the formation of Cambrian conglomerates. The diabasic intrusions in these have a slightly alkaline character. Those in the Bruckberg-Acker series of cherty rocks in the Harz region are analcitic diabase, and alkaline hornblende-proterobases with more or less biotite (Erdmannsdoerfer '08). They seem to be intermediate in character between teschenitic and spilitic rocks. The diabases and porphyrites in the Lower Silurian rocks of Bolkenhaim in Silesia probably represent a further example. They are more or less schistose, and glaucophane has developed, replacing an original mantle of alkali-pyroxene about the normal augite. They are associated with keratophyres (Finckh '13).

The greatest development of basic igneous rocks is that which occurs in the Devonian series, and these are grouped by Steinmann ('05, p. 61) among the ophiolites, though, as will be seen, they are not exactly the equivalent of our alpine type of development. Two zones may be recognized, that stretching from the Rhine to the Harz Mountains and that in the Fichtelgebirge running from northeastern Bavaria (Hof) into Saxony (Plauen). In the first the igneous rocks consists of sills, flows, and tuffs, of spilitic, diabasic, essexitic, and keratophyric rocks, with some picrites, interstratified with a series of geosynclinal sediments, which lie unconformably on the Silurian beds. The sequence commences with the Lower Devonian (Coblenzian) sandstones, above which comes the Wissenbach slates, containing the earliest of these igneous rocks. The Middle Devonian period was occupied by the deposition of slates, cherts, and limestones, in which time the development of massive and fragmental igneous rocks reached its maximum, the rocks developed being in part alkaline in character. Continued subsidence during Upper Devonian times was marked by the development of clay slates more or less calcareous with impersistent cherts, probably radiolarian (Meyer '09). The accompanying diabasic submarine lavas with pillow-structure are without any noteworthy alkaline features. The Carboniferous period saw the formation of radiolarian cherts, followed by clay slates, which rapidly pass up into the conglomerates, indicating the commencement of the Variscan folding.

The petrographical character of these igneous rocks has been studied in much detail by Brauns and his students, Doermer, Heineck, Reuning, and Rinne. The general summary of

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[8] The writer has collected and examined a number of these rocks. They seem very different from the indubitable examples of altered Devonian basic eruptive rocks recorded by Beck ('03), though certainly the pressures suffered by the latter would not have been so great as required by Lepsius' view of the origin of the rocks in question.

this work has been given by Brauns ('09). While in some respects the mode of occurrence and range of petrographical characters exhibited is analogous with those of the rocks of similar age in Devonshire, as pointed out by Flett and Dewey ('11), there is but rarely much albitisation and generally no association with radiolarian chert. The intrusions in the Middle Devonian rocks comprise essexite (in one instance containing 5.48 per cent of Na_2O, 3.77 per cent of K_2O, and 48.79 per cent of SiO_2), essexitic diabase, mica-diabase, hornblende-diabase, and amphibole-picrite (generally in independent intrusions, but in one instance occurring within diabase, into which it passes by gradual transition). With these partly alkaline intrusions are associated porphyritic diabases, not unusually sodic, but containing epidote and secondary albite, though the primary feldspar is labradorite or bytownite (Heineck '03); flows of dense and vesicular diabase-schalsteins, and tuffs with volcanic bombs. The keratophyres ("lahnporphyries") vary betwen highly sodic types (one of which Prior described as a reibeckite-tinguaite) and quartz-keratophyres, in which potash predominates. The great variation even in a single mass between the proportions of the two alkalies is very characteristic of the series, and may be due to a varying degree of secondary albitization, as Flett and Neithammer ('09) would suggest. The presence of reibeckite and aegyrine was urged by Erdmannsdoerfer ('07) as strong evidence of their alkaline character. The Upper Devonian intrusions are much less varied. The diabasic rocks frequently show pillow-structure, and hornblende is absent from both the diabases and the associated picrites. No sign of alkaline minerals occurs. (Brauns '04, '06; Reuning '07.)

In the Harz Mountains no distinction has yet been observed between an earlier alkaline and later calcic series of Devonian igneous rocks, though both sodic and normal types occur. Erdmannsdoerfer ('09) has shown the consanguinity between the diabase of this region and the distinctly alkaline keratophyre, which contains both potassic and sodic types. In the latter albite, soda-orthoclase, aegyrine, and arfvedsonite are present. The Devonian igneous rocks of the Fichtelgebirge present an analogous range of types; according to the most recent studies of Riman ('07) and Weber ('10) diabase, leucophyres, spilites, and keratophyres are present, together with numerous sills and some dikes of picrite, which have been elaborately studied by Uhlemann ('09).

The Carboniferous period saw the great Variscan folding following on this long period of geosynclinal depression, and considerable crushing and even great overthrusting occurred (Kayser '00). This rolled out the igneous rocks, both massive and pyroclastic, into schalsteins, which occur on the Rhine (Milch '89), in the Harz, and in the Fichtelgebirge (Lossen '82, Pelikan '98, '99). Accompanying this folding were great plutonic intrusions in the Harz and in Saxony. The massif of the Brocken is a differentiated complex (Lossen '82 Erdmannsdoerfer '05), consisting of peridotite, gabbros, and norites followed by less basic and finally acid granites. The basic and ultrabasic masses are disposed in roughly stratiform masses approximately parallel to the direction of Variscan folding. The granites, the intrusion of which occurred before the gabbros had cooled, have much more transgressive boundaries, and the latest dikes appear to follow the Hercynian structure-lines and run almost perpendicular to the Variscan direction. (See fig. 6.) Veins of nephrite fill fissures in the harzbergite which also run parallel to the Hercynian direction, and therefore transversely to the longer axes of these ultrabasic rocks (Uhlig '10). The norite is rich in biotite, and in it occurs the biotite-peridotite found by Koch ('89) in the Kaltenthal, which Rosenbusch ('07) classsed doubtfully with the alkaline rocks. A brief examination of the locality suggested to the writer that it may be merely a schlieren band in an olivine-biotite-norite. It has no association with any alkaline features.

In the Odenwald, there is also a differentiated series of intrusions into highly folded Devonian rocks. They vary from ultrabasic to acid types, with a stratiform arrangement most marked in the basic members, e. g., at Beerbach. Though there have been claimed to be passage-rocks between the basic and acid members, those rocks of intermediate position and composition, seen by the writer near Darmstadt, appeared rather to be hybrids; they have a markedly blotched appearance and resemble the hybrid rocks in Skye, and the rocks believed by Dr. Harker to be such in the Glen Doll complex and in Mull. The "picrite" of

Schriesheim which invades the granite is perhaps analogous to the ultrabasic dike-rocks which close the dike-retinue of the Skye plutonic complex.

Perhaps we should include among intrusions of this age the ultrabasic rocks of the Vosges and Schwarzwald (von Seidlitz '14, Bubnoff '13) and those of Saxony (Bergt '03, Uhlig '07), but much uncertainty is involved in the discussion of these.

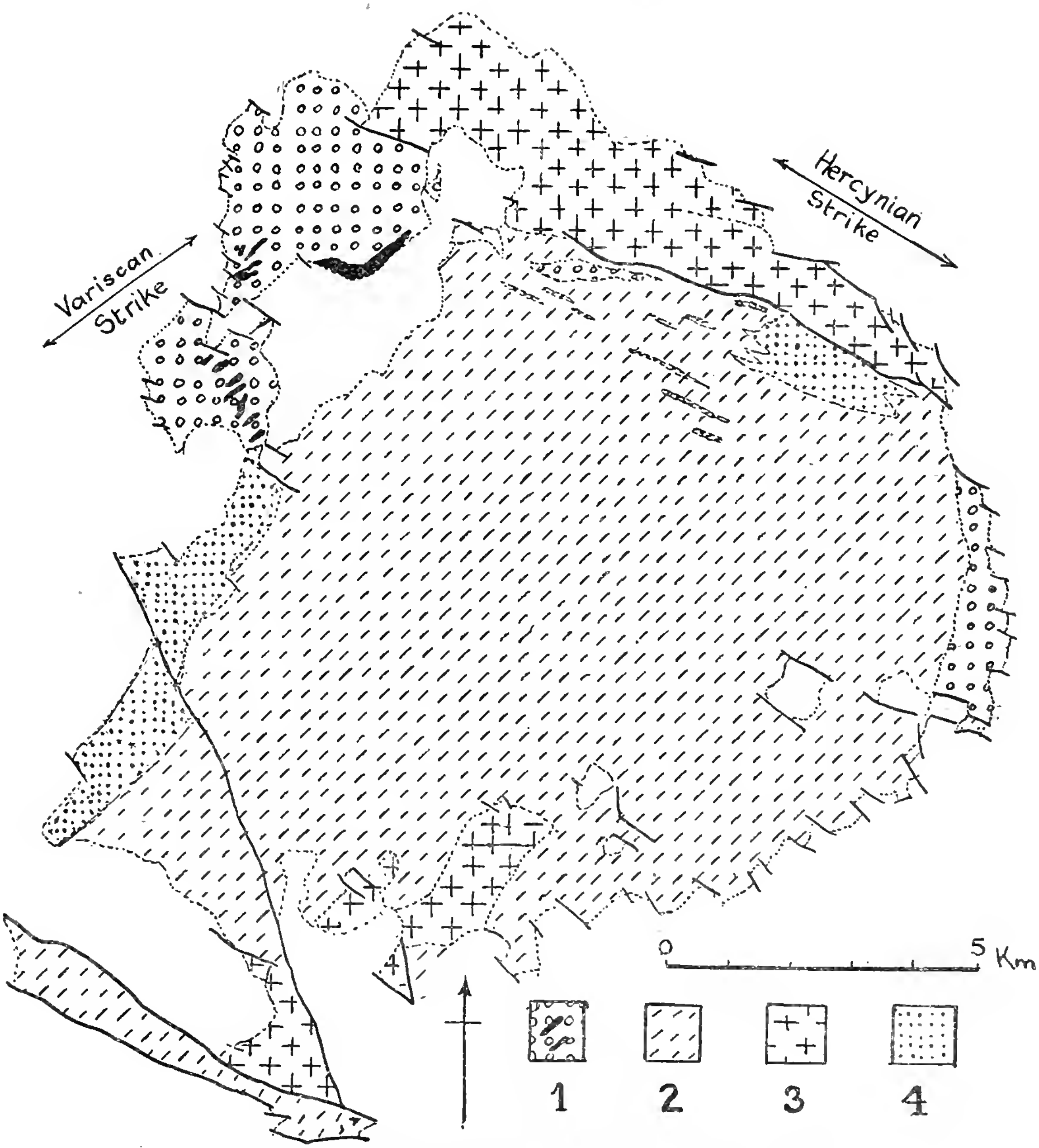

FIG. 6.—Geological map of the Brocken massif, Harz Mountains. (After Erdmannsdoerfer.)
1. Gabbro and norite with harzbergite, etc. (solid black). 2. Central granite. 3. Marginal porphyritic granite. 4. Hornblende-granite-porphyry.

In Silesia, a gabbro-peridotite complex is exposed near Zobten, the age of which is at present indefinite. Tannhauser ('08) considers it Devonian, offering rather unconvincing evidence, while Finckh ('12) holds that it is post-Devonian. It may therefore be considered as formed probably during Hercynian folding. Further to the southeast in the Dobschau region, where the Palaeozoic formations have become involved in the Carpathian folds, upper

Carboniferous or Permian conglomerate lies over a series of probably Devonian phyllites, in which is a zone of porphyroid rocks consisting of sodic keratophyres and submarine flows of diabase and tuffs. The whole series was invaded by gabbros apparently of lower Carboniferous age. The whole has been much disturbed and sheared into flakes by the later Mesozoic folding (Woldrich '12, '13).

The latest basic intrusive rocks in north central Europe are the essexitic rocks of the Rhön, Vogelsberg and Lausitz, with which must be grouped the great masses of essexites, theralites, teschenites, and picrites of the Bohemian Mittelgebirge. These form the typical Atlantic or alkaline rocks of Becke ('03), formed during the fracture and differential movement of blocks unfolded since Permian times. (See also Hibsch '03.)

Of special interest, however, are the eruptions of very basic alkaline rocks, often melilite-basalts in the south of the block-faulted Bavarian tableland. They occur in volcanic pipes filled either by massive melilite-basalt, alnoite, etc., or by breccias including kimberlitic rocks (Branca, '94, Schwartz, '05).

NORTHERN FRANCE AND THE CHANNEL ISLANDS.

Excepting the basic rocks of the Pyrenees and Alps, treated in the next chapter, there are few masses of basic intrusive rock in France. A few small masses of serpentine and gabbro have been noted in the folded Lower Paleozoic rocks of Brittany (Brun '05), but no data are available concerning the conditions of intrusion of these, nor of the gabbro of Pallet described by Lacroix ('99), which invades a series of mica-schists with very poorly exposed boundaries. The Hercynian intrusions are probably represented in the Channel Islands by the hornblende-gabbro and diorite of Guernsey described by Parkinson ('07).

Chapter IV.

THE BASIC AND ULTRABASIC INTRUSIVE ROCKS OF THE ALPINE MOUNTAIN SYSTEM IN SOUTHERN EUROPE AND THE ATLAS MOUNTAINS.

The younger basic intrusions of the Pyrenees occur sometimes in rounded masses, at other times as parts of dikes, and again as intercalations which may reach lengths of from 1 to 4 kilometers. According to the detailed accounts of Carez ('03), two groups of intrusions may be distinguished, one belonging to the Lower Lias containing ophite (diabase) only. The second ranges into the Gault, and presents, in addition to the ophite, lherzolite-serpentine, diorite, peridotite, and anorthosite, the latter as a dike in peridotite. Here, then, we find repeated a series of green-rocks which occurs at various horizons through the whole chain of the alpine folds. Steinmann ('05) has drawn attention to the frequent association of these intrusions with the radiolarian shales of the deep sea, but "in the Pyrenees, the south of Spain, and the northwest of Africa they occur in sediments of a kind which is not known in the deep sea, and in this case the facts are not favourable to Steinmann's generalisation. In Europe these green intrusions or fragmentary traces of them are to be seen in hundreds of localities within regions of great dislocation which extend from the Wolfgang See to the margin of the Sahara. We do not find them in the foreland either in the north or the south, and in Europe we regard them, therefore, as accompaniments of tectonic movements." [1] Lacroix ('01) points out that there is an absolute distinction between the ophites and lherzolites; they are never found passing into one another. The intrusion of the lherzolite occurred subsequent to Lower Cretaceous times, as rocks of that age have been modified by it. It appears in streaked masses with segregation-bands of ariègite, a condition probably resulting from intrusion under great stress.

Besides the basic rocks we have just described, there are small amounts of an earlier formation. Caralp ('02) has described a series of diabases and picrites among Paleozoic rocks which seem to have some of the characteristics of members of the spilitic suite.

We will now attempt to follow the line of the alpine folds among which are numerous instances of ultrabasic and basic intrusive rocks. Commencing in the Betic Cordillera (Sierra de Ronda), there appears a large lenticular mass of serpentine which, as has recently been shown by Orueta and Rubies ('16) and Duparc and Grosset ('16), invades the Cambrian and pre-Cambrian schists and gneisses, but is itself of pre-Permian date, for there are abundant pebbles of peridotite in the Permian or Triassic conglomerates that unconformably overlie the Paleozoic complex. Hence this intrusion, though possibly of Altaid age, was unconnected with the alpine folding.

MOROCCO AND TUNIS.

The folds of the Betic Cordillera strike across the Straits of Gibraltar and continue along the coast of Morocco and Algeria.[2] This portion of the alpine line of folding presents many remarkable features. There is an inner coastal zone of volcanic rocks, followed by a strip of gneiss and schist, beyond which are the highly folded sedimentary rocks, thrust toward the Sahara. Triassic rocks of the gypsiferous Rotliegende occur with saline beds and limestone, which have been so involved in the orogenic movement that they have been rolled out, mylonitized, or kneaded together. Large fragments of gneiss and other basement-rocks occur as alien blocks thrust into these softer contorted strata with a great variety of intrusive rocks. Gentil ('02) recognized diabase, diorite, and gabbro, and these are intrusive in every instance, and have produced contact-effects on the Triassic limestone. Almost without exception they have been broken up by tectonic movements and frequently kneaded up with the gypsiferous beds into a breccia. These have been met with throughout the whole range from Morocco to Tunis.

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[1] The above remarks are a condensation of the account given by Suess (IV, p. 247). The writer was unable to obtain access to the most important original works on the geology of the Pyrenees, particularly that of Carez, to which reference should be made.

[2] This is the view held by Suess, but it has not been supported by recent work, especially that of Gentil, who has shown that the Riff or African extension of the Betic Cordillera does not continue into the Atlas Mountains. (See La Face de la Terre Vol. III, 2nd ed. 1921, p. 886, footnote.)

ITALY.

The range then continues to Italy, where gabbro and serpentine appear in the ancient rocks of southern Calabria. Lovisato ('78) compared these with the green-rocks of northern Italy and was supported by Novarese ('06). Tilmann ('12) suggests that they are the roots of the green-rocks in the Eocene formations of northern Calabria.

The green-rocks appear again in the neighborhood of Florence, whence they stretch in a series of intrusions through the Tuscan Sub-Apennines (Catena Metallifera) and the Ligurian Alps, and sweep in great masses into the Maritime Alps, and especially the Piedmontese Alps. They also occur in Elba and Corsica. The problem of the origin of these rocks has long been a battleground for geologists, and the most diverse views are held even to the present. The following remarks are based upon the account given by Suess (IV) and (what appears to be more in accord with the views of Italian geologists so far as the writer has been able to ascertain them), the recent review of Preller ('18) in which numerous important papers are cited.[3] The reason for the great diversion of opinion is the exceedingly disturbed character of the rocks, so that it is not clear whether the green-rocks are a series of contemporaneous flows and intrusions in moderately displaced but still autochthonous formations (the Italian view), or have been passively moved hither and thither in a series of immense sheet-folds rooting in the Dinaric Alps, or in Corsica, and are thus largely exotic (the view of Steinmann ('07, '13), who holds the serpentine, etc., are entirely of Jurassic age, of Termier ('10, '12), and their followers), or whether they have been injected into the weaker formations during immense overthrustings (Suess IV). According to the Italian geologists the ophiolitic rocks of the Tuscan Sub-Apennines are lenticularly infolded in the Eocene sediments; they show no evidence of angular intrusion, apophyses, or contact-metamorphism, but were a series of submarine lava-flows which became incorporated in the plastic sediments. Not unfrequently the spheroidal pillow-structure is visible in the diabasic rocks (Mazzuoli and Issel '81, Delkeskamp '07), even when they have been altered to felspathic amphibolite or prasinite. There are no visible channels of eruption. The sediments with which they are interbedded are mostly somewhat siliceous limestones, often nummulitic, passing into calcareous chert, "*diaspri*," containing radiolaria. In the larger intrusive masses the superposition of the principal basic rocks in differentiated areas shows almost invariably a basal layer of serpentine followed by gabbro and felspathic diabase. Daly ('14, p. 449) cites a clear illustration of this feature. In rare instances gabbro is absent and diabase overlies serpentine directly. Nevertheless the serpentine frequently contains veins and intercalations of gabbro, less frequently of diabase, which on the other hand invades gabbro. Preller adds: "This order of superposition and intercalation corresponds to the order of eruption and consolidation from essentially the same magma, which also produced the occasionally associated granitic rocks as acid concentrations."

It will be useful here to cite Suess's brief summary (IV, p. 147):

> In the Apennines the green-rocks of the Alps are repeated chiefly in the Cretaceous, Eocene, and Oligocene (or Upper Eocene) beds as in Corsica. On the Middle Trebbia, where they are not older than Oligocene, Traverso distinguishes a series of igneous rocks, which has arisen from the differentiation of a common magma. The first products gave rise to Iherzolite and serpentine, the second to gabbro and diabase, the most recent to granite. The granite occurs only in limited areas, generally as veins. In Elba the granite makes its appearance in greater mass, and there, too, represents a comparatively late product. The green-rocks are transformed by contact with it into alternating layers of hornblende-schist and enstatite-serpentine. This granite is younger than the folding of the Apennines.

The divergence of interpretation is very marked in the case of Elba, where, in opposition to Termier's ('10) "geopoetic" conception of three immense recumbent sheets, the lowest thrust *subterraneously* from the Dinaric Alps 300 miles to the east, Lotti ('10), followed by Preller, considers the formations are autochthonous. The submarine eruptions of diabase and variolite occurred in Early and Middle Eocene time, and are associated with very silicified red calcareous radiolarian chert resulting from the alteration of limestones by silico-ferruginous solutions from the basic lavas. The abundance of these waters is indicated by the fact that

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[3] An extensive bibliography of the Italian "*pietre verdi*" is given by Franchi ('10).

the cherts are at least as extensive as the igneous rocks. In the later Eocene and Miocene times there was a general upheaval and folding with the intrusion of laccolitic masses of acid porphyry and granite.

On the mainland tracing the sequence further to the north, the Ligurian Apennines are found to show many features similar to those already described. Serpentine, compact, schistose, or porphyritic, is associated with gabbro (euphotide) and diabase, but there is no passage from serpentine into the two latter rocks, between which there are often transitions. They are associated with silico-calcareous greenish and reddish schist containing radiolaria, and forming bands on the margin of ophiolitic rocks in the neighborhood of calcareous deposits. They are stated to be of Upper Middle Eocene age and rest on Middle Eocene sandstone.

In the west of Liguria the Alps and Apennines come into contact. The Eocene *pietre verdi* or green-rocks are brought into contact with a Triassic series of similar origin, but rather different facies, being dark blue limestone and calc-schists, which, with the exception of some small occurrences in Elba, are the southernmost portions of the great series of Mesozoic rocks with intercalated green-rocks that play so prominent a part in the composition of the Maritime and Piedmontese Alps. Here, too, we find a marked divergence between the explanations given: the essentially autochthonous character of the formations in Western Liguria, though with minor overthrustings, is supported by Rovereto ('09), Preller ('18), and the weight of Italian geologists, while that they are immense exotic sheets is suggested by Termier and Broussac ('12).

The structure of Corsica indicates that it is a southern spur from the Piedmontese Alps. There is, however, still considerable doubt as to the structure of the island. With the highly folded ancient Mesozoic and Tertiary rocks there are intrusions of peridotite, norite, gabbro, diabase, and particularly serpentine which occur just as they do in the Alps. Maury ('03), whose view is accepted by Suess, states that they penetrate as far up as the Oligocene Flysch, and are overlain by the first Mediterranean stage, but Rovereto ('05) holds that they are older than the Rhaetic, though younger than Middle Trias and occur among Triassic calc-schists.

The modern views of the nature of the green-rocks in the Piedmontese arc of the Alps are due in very large measure to the work of Franchi, together with Novarese and Stella (Franchi '98, '04, Novarese '95). Omitting reference to the Ivrea zone of intrusions the following appears to represent the view generally accepted by Italian geologists. The green-rocks appear at all elevations throughout the regions; except in the prevalence of green-rocks with unaltered minerals in Permo-Carboniferous mica-schists, and those more altered in the Liassic calc-schist, there seems to be no regular order of succession, superposition, or distribution among them. In the mica-schists they appear not as irruptive angular injections with apophyses, but as lenticular concordantly stratiform masses, that, owing to the differential crushing, show pseudo-intrusive phenomena. There are frequent passages between the several types of eruptive rocks [4] but there is no conclusive evidence of contact-alteration. This close association of rocks of different origin is considered to be the result of repeated penetration of eruptive viscid lavas into the sedimentary deposits in the course of consolidation. Sometimes in the less metamorphosed regions, as at Monte Genèvre, one may see the pillow-structure perhaps formed in the variolitic consolidations of the magma as it was injected into watery silt, and quite adjacent to these appear coarse-grained gabbros (euphotides) (Cole and Gregory '90). Altered pillow-lavas also occur with diabase and amphibolite-schists at Monte Viso (Zaccagna '87). In neither horizon do these appear as deep-seated rocks; they are on the contrary associated and interstratified with the other green-rocks at all levels, overlying and underlying, and intercalated in them and the crystalline schists. All green-rocks are of more or less altered condition, and the schists formed from them present the usual actinolitic, glaucophanitic, zoisitic, chloritic and talcose varieties, while garnetiferous types tending to eclogites are also present. They all may exhibit a marked tendency to chloritic decomposition, which applies even to the lherzolites and associated euphotides. This process is much less in evidence in the green-rocks of the older or mica-schist formation than in the younger or calc-schist formation, for the former are much less permeable and contain less magnesia than the latter.

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[4] See e. g. Zambonini's ('06) detailed account.

According to the views of Franchi ('06) and Schmidt ('08), the Ivrea zone of basic intrusive rocks should be classed among the Permo-Carboniferous formations, while Suess considers it of common origin with the green-rocks of the Piedmontese Alps. The mass is infolded in the mica-schists without evidence of transgressive intrusion, and contains a group of rocks ranging from granite, quartz, diorite, gabbro and norite to peridotite, but diabase is absent. There is a fairly regular arrangement of the rock-types, the highly basic rocks collecting toward the west, while in the east the diorites predominate. Suess (IV, pp. 134, 566) would correlate this zone with the tonalite series of Monzoni farther to the east, and believes it to have been injected into the sole-plane upon which the Dinarides were thrust on to the Alps in which case the western would be the lower side of the plutonic complex. According to Spitz ('15) these intrusions are in part Tertiary, in part pre-Permian, and there are some portions of uncertain age. Kober ('21) holds that they are partly of late Mesozoic age, and partly younger than the folding movements "But the problem of the Dinaric cicatrice with which the Alpine geologists have been so long concerned is not yet completely solved."

There are very many details concerning these much-discussed rocks for which reference must be made to the authorities cited by Suess (IV, p. 130–134) or to later discussions, e. g. that of Kober ('21) which propound different explanations of the Ivrea zone.

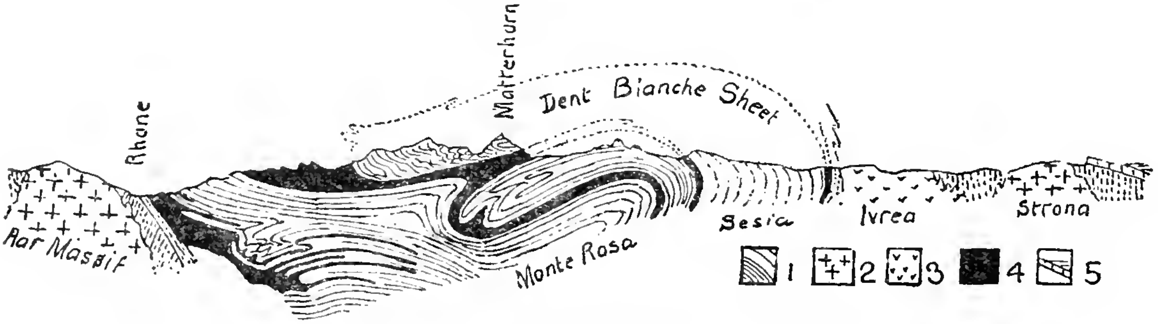

FIG. 7.—Geological section across the Pennine Alps. (After Argand.)
1. Gneiss. 2. Granite. 3. Basic plutonic rocks. 4. Alpine Triassic and Jurassic rocks. 5. Southern Permian and Triassic rocks.

THE SWISS ALPS.

In regard to the Lepontine Alps there are again to be noted the divergences of opinion between the Italian authors and the Swiss geologists, whose views are accepted in the main by Suess. The former are disposed to consider the bulk of the mountains as autochthonous overthrust folds, but to the Swiss geologists, following the researches of Lugeon they appear to be made up of a series of immense largely exotic recumbent folds. The great band of basic and ultrabasic rocks which extends from Greisoney and the Breithorn towards Zermatt, as also those in the lower parts of the Dente Blanche and the Matterhorn are correlated by Argand ('06) with the rocks of Ivrea (see fig. 7), a correlation to which objection has been raised by Novarese ('06) on petrographic grounds, particularly in the absence of diabase from the Ivrea zone. Schmidt ('07, '08), on the other hand (see fig. 8), considers the Ivrea basic rocks as older than those of the Dente Blanche, probably Carboniferous, and believes all the Dente Blanche group of green-rocks, and the calc-schists in which they occur, to be derived from the Dinaric Alps, and thrust through the syncline between Mont Blanc and St. Gotthard. He classes, also, as an extension of the same flake, the upper portion of the Freiberg Alps in which basic rocks were found by Lugeon ('96) and Jaccard ('04), with which are some radiolarian cherts.

Beneath the great mass of basic plutonic rocks of the Dente Blanche sheet lie the Bündnerschiefer corresponding to the Mesozoic calc-schists, containing other green-rocks, which are apparently a series of intercalated contemporaneous flows and tuffs with shallow intrusions. In the Bagnetal, Woyno ('11) showed the green-schists, glaucophane schists, prasinites, and serpentine were probably derived from slightly sodic tuffs and lavas.[5] Further to the northeast near Brig the green-rocks have been studied by Schmidt ('08) and Preiswerk ('03, '07). The Mes-

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[5] The writer examined specimens of these rocks in Basel and Zürich through the courtesy of Drs. Preiswerk and Woyno. They are very different from the rocks of the Ivrea zone studied by Schaefer ('98) and those forming the gneissic gabbros and allalinites of Zermatt and the Saasthal (Schaefer '95 Bonney '92) of which representative collections were examined by the writer in Heidelberg and Cambridge.

ozoic rocks form deep synclines in the wonderful folded packet of recumbent folds in the Simplon complex. The fundamental gneissic rocks are followed by Triassic quartzites and dolomite and Jurassic calc-phyllites in which the green-rocks occur—lying so placed that it seems difficult to conceive that they could be other than the product of Jurassic submarine eruptions. They are now prasinites, picrites, serpentines, etc., but originally were diabases, "gabbros," picrites, and peridotites, appearing in some cases very like the coarser members of the English Devonian spilitic suite of rocks.[5] The rocks of the series have sometimes a notable amount of albite as revealed by chemical analyses, of which certain are like those of keratophyres, while albitic products of contact alteration have been formed in the invaded calc-phyllites. It may thus be suggested that these rocks have some features of those of the spilitic suite, and were formed during Jurassic subsidence prior to the great alpine folding. Dunite and wehrlite, though also present in the calc-schists near Visp (Preiswerk '03), are found chiefly in the gneisses of a higher recumbent sheet in the Geisspfad and Upper Tessin areas (Preiswerk '01, '18). Another lenticular mass of peridotite in gneiss occurs near Andermatt (Schneider '12).

We now pass to eastern Switzerland whereon Steinmann based his discussion of ophiolitic rocks ('05). These basic intrusive rocks are associated with radiolarian rocks as well as calc-phyllites (the East Alpine facies of the Bündnerschiefer), and lie entirely within the Rhaetic sheet overlain by the largely gneissic East Alpine sheet. Lorenz ('02) held that the diabase-porphyrites were intrusive into the Jurassic radiolarite and Cretaceous marls along lines of thrust during the period of great overthrusting, von Seidlitz ('06) considered that in the absence of Tertiary rocks there was no evidence that they were younger than Cretaceous, while Hoek ('03, '06) showed that they invaded all rocks up to the Jurassic radiolarite and the Cennomanian breccia, but did not enter the Cretaceous flysch. The petrographic description of these rocks has been given by Ball ('97) and Bodmer-Beder ('97).

The green-rocks of the Julier Pass at the southwestern end of the Engadine have recently been investigated by Cornelius ('12).[6] The stratigraphy is intensely disturbed. The Rhaetic sheet consists of

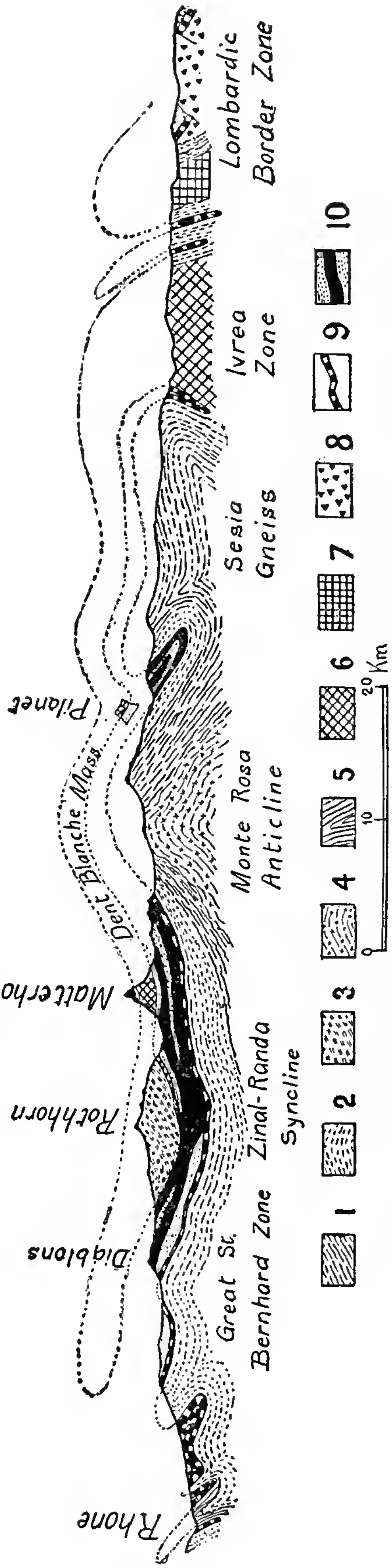

FIG. 8.—Geological section across the Pennine Alps. (After Schmidt.)

1. Orthogneiss. 2. Mica schist. Arolla gneiss. 4. Granite. 5. Carboniferous schists. 6. Ivrea amphibolite, etc. 7. Baveno granite. 8. Porphyry. 9. Permian and Triassic sediments. 10. Jurassic sediments with intercalated green-rocks (solid black).

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[5] The writer examined specimens of these rocks in Basel and Zürich through the courtesy of Drs. Preiswerk and Woyno. They are very different from the rocks of the Ivrea zone studied by Schaefer ('98) and those forming the gneissic gabbros and allalinites of Zermatt and the Saasthal (Schaefer '95, Bonney '92) of which representative collections were examined by the writer in Heidelberg and Cambridge.

[6] The writer is indebted to Dr. Cornelius for the opportunity of examining his collections in Zürich and discussing the same. The extreme complexity of the crushing in the area examined may be gathered from the following remark (op. cit. p. 382): "The Triassic dolomite is torn apart into isolated lenses, between which wind in and out dark Liassic limestones and phyllites, while gneiss is gripped in between them in bands sometimes a kilometer in length, but only a few yards in width."

gneiss, quartzite, and dolomite, clay and calc schists, and radiolarite with green-rocks, forming narrow more or less concordant sills, but never appearing to be extrusive. In the mass, serpentine, diabase and green schist may occur, associated alternating or singly with sporadic masses of highly metamorphosed gabbros, which in composition are like albitediabase. Cornelius also concludes that the intrusions took place during the overthrust-movement, following planes of marked discontinuity and even traversing the broken ends of folds, though occurring sill-like in the septa of the folds.

In the window of the Lower Engadine the green-rocks of the Rhaetic sheet are again exposed and have been studied by Grubenmann and Tarnuzzer ('09). They occur among clay shale, chert, calc-phyllite, and radiolarite.[7] Here are green schists with spilite, variolite, diabase, gabbro, hornblendite, and serpentine. Hezner's numerous excellent analyses show that, with the exception of two biotite-gabbros of monzonitic composition, the plutonic types are all characteristically calcic. The diabases and variolites, on the other hand, are notably different, being nearly all strongly sodic, except one example which contains orthoclase. Grubenmann draws special attention to their "essexitic" character. Some features of the analyses, however, strongly recall those of the decalcified diabases described by Termier ('98), so that the analogy suggested with spilitic rocks may not be a valid one. The association of the gabbros and ultrabasic rocks on the one hand with the diabases and variolites on the other is so intimate as to suggest they belonged to a single period of igneous activity.

In the Antirhatikon, Paulcke ('04) found that the ophiolitic rocks were closely associated with the most disturbed regions, and concluded that their intrusion had taken place (probably) during the Tertiary orogenic movements. From Schiller's ('06) account of the most easterly ophiolitic rocks in Switzerland the reader can draw the same inference. This association of intrusions of basic magma with orogenic movements in Switzerland has been further discussed by Heim ('21) and Staub ('15 and later memoirs) whose writings have not been accessible to the writer.

AUSTRIA-HUNGARY.

Eastward from here we pass to the Austrian Tyrol, where the green-rocks are exposed around the framework of the window of the Tauern. Very diverse accounts are given of this region, Suess (IV, pp. 169–176) following in general Termier's views. The central gneissic mass is believed to be of intrusive origin but to have been brought passively into its present position. Surrounding it is a frame of Lepontine rocks, Triassic conglomerates, etc., and more or less calcareous Mesozoic schists which contain greenstones (altered tuffs and diabase) and serpentine peridotites (as at Windisch Matrei). Becke ('03) believes that the peridotite was injected during the overthrusting movements into the calc-mica-schists and green schists, which are in part of Mesozoic age, and the central granite invades the serpentine.[8] Weinschenk ('03) also considers this granite to be Tertiary. Northward of these rocks is a monotonous series of phyllites stretching to Salzburg, where they contain Silurian fossils. Spitz ('09) has found in these a series of tuffs, flows of sodic diabase and proterobase, with sills of picrite which strongly suggest an affinity between these and the spilitic suite of Flett or the essexitic group recognized by Erdmannsdoerfer.

No further basic rocks have been recorded as we pass eastward through the Carpathians until we come to Dobschau, where, as pointed out already, they overlie the probable extension of the German Hercynian diabase and gabbroid eruptions. (See p. 20.)

RUMANIA.

In the southwestern end of the Carpathians is the region of the Paring, the structure of which has been investigated by Murgoci ('98, '05) and Mrazec ('03). A series of schists overlain by Mesozoic rocks have been overridden by a different group of Mesozoic rocks lying on a different series of schists. A mass of ultrabasic rock was injected beneath the thrust-plane,

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[7] Discovered since the publication of the work cited (*fide* Prof. Grubenmann), whose collection the writer was permitted to see.

[8] Meyer and Weber ('10), on the other hand, consider the serpentine and green schists to represent intrusions and flows in the Mesozoic rocks.

and has invaded the lower series of Mesozoic rocks, producing contact rocks. Mrazec recognizes a clear connection between the injection of the serpentine and the dislocations, and holds it has no genetic relationship with the greenstones among which it occurs.

THE BALKAN PENINSULA.

Though there is a very extensive literature on the geology of the Balkans (Toula's ('03) bibliography enumerates over 1,300 papers), it is difficult to obtain a comprehensive idea of the occurrence of the green-rocks except in the useful summaries given by Katzer ('03), Vinassa de Regny ('03), and Philippson ('03). Apparently these have many features in common with the alpine green-rocks. A great zone of serpentines and peridotite extends from Croatia into Bosnia, where these rocks are associated with gabbros and thrust among Jurassic and Cretaceous jasper, chert, limestone, flysch-sandstone, and tuffs, together with diabase and amygdaloidal melaphyre, about which the sedimentary rocks are more or less silicified. Some observers consider that the green-rocks are a single series which were injected in Tertiary times, but Tietze and Bittner (cited by Kišpatić '00) place them in the Upper Cretaceous, the former connecting them doubtfully with the tuffs as in part effusive. Kišpatić, on the other hand, separates the gabbro, peridotites, amphibolites, and eclogites from this series, and considers them to be passively inthrust Archaean rocks. Katzer ('03) notes that pebbles of serpentine occur in the Lower Cretaceous sandstones beneath which lie the uppermost Jurassic beds, the green-rocks, the lower Jurassic, Triassic, and Palaeozoic beds, and therefore concludes that some at least of the green-rocks are of Middle Jurassic age, but does not discuss their *mise-en-place*. Invading the serpentine are a series of post-Triassic, possibly Cretaceous gabbros and norites, diorites, and granites.

In Montenegro the only sign of green-rocks recorded are pebbles in conglomerates, but porphyrites, diabases, and diorites invade the Triassic rocks (Vinassa de Regny '03).

Southeastward the Bosnian serpentine zone is continued into Herzegovina and into Macedonia and Greece. In the latter country, according to Philippson ('03), there is a foundation of crystalline schists, the earliest fossiliferous formations being Liassic shales, limestones, and radiolarian chert which probably extend up into the early Cretaceous.[9] The absence of the early Tertiary rocks suggests that this was a period of considerable crustal movement, and to this period has been assigned the intrusion of the numerous serpentine-masses which occur associated with gabbro, diorite, and diabase which are certainly pre-Miocene (Lepsius '93). Detailed petrographical descriptions of the probably Jurassic radiolarian jaspers and cherts, the hornblende schists, diabase, amygdaloid schalstein, and the plutonic series recall many of the features of the Alpine occurrences (Hilber and Ippen '04). Ktenas ('07) has described the occurrence of serpentine in the Cyclades, where it is associated with saussurite-gabbro and gabbro-schist, jadeite, garnet-amphibolite, epidote-zoisite, and glaucophane-schists, and also chloritic talc-schists. He believes that the serpentine and gabbros are intrusive, the latter possibly related to a gabbro which invades the *Hippurites* limestone of Euboea.

From Greece the zones of green-rocks continue in two series, the one striking directly into Asia Minor across the Aegean Sea, the other passing into Syria by way of Crete and Cyprus. No green-rocks appear to have been reported from Turkey. In Crete, according to Cayeux ('02), the Mesozoic formation is chiefly Jurassic and in part Triassic. It contains a series of intrusions of serpentine, and gabbro invaded by diorite and syenite, apparently pre-Cretaceous in age, and accompanied by diabase, the age of which is uncertain. Bergeat ('92) shows that altered diabase and epidosite invaded by gabbro and serpentine forms the central chain of Cyprus. These invade also the Cretaceous limestone, and fragments of the gabbro occur as pebbles in the Miocene beds, which are unconformable with the Eocene, as also are the latter upon the Cretaceous beds.

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[9] For a recent discussion of the structure of this country see Renz ('12).

Chapter V.

BASIC AND ULTRABASIC INTRUSIVE ROCKS IN ASIA AND THE MALAY ARCHIPELAGO.

Asia possesses a simpler structure than the smaller area of Europe, and basic intrusive rocks are much less abundant, and are confined chiefly to the youngest folded series. The foundation of Siberia is composed of gneisses and schists, and these extend eastward into Mongolia, Manchuria, and Korea, where they are overlain by Cambrian sandstones, and by widely transgressive Devonian formations. Serpentines appear in the gneissic complex in Korea (Schulz '10) and south of Lake Baikal (Suess III, p. 67). The Devonian sediments are locally folded in eastern Siberia, and have been invaded by diorite and gabbro (Suess III, p. 123), but to the southwest of Siberia they are overlain by lower Carboniferous rocks upon which generally, though not always, the upper Carboniferous beds are strongly unconformable. In the period of folding which, therefore, occured in Carboniferous times, there were intruded the granites, syenites, and diorites of the Altai Mountains, in the contact zones of which are many important ore bodies. Ultrabasic rocks are rarely described from these complexes, but serpentines occur in the southeast of the Province of Akmolinsk (*fide*, J. M. Bell). According to Loczy ('95), there were eruptions of greenstone and serpentine with porphyrite and amygdaloidal diabase, following the formation of Carboniferous limestone in western China. These perhaps may also be connected with the Altaid folding.[1]

Between these Carboniferous folds which surround the Siberian shield and the massifs of Peninsula India and Arabia extend the great mountainous zone comprising the eastward continuation of the alpine mountain system, the former Tethyan geosyncline. The trend-lines connecting the Balkan Peninsula and Asia Minor have been indicated by Naumann ('96), but very little of the literature on this region has been accessible to the writer. In particular Frech's valuable summary ('16) was not available. Broadly speaking, Asia Minor consists of a central plateau of faulted horizontal strata, while the surrounding ranges consist of intensely folded strata. The oldest fossiliferous formations are Devonian, followed conformably by Carboniferous rocks, but beneath these are areas of schists and limestones with talc-schists, serpentines, peridotites, and granites. (Encyl. Britannica, 11th ed.) The ultrabasic rocks have been noted at Samos (Spratt '47, Butz '12), Mitylene (Launay '90, '98), Mount Ida (Diller '83), and near the Olympus of Brussa (Wilkinson '95). More definite, however, is the age of the serpentine lying farther to the east. It extends through the Pontic Mountains in the Cicilian Taurus, and continuing into the Ala Dagh is associated with Cretaceous limestone (Schaffer '00). Oswald ('11) shows that it has a wide distribution in Armenia, there being two principal zones, the northern crescentic zone extending through Erzerum, along the headwaters of the Frat, and bending to the east-southeast to follow the Goktsche and Pambek ranges. In this zone the serpentines are associated with Jurassic, Cretaceous, and Lower Tertiary rocks. South of this there extends a roughly parallel arcuate line of ultrabasic intrusions along the Taurus Mountains toward Lake Umri. In this zone we find a continuation of the serpentine-zone of Cyprus. Oswald considers

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[1] Devonian and Silurian rocks also occur, the latter consisting of clay-shales with chert interbedded with diabase and melaphyre-tuff. Since the above was written Leuchs's ('16) account of Central Asia has been received. He states that a widespread orogeny occurred in pre-Devonian time, accompanied by granite intrusions. The marine strata laid down in the Devonian transgression are very generally intercalated with diabase, melaphyre, and basic tuff, and were folded at the close of Devonian time when an extensive orogeny occurred with intrusion of granite. After the deposition of Lower Carboniferous marine beds there was a third period of mountain-building (the typical Altaid orogeny), in which a further series of plutonic intrusions took place, on the eroded surfaces of which the Upper Carboniferous sediments now rest. Associated with the last series of intrusions are numerous masses of gabbro in the Ala and Pamir ranges and particularly in the Tian Shan, while peridotite, pyroxenite, and serpentine are known in the Tian Shan, the Tarbagati and especially in the western Kuen Lun ranges.

that the bulk of these basic rocks were intruded during the widespread folding in early Miocene times, to which is due the general unconformity between Oligocene and Miocene rocks. Numerous pebbles of serpentine occur in the Tortonian beds. In northern Syria, Finckh ('98) concludes from Blackenhorn's investigations that the main eruption of the ultrabasic and basic rocks was between Cretaceous and Eocene and was continued into the latter period. They occur only in the folded region north of the Orontes, not in the plateau to the south. An extensive petrographic study of gabbros and of the origin of serpentine is given by this author. Philippson ('18), whose important work came to hand after the above was written, remarks on the wide distribution of the gabbro-peridotite rocks in Asia Minor, and their close association with the Eocene rocks. He assigns to a post-Eocene age the basic intrusions in the outermost Taurus-Cyprus zone of folding, of which Kober's ('15) study is noteworthy. Figure 8a herewith has been taken from Kober's ('21) summary of it. Philippson, however, notes that in the northern zone of basic and ultrabasic intrusions in Karia and Lycia, though the serpentine appears to overlie Eocene rocks, it is also apparently overlain by Mesozoic limestone, detritus derived from the same occurs in Eocene sediments. He considers, therefore, that its present position is due to overthrusting and that the actual eruption of the peridotites, etc., here occurred in Mesozoic (possibly Jurassic) times.

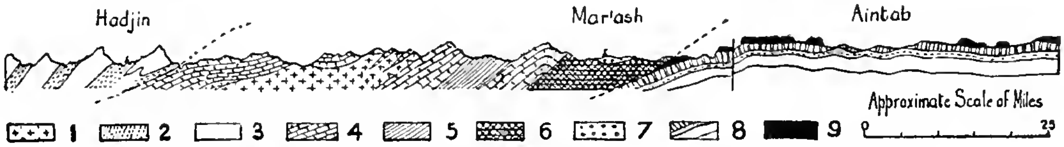

FIG. 8a.—Section across the Taurus Mountains and the plateau of Northern Syria. (After L. Kober.)

1. Crystalline schists, etc.
2. Paleozoic slates.
3. Paleozoic limestone.
4. Cretaceous and Eocene limestone.
5. Cretaceous and Eocene "Flysch" (sandstone, etc.).
6. Serpentine.
7. Miocene (?).
8. Cretaceous and Eocene sediments.
9. Basalt.

The zones of folding continue southeasterly into Persia, but the only intrusive masses of serpentine known are those occurring among the pre-Devonian gneisses and granite near Anarek (Stahl '11), but in the northeast of Arabia a sill-like mass of gabbro and dolerite with serpentine of post-Triassic age is found in very disturbed sediments near Muscat. The sheet of igneous rocks is unconformably overlain by Upper Cretaceous rocks (Pilgrim '08). There is another group of intrusions near the northern boundary of Beloochistan running to the northeast of Quetta for about 60 miles. They are sill-like in character, and form a mass sometimes 8 miles in width, lying in Senonian beds (Vredenburg '04). They here join a long arc of folded mountains which extends northward from Kurrachi toward Kalat. In these there occur enormous intrusive masses of basalt and dolerite with interspersed ash-beds and serpentine lying within the Upper Cretaceous sandstones. Vredenburg ('09) considers that those are the result of intrusion in the geosynclinal area about the Peninsula massif, coeval with the outpouring of the Deccan traps. His detailed account of these is not yet available, and the conditions under which the intrusions took place remain obscure. According to Vredenburg ('10) they are represented also by the peridotites and gabbros at Ladakh, described by McMahon ('01), though the latter considers they are only accidentally associated with the basalts and agglomerates in which they occur, which he supposed to be Tertiary.

Krafft ('02) described a great series of exotic blocks of Thibetan origin near Balchdura, included in andesitic or diabasic rocks, often amygdaloidal, among which a little serpentine occurs. They have partly the appearance of flows, partly of agglomerates. The included blocks are of all sizes up to mountainous masses. The whole complex lies on Cretaceous Flysch, but as this contains no intrusions from which the overlying volcanic material might be derived, the source of this discharge must also have been outside the region, and Suess concludes (IV, p.

565) that the overthrusting of the Thibetan segments and the emergence of the basic rocks took place simultaneously. He attaches considerable importance to this area in his general discussion of the green-rocks. Traces of such "Tertiary" igneous intercalations extend back to Kargil, on the Indus in Central Kashmir.

The Himalayas, lying farther to the southeast, are but slightly known. Several traverses near Sikhim record sills of peridotite, but it is not until we reach Burma that it becomes abundant.

In Upper Burma there occurs a mass of peridotite of unknown age which was originally surrounded by gabbro. Into these sodic veins were injected as a last consolidation-product of the ultrabasic magma, but instead of being merely albitic, as is usually the case (Benson '13), the veins contained also nepheline and inclusions of serpentine and gabbro. Bleek ('08) considers that great pressure, preceding and accompanying the intrusion of a mass of granite into the complex, resulted in the change of the gabbros into amphibole-schists and of the sodic veins into jadeite.[2]

The greatest developments of ultrabasic rocks are in the region of the Arakan Yoma and occur in elongated masses intrusive into the Triassic beds and also into rocks that are Upper Cretaceous or Eocene (Theobald '73). Vredenburg ('10) classes these with the cretaceous igneous rocks.

In the Andaman Islands, according to Oldham ('85) and Tipper ('11), there are pre-Tertiary jaspers, quartzites, and porcellanous limestone, like the Lower Cretaceous limestones of Beloochistan. Serpentines and a little diorite are intrusive into these, and pebbles derived from the serpentine and jaspers occur in the overlying Eocene conglomerate. The data are not sufficient to permit one to estimate the intensity of the folding of the pre-Tertiary beds.

On the west coast of Sumatra, near Padang, serpentines and gabbros again appear, intrusive in the Carboniferous rocks, but pre-Eocene in age (Verbeek '05, p. 53).

In the islands of Mentawei and Sipora off the west coast the serpentines are pre-Miocene (Traverso '95). They extend across the Straits of Sunda into western Java (Van Es, Jr. '16), and there they include masses of Cretaceous *Orbitolina* limestone, but do not invade the Eocene rocks, which lie discordantly on them (Verbeek and Fennema '96). Gabbros and diabase, sometimes pillowy or amygdaloidal, occur with tuffs in the Cretaceous rocks of Java, in a series also containing Jurassic radiolarite (Neithammer '09), and they appear again in Flores, Wetter, Luang, Sumba, Rotti, Timor, Kisar Letti, Moa, and Babar (Brower '19). Wanner ('13) has shown the occurrence of some of the alpine tectonic structures with great sheet-folding in Timor, Molengraaff ('13) has confirmed this, but the detailed account of his investigations are not yet available to the writer. In the island of Letti, which lies off the northeastern end of Timor, Molengraaff ('14) has shown that the basement consists of folded Permian mudstones, sandstones, and greywackes, with limestones and interbedded basic lavas and tuffs. These are greatly disturbed and metamorphosed and pass northward into crystalline schists. On the northern side of the island there are masses of serpentine thrust concordantly into and over the schist, and upon these and the adjacent schists there rest a long series of exotic blocks of crystalline schist, various volcanic rocks, and fossiliferous Permian, Triassic (*Halobia* beds of radiolarian chert), Jurassic, Cretaceous, and Lower Miocene rocks. The majority of these rocks have no analogues in the island itself, though some of them are similar to rocks occurring *in situ* in the adjacent islands of Timor and Moa. Molengraaff believes that these are remnants of a recumbent sheet that was once thrust over the serpentines, and thus analogous to the "klippen" of the Swiss Alps. He rejects the idea that they may have been thrust up with the intrusive basic rocks, as suggested by Krafft ('02) for the exotic blocks of the Himalayas. His section across central Timor cited by Brouwer ('19) shows analogous features. In Moa,

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[2] Du Toit ('18) has described a region in Natal where normal quartz-bearing aplites, which traversed a series of schists and extended therefrom into intercalated masses of serpentine, are changed to plumasite, or corundum-oligoclase-rock. This, he thinks, is due to the desilicifying action of the ultrabasic rock on the invading acid magma. The serpentine has become silicified, with the formation of talc, etc. It may be queried whether the development of nepheline-rocks and jadeite instead of the usual albitic dykes may not be due likewise to a process of desilicification by the invaded ultra basic rock for some local reason not at present apparent.

Brouwer ('16) has suggested the occurrence of a similar structure and notes the presence of pillow-lavas, probably of upper Triassic age.

As the Malayan arc swings round the Banda Sea into Timor Laut and Amboina, one finds again immense amounts of peridotite and serpentine invaded by diabase and later by granite and, after erosion, overlain by Tertiary rocks. In Amboina the ultrabasic rocks are the most ancient, but in the adjacent islands of Ceram they have been injected into a mass of schists of unknown age (Verbeek '05). This series of occurrences of green-rocks were grouped by Steinmann ('05) with ophiolitic rocks, and were held to have been formed under the conditions which he described for the genesis of such rocks. (See p. 2.) Mesozoic radiolarite is frequently present in this archipelago (Hinde '08), but Martin ('07) has challenged the assumption that they necessarily represent deep-sea deposits. Brouwer ('19) has discussed the age of the green-rocks of the Molluccas. Some, such as that of Amboina, appears to be probably pre-Permian; much is intrusive into the Mesozoic rocks, and is itself probably of late Mesozoic age, though there are also effusive diabasic rocks and tuffs of Triassic age; some again occur as sills in older Tertiary rocks. It was in early Tertiary times that the great thrusting movements occurred directed toward the south. The development of serpentine of about this age is, however, in immediate connection with pillow-lavas, "concordantly overlying" them, and Brouwer compares this association with the development of picrite with diabases and pillow-lavas in Germany.

According to Suess, the Philippine Islands, though very imperfectly known, appear to be the region of linking of four lines of Tertiary folding, along which elongated masses of ultrabasic rock may occur. To the southwest are the Palawan line and the Sulu line, to the southeast the Sangi or Celebes line, with a subsidiary line through Halmahera inserted between Celebes and New Guinea, while the fourth main line strikes north from Luzon into Formosa. Gabbros and peridotites are numerous in Halmahera and the adjacent smaller islands and in Celebes. A considerable amount of research work has recently been accomplished in the last island, most of which has not been accessible to the writer. (See Van Waterschoot van der Gracht '14, Abendanon '17, '19, Giswolf '17.) The following has been taken from a review of this literature by Wanner ('19):

That the outline and topography of Celebes is determined by recent fractures is shown by both geological and physiographic studies. Central Celebes shows a basement-complex of gneissic and schistose rocks invaded by a series of peridotites, flaser-gabbros, and granites, which farther south in the less altered Latimondjong range show evidence of having invaded Paleozoic phyllites, diabases, and diabase-tuffs. To the east this basement becomes less metamorphosed. According to Abendanon, it formed a continental platform which he terms Aequinoctia, at the close of Paleozoic times. (See Abendanon '19.) This was flooded by Triassic seas, which deposited radiolarite, and after some warping and erosion Cretaceo-Tertiary claystones were deposited unconformably on these. This covering has now been largely removed from the uplifted and dismantled peneplane, though retained in the west and southwest beneath a series of Tertiary andesites, trachytes, rhyolites, and leucite-lavas. The eastern margin of the continental region is determined by a long narrow intrusion ("1,100 meters thick") of ultrabasic rock, extending to the south-southeast from near the Gulf of Tomini past the head of the Gulf of Tolo, and for an unknown distance into the southeastern peninsula. This ultrabasic rock is stated to be "essentially Mesozoic," though the precise age can not be determined. There is abundant evidence of the action of much lateral pressure on the serpentine. Near the Gulf of Tolo it is associated with Mesozoic radiolarite, and Cretaceo-Tertiary marls and limestone, both intensely folded, which movement Abendanon holds to have displaced the passive ultrabasic rock. Farther north the serpentine is associated with steeply dipping and more or less reddish crushed phyllite and diabase-tuff, associated with brick-red radiolarite traversed by white veins, a striking analogy with the features to be described in the Devono-Carboniferous serpentine belt of New South Wales. A fault-trough separates this serpentine-line from the eastern peninsula, which has been described by Wanner ('10), whose paper is not accessible to the writer. According to Brouwer's citation, gabbro and diabase of Upper Oligocene age occur here.

Gabbros and peridotites are also numerous along a subsidiary tectonic line inserted in the southeastern part of Borneo and the little island of Siboku adjacent thereto, where the serpentine is overlain with Eocene deposits. On the mainland leaving the coast near Cape Selatan, the Meratus range runs to the northeast. Hooze ('93) has traced it for over 50 miles, and his map reproduced in La Face de la Terre (Vol. III, p. 337) shows a great series of sheet-like masses of serpentine, gabbro, and diorite invading crystalline schists and older Cretaceous rocks. In the northeast of Borneo the folded Kapua range consists of phyllite but with Mesozoic marls, limestone and radiolarian jaspers associated with diabasic sills and tuffs. There are post Jurassic intrusions of gabbro and serpentine noted here (Molengraaff '02), but the chief masses are on Palawan, where there is a large development of the ultra-basic rocks. When we pass east into the Philippines, the basic rocks appear in several regions from under a covering mantle of generally Tertiary sediments and volcanic rocks. In the incompleteness of our knowledge concerning these (see e. g. W. D. Smith '10, '11) nothing is to be gained for our present purpose from a discussion of individual occurrences. We note that the tectonic line, which strikes north into Formosa, is there accompanied by serpentine rocks, while serpentine appears also in the Liu Kiu Islands (Yoshiwara '01). When we pass into Japan the regularity of the serpentine-occurrences is no longer marked, but the information available to the writer does not permit him to give many details. Serpentines and gabbros appear in the basement-complex of crystalline schists. They are again recorded among Lower Paleozoic rocks, where they invade a group of more or less metamorphosed tuffs, breccias, conglomerates, and lavas with intrusive rocks that are pyroxenites, amphibolites, chlorite schist, etc. In the Middle and Upper Paleozoic (Devonian ?) and Carboniferous period there were developed "schalstein" associated with radiolarite, clay, shale, sandstone, and limestone, recalling the English and Australian spilitic occurrences, though the eruptions are probably chiefly of Carboniferous age. "Schalstein" and diabase or augite-porphyries intercalated in marine Jurassic rocks are invaded in Shiko-Ku by sills of gabbro and serpentine, and in Eastern Honshu a gabbro grading on either hand into diorite and peridotite is supposed to be of Tertiary age (Inouye '11 and Kozu '13). Thus while there is in this account a suggestion of the possibility of the division of the ultrabasic intrusive masses into the products of Caledonian, Hercynian, and Alpine folding, the two latter being preceded by geosynclinal periods of spilitic eruptions, the evidence as yet is not sufficient to permit a definite statement.

Apart from these basic rocks in the folded ranges, there is another group of intrusions of a very different character in the foreland-block of Peninsula India. These have been most fully described from the Giridih (Karharbari) coal-field, having been studied by Holland ('95). The rocks described as "mica traps" occur in this and in most of the Bengal (Permian) coal-fields in the form of dikes and intrusive sheets, composed of biotite, olivine, magnetite, chromite, apatite, and a perhaps glassy base. Augite and anthophyllite are present in some instances. The stratified rocks among which they occur are not strongly folded, but form a rather warped faulted basin. The dikes and sheets are younger than some of the faults, but older than the bounding fault of the field. Thus it appears probable that these intrusions occurred during an epoch of crust-faulting and warping, but no marked folding. The rock itself is like the type which is associated with the occurrences of kimberlite-breccia of South Africa and of southern Bavaria, and forms the peculiar dike rocks which we shall describe from the eastern United States. In petrographic character and the tectonic conditions accompanying their development these form a definite petrogenetic group, which we have termed the alkaline-peridotites.

The basement gneissic complex of Peninsula India contains a number of ultrabasic masses, especially in the Madras Presidency (Middlemiss '96 Holland '00), but these give us no evidence of the tectonic conditions that accompanied their intrusion other than that of intense pressure. In Singhbhum, however, to the west of Calcutta, there are three masses of serpentinized peridotite which are described as laccolitic intrusions several hundred feet thick that have participated in the later stages of the folding of the Dharwar "Huronian" rocks (Fermor, '19).

Chapter VI.

THE OCCURRENCE OF BASIC AND ULTRABASIC INTRUSIVE ROCKS IN AUSTRALASIA.

The summaries of the structure of Australasia given by David ('11) and Andrews ('16), show that some analogy exists in its general plan with that of Asia, in that it has on one side an ancient nucleus, the massif of Western Australia, against which the Paleozoic and later rocks have accumulated and have been ridged into a series of roughly concentric folds of progressively more recent date as we recede from the nucleus.

The recent investigations of the Western Australian Geological Survey in the Coolgardie region show that the most ancient rock is gneiss, upon which rests a mass of amygdaloidal basic lavas, perhaps pillowy, together with porphyrites and rhyolites, associated with slates and conglomerates. These together make up the ancient green stones, and after a period of intense folding, they were invaded by the great series of plutonic rocks that now occupy the greater part of the surface of the Western Australian plateau, consisting of peridotite and gabbro in small amount, diorite, syenite and abundant granite, with dykes of pegmatite, porphyry, and diabase (Honman '17). This may be taken as generally typical of other areas in the state where an extensive sequence of events has been proved. The peridotites appear not only in the region cited, but in most of the carefully studied areas that lie in a broad belt extending to the northwest coast at Roebourne, and toward the south coast at Port Esperance, a distance of nearly a thousand miles, over which the strike of the gneisses remains almost constant. They have been described especially from the following districts: Pilbara (Maitland '08), Meekatharra (Clark '16), Phillips River and Norseman (Woodward '09). Much younger and massive intrusions of norite have been found in several areas, notably in the last mentioned. They also occur in some variety in the Cavanagh Range near the boundary between Western and South Australia. (Thomson '11.) A further example occurs near the Murray River in South Australia, and was described by Chewings ('94). This last rock, like the other norites, is very much less altered than are the rocks in the dikes of diabase, which occur in north and south-central South Australia, and were, probably, erupted during an early Paleozoic period of orogeny (Benson '09). Thomson, indeed suggested that the dolerites may be coeval with the late Mesozoic dolerites of Tasmania, and that their eruption may have been connected with the crust-movements during the breaking-up of Gondwanaland.

No ultrabasic rocks are known in South Australia or the Northern Territory, but they appear in each of the four eastern States. In Tasmania, great folding occurred in the pre-Cambrian and late Ordovician times, but was not then accompanied by the intrusion of basic rocks. Folding again took place between Silurian and Permo-Carboniferous (Permian) times accompanied with abundant plutonic intrusions. In the absence of any Devonian and Carboniferous sediments, the period of folding has been held to be Lower Devonian, coeval with that of Victoria, during which extensive granodioritic intrusions occurred (Skeats '09).

The plutonic rocks of Tasmania range from ultrabasic to acid types, but intermediate types are very rare. In general, the basic and ultrabasic types form long intrusions approximately parallel to the general strike of the invaded Silurian and older rocks. The largest masses appear to extend in a belt about 30 miles from south to north and from less than 2 to 5 miles from east to west, running intermittently from the Dundas to beyond the Waratah mining field (Twelvetrees '14). It is invaded by granite, and in the southern portion is divided into two parallel belts (Ward '09, '11, Waterhouse '14, Conder '18). Other less continuous masses of ultrabasic and basic rocks lie to the west of this (Twelvetrees and Ward '10, Hills '14, Waterhouse '16). Generally the gabbro and peridotite (now serpentine) are so closely associated that they are not separately mapped, but in the South Heemskirk region they form areas separate from each other and from the granite to which they are roughly peripheral (Waterhouse '16). However, there is generally a marked contrast between the approximately concordant or sill-like masses of basic and ultrabasic rocks and the transgressive boundaries of the granite. Reid's ('21) more detailed mapping of these areas reveals the presence of several laccolitic differentiated complexes of peridotite, pyroxenite and gabbro, either quite separate from the granite or invaded by it. That of the Heazelwood District (fig. 9) appears to dip generally toward the southeast, and the succession of peridotite, pyroxenite, and gabbro in this direction recalls Bowen's explanation of the origin of the Tagil complex in the Ural Mountains. Osmiridium and diamonds occur in the Heazelwood peridotite. All these lie in the western districts, but sill-like masses of peridotite-serpentine have also been found in the south of the island invading Cambrian quartzite (Twelvetrees '09) and in the north between Cambrian quartzite and ancient amphibolite-schists (ibid. '02), and again in a mass a mile in width and 4 miles in length, invading, apparently concordantly, the lower Paleozoic sandstones, and in turn invaded by dikes of granite (ibid. '17).

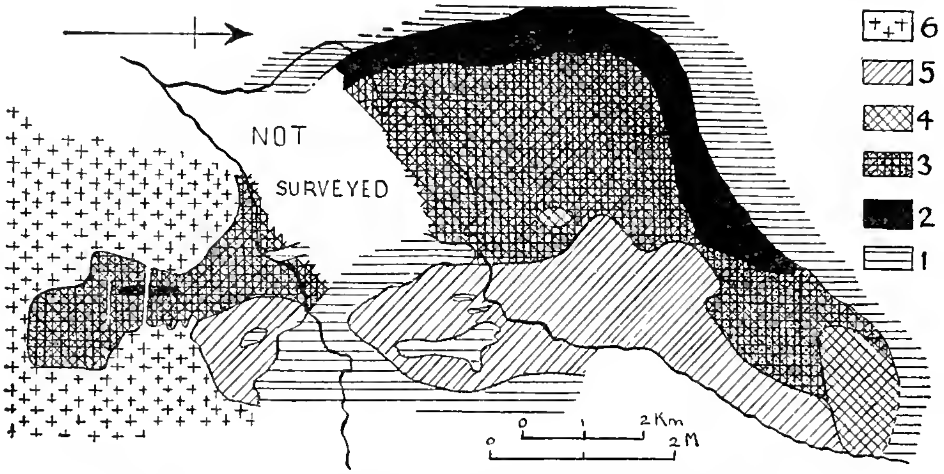

Fig. 9.—Geological sketch-map of the Heazelwood District, northwest Tasmania. (After A. M. Reid.)
1. Invaded Ordovician lavas and Silurian sediments and limestone.
2. Devonian peridotite.
3. Pyroxenite
4. Bronzitite.
5. Gabbro.
6. Granite.

Central and eastern Tasmania is occupied by an unbroken series of conformable Permo-Carboniferous and Mesozoic sediments, which are nearly horizontal and according to Nye ('20, '21) have been invaded in their lower portions by an immense sill-like mass of quartz-dolerite from which rise minor intrusions of various forms including large and small dikes and sills. These are comparable in many respects with the dolerites of Antarctica, the Karroo, and the Newark series of New Jersey. (Twelvetrees and Petterd '99, Twelvetrees '02, Thomson '11, Benson '16.) Their intrusion was clearly unaccompanied by any crust folding.

Teale ('19) has described in central Victoria, near Mansfield, a series of Cambrian *Protospongia* cherts. These contain normal and richly albitic diabase, the spilitic nature of which is apparent. In addition, there are diabasic tuffs and agglomerates, together with small masses of serpentine. The whole igneous complex has been so strongly silicified that the tuff has been more or less changed to chert, while the diabase has in places become a red jasper. The linear arrangement of the masses of jasper suggests the occurrence of a shear or fracturing zone which favored at recurrent intervals the access of silicifying solutions. A similar complex occurs at Heathcote (Skeats '08) and probably in several other parts of Victoria.

The ultrabasic rocks of the Mount Wellington area have also been described by Teale ('20). Here there occurs an elongated mass of serpentine running for a distance of over 3 miles in a northwesterly direction with a width varying from two chains to a quarter of a mile. It lies between black jasperoid slate, and black slate with bluish calcareous bands in which Upper Cambrian fossils occur (Chapman '11). A serpentinous conglomerate is associated with the slate, and the serpentine is therefore regarded as older than the slate. It contains besides chromite a considerable amount of corundum.

In the pre-Cambrian complex of Broken Hill, New South Wales, Andrews ('22) and his colleagues have found two series of basic igneous rocks. The older consists of laccolitic or sill-like masses for the most part, but also form dikes in the sedimentary schists and augen-gneisses. They comprise more or less altered peridototes, pyroxenites, gabbros, and norites, and are intimately associated with dike-like masses of an aplitic rock rich in barium, and garnet-quartz-magnetite rocks. A noteworthy feature is the frequent association of fine and coarse grained types of gabbro, probably as the result of successive injections of magma into the plane of the sill. The newer series consists merely of dikes of uralitic dolorite, possibly of post-Cambrian age.

In southeastern New South Wales a band of peridotitic and pyroxenic serpentine extends from near Tumut to beyond Gundagai, a distance of 40 miles. It has been traced by Carne ('92, '95), who has shown it to follow approximately parallel to the nearly meridional line of strike of the probably Ordovician rocks which it invades, while smaller parallel bands occur associated with it. No definite evidence of its age is available, nor is there definite information of the time and conditions of intrusion of the norite of Kiandra (Andrews '01) or the serpentine of Berthong (Jaquet '96). Considerable folding seems to have occurred between the times of deposition of the Ordovician and Silurian rocks, for the two series are generally unconformable, but no plutonic intrusions have yet been shown to have formed in this interval. Süssmilch ('14) and Andrews ('16) conclude that during the Devonian period a movement of folding strongly affected the eastern portions of southern New South Wales, the strikes of the two epochs of folding being parallel to each other and to the Gundagai serpentine-belt.

There appears less uncertainty in regard to the great serpentine-belt of northeastern New South Wales which has been studied in detail by the writer. (See Benson '13, '15, '17, '18.) It seems that no folding occurred from Middle Devonian until Middle Carboniferous times, when the orogenic movements commenced. The sequence of events is as follows: The belt of country extending northward and to the north-northwest of Newcastle was a geosynclinal area during Devonian and early Carboniferous times. In this was deposited a great thickness of radiolarian sediments, interstratified with three bands of Middle Devonian coral-limestone. Submarine eruptions took place producing an immense amount of tuff, breccia, and agglomerate, with accompanying formation of probably intrusive spilites, and vesicular pillow-lavas and dolerites (diabase), generally albitic,[1] with locally large amounts of very albitic keratophyre. This series of rocks in regard to their age, the tectonic conditions of their origin, their sedimentary associations, and their mineralogical characters, are most closely allied to the spilitic suite of rocks of Devonshire, Germany, and probably also to those of the Urals. (Compare, e. g., pp. 12, 16, 19, 20, above.) But the comparison does not cease here. In Upper Devonian times deposition of radiolarian mudstone and tuffs continued with rare intrusions of dolerite (Benson '17). In early Carboniferous times (perhaps after an erosion-interval and consequent disconformity), the deposition of mudstone (but not radiolarian) continued with formation of interstratified crinoidal limestone in small amount; later keratophyric tuffs appeared more abundantly, followed by a great series of conglomerates and tillites (the development of which seem to indicate the commencement of crust-folding), with tuffaceous sandstones with plant remains of lower to middle Carboniferous age (Walkom '19) invaded by an extensive series of igneous rocks rising through longitudinal and transverse fissures. These intrusions appear to have been closely connected with the outpouring of the

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[1] The examination of a sill of albite-dolerite 1,500 feet thick showed that it was uniformly sodic, a contrast to the concentration of albite in the upper portion that might have been expected on the hypothesis of the upward concentration of soda by resurgent water. (See Daly '14, Benson '15.)

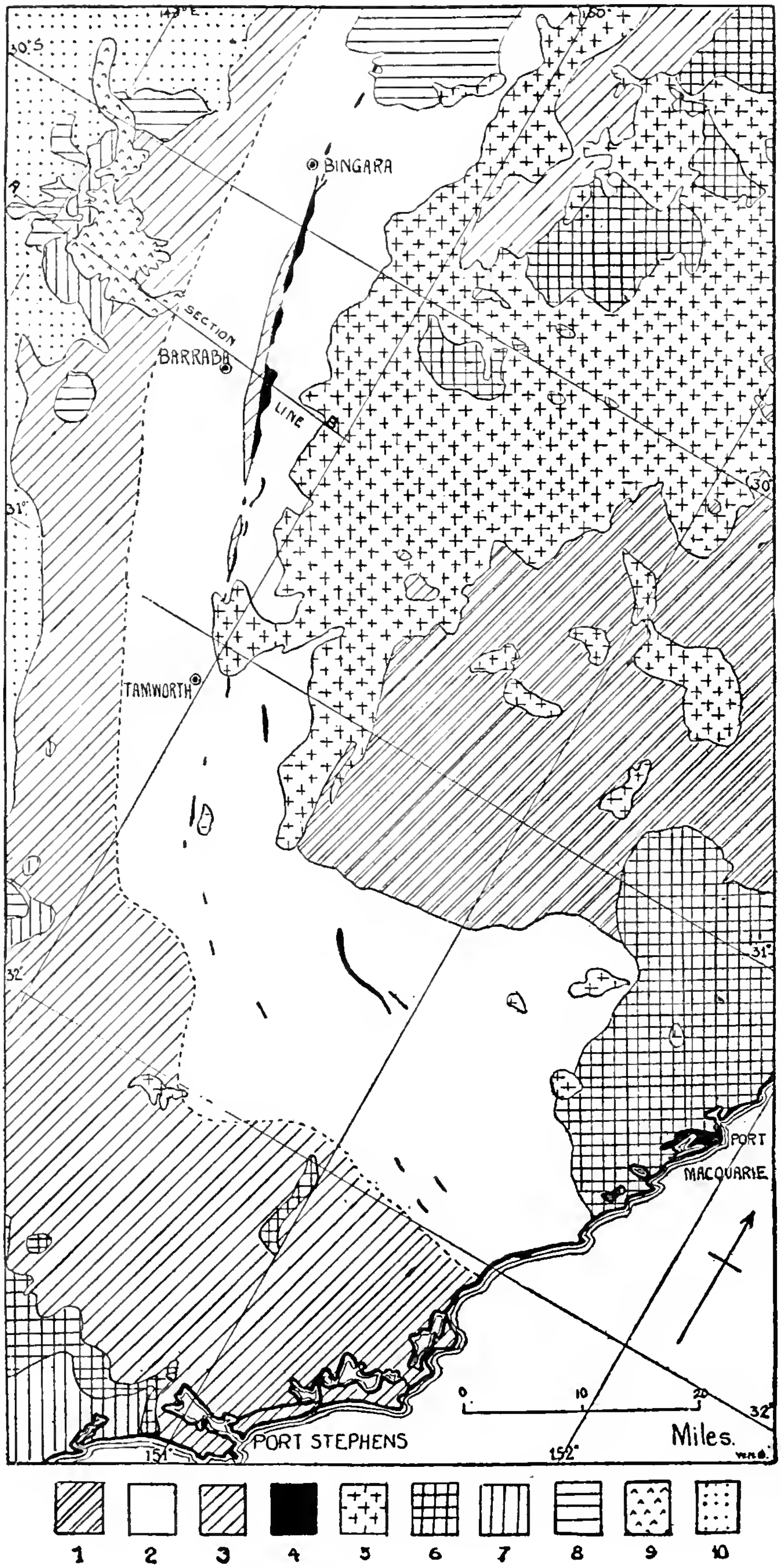

FIG. 10.—Geological map of the Great Serpentine Belt of New South Wales.

1. Old highly folded sediments.
2. Devonian.
3. Carboniferous.
4. Serpentine.
5. Granite.
6. Permo-Carboniferous.
7. Triassic.
8. Tertiary basalt.
9. Tertiary trachyte.
10. Alluvium.

basalts that overlie the Carboniferous formations and perhaps extended up into the Permo-Carboniferous. The investigations of Mr. W. R. Browne and the writer ('20) show that the volcanic rocks, sills, and dikes of the Carboniferous series comprise normally calcic rocks such as andesites, dolerites, and basalts with rather more alkaline types such as soda-rhyolite, keratophyre, and an albitized dolerite. The distinction between the Devonian and Carboniferous types of eruptive rocks in New South Wales is therefore comparable with that between the Devonian and Carboniferous types in the Urals (p. 16). As in the Urals, the changes of eruptive rock-facies marked the change from geosynclinal conditions of crust-sagging to orogenic conditions of up-folding of the crust. This produced an unconformity above Carboniferous beds which, though marked in the northern part of this serpentine-belt where the lower and middle portion of the Permo-Carboniferous series is absent, is much less marked near Maitland, where the complete Permo-Carboniferous sequence rests with disconformity or slight unconformity upon the Carboniferous beds (David '19). This Carboniferous folding, ushered in by the outpouring of lavas and production of sills, culminated in the development of the plutonc series of New England which commenced with the intrusion of peridotites, intimately associated with the slightly newer gabbros, which were followed by a long series of granites, the later members of which invaded even Permo-Carboniferous marine beds that had developed during a lull in the orogeny (Andrews '05).

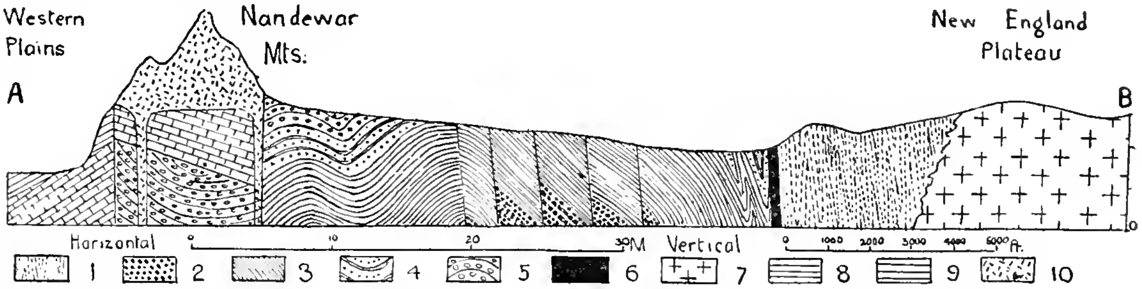

Fig. 11.—Geological section across the Great Serpentine Belt of New South Wales. (See fig. 10.)

1. Highly folded Devonian sediments.
2. Middle Devonian agglomerate.
3. Upper Devonian mudstone.
4. Lower Carboniferous mudstone.
5. Middle and Upper Carboniferous conglomerate, etc.
6. Serpentine.
7. Granite.
8. Permian.
9. Triassic.
10. Tertiary trachyte, etc.

The characteristic feature of this occurrence of peridotite (now serpentine) is its linear character. It runs intermittently for over 250 miles from the coast, a short distance north of Port Stephens, to Warialda. (See Benson '17, '18a.) The serpentine-belt is rarely as much as a mile in width; frequently it is only a few yards across. Generally it occupies a well-marked structure-plane separating highly crushed from less crushed rock. (See figs. 10, 11.) The fact that the boundaries of the subsequent intrusions of granite are so highly irregular, and their irregularities in no way affect the continuity of these lines of serpentine shows most strikingly how distinctly different must be the mode of intrusion of the ultrabasic mass and associated gabbros, "forming sills in dislocated mountains, which sometimes follows the planes of movement and sometimes the plane of bedding," and the mechanics of intrusion of granite-batholiths.

The distribution of rock-types within this narrow strip is significant. The serpentine has been almost all derived from harzbergite, a minor amount from lherzolite; pyroxenite is rare, but a small amount of pure enstatite rock occurs. In the northern end of the belt must have been the locality where was found the aggregate of picotite which Judd ('95) described as a vein of picotite rock. This the writer could not rediscover. Gabbros occur here and there, generally confined within the sheet-like mass of ultrabasic rock, and but rarely protruding therefrom to invade the adjacent sediments. They are more abundant proportionately where the serpentine belt is unusually wide (with the exception of the region of maximum width). The smaller masses of gabbro cut sharply through the serpentine in irregular directions, but so far as the limited information goes, the larger masses of gabbro form broad gneissic intercalations lying more or less concordantly within the serpentine belt. But here detailed mapping is wanting. The gabbros are largely saussuritised, olivine gabbro is rare, and the eucrite type is the most abundant. The writer's analysis of the least altered specimen showed it to consist of anorthite-bytownite and chromiferous diallage in which the enstatite-molecule was richly present (Benson '13). The gabbro-veins of the smaller masses have sometimes a very coarse pegmatitic-ophitic structure. As a result of secondary changes, veins of grossularite have been produced. Judd ('95) also noted these rocks.

Several parallel but shorter bands of serpentine are known to lie east of the main belt, but they have been little investigated. An interesting structural problem is afforded by the occurrence of masses of serpentine as at Port Macquarie directed to the northeast (Carne '97). The writer has suggested that these result from virgations of the strike of the main axis of folding and serpentine-intrusions, and that the serpentine is not (as has been stated) essentially a roughly elliptical peripheral zone about a central complex of granite batholiths (Benson '18a).

Other small patches occur farther to the northeast on the Clarence River, but are less well known. They seem to be sill-like masses, invading highly crushed Devonian (?) phyllites, etc., parallel to the general north-northwesterly strike.

Very different from these is a small mass of essexite of roughly lopolithic form and presumably Tertiary age, invading the horizontally bedded Triassic mudstones at Prospect near Sydney, described by Jevons ('11) and others. It is suggested that here the spreading of the magma from the central feeding channel was controlled by the varying thickness of the covering strata, probably not more than 1,000 feet, due to the surface topography.

Nothing definite has been published with regard to the serpentines of Queensland. They are known to occur at Pine Mountain near Ipswich, an isolated patch striking to the northwest, but completely surrounded by younger Mesozoic sandstones (Cameron '99); they form a long broad band running in the same direction west of Gympie, and another similarly placed but longer band east of Rockhampton. Both of these are considered by Mr. Dunstan, Chief Government Geologist for Queensland, to lie for the most part concordantly within Devonian strata which are more or less metamorphosed. The Gympie mass of serpentine has been invaded by granite, which forms also a batholith farther to the west but adjacent to the serpentine.[2] Other isolated occurrences have been reported but not yet described.

In Queensland the latest folding is more modern than elsewhere in the continent, even Cretaceous rocks being involved (Andrews '16) but in southern New Guinea, Tertiary rocks even as late as Pliocene have been folded and thrust toward Australia (David '14a).[3] This is the first of the arcs of folded ranges of Tertiary age that surround the Australian nucleus. Its northern margin exposes the arc of ancient schist, but strongly folded Mesozoic rocks occur, the strike of which may be traced west into Buru and Ceram, where Cretaceous rocks are greatly involved. In these islands basic eruptive rocks occur, and these are traced in isolated occurrences of gabbro and serpentine along the north coast of New Guinea, both in Dutch New Guinea and the Finnisterre Range. This is continued into the Louisiade Islands to the southeast of New Guinea. Stanley ('12, '15, '21) reported serpentines, etc., in the metamorphic sediments of the Owen Stanley Range and Woodlark Island, and found a long sill-like mass of gabbro in the schists and gneiss of Misima (St. Aignan), the easternmost of the Louisiade group, its general strike being very slightly south of east. In the Solomon Islands, belonging to an outer arc, numerous fragments of peridotite and gabbro have been found of which some details have been cited by Suess (IV pp. 311–312). Mention may here be made of the occurrence of gabbro in Tahiti, at the base of a varied complex of foyaitic rocks, and very basic basalts. The relationship of the gabbro to the other rocks does not seem quite clear yet (Lacroix '10, Marshall '14).

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[2] Private communication.

[3] These strongly folded rocks are now considered pre-B. Miocene. (Cf. Benson Trans. N.Z. Inst. IV, pp. 115.)

The discussion of the geology of New Caledonia given by Suess (IV) based on the work of (Pelatan '91); Glasser ('03), Deprat and Piroutet ('05), and their predecessors, must now be greatly modified as a result of Piroutet's masterly account of the island ('17). The following is a brief summary of this most interesting work. (See fig. 12.) The most ancient rocks are a series of mica-, amphibole-, and glaucophane-schists and gneisses, which are followed by gradual passage into sericite-schists and unfossiliferous phyllites, to which an Algonkian or early Paleozoic age is assigned. These were strongly folded along a northwest-southeast axis and eroded before the transgression across them of Permian and Triassic seas, passing from the northeast to the southwest, with a regressive period in the Middle Triassic, but subsequent transgression of the Upper Triassic in the same direction. Rhyolitic eruptions occurred during Lower Triassic times; trachytic, andesitic, and diabasic in Upper Triassic. Folding then occurred along lines slightly oblique to the earlier folding, and the land to the west was again submerged at the close of Jurassic times. A succession of transgressions from the southwest to the northeast deposited a series of marine and coal-bearing strata alternating with one another, there being also extensive eruptions of rhyolitic and andesitic lavas and tuffs in Neocomian time. By the Senonian period the whole land was submerged, but orogeny followed, again along a direction approximately northwest and southeast as before, but slightly oblique to the older folds. A further marine transgression occurred in Middle Eocene times, again passing from the southwest toward the northeast, with such evidence of minor regressions and breaks as to show the instability of the crust at this period. Andesitic and diabasic eruptions took place. A profound orogeny followed, the direction of the folding being only very slightly oblique to the preceding movements. The dominant overthrusting force came from the northeast, causing the overturning to the southwest, of the majority of the folds, especially those along the west coast, which are sometimes broken, and piled up into a series of overthrust flakes, with reversal of the normal order of superposition. Owing to the inequality in the distribution of the folding force along the line of strike, and the uneven resistance of the ancient folded subcrustal masses, arcuate folds open to the north occur in the northeastern part of the island, while the existence in a zone along the east coast of a series of folds overturned in a northeasterly direction, may be due to the foundering of crust-blocks in that region, of which there is other evidence. It was during this Tertiary period of intense crust-folding that the huge masses of ultrabasic rocks were injected, which occupy, according to the map reproduced herewith, an area of approximately 2,600 square miles out of a total area for the whole island of 6,450 square miles. Piroutet has clearly shown

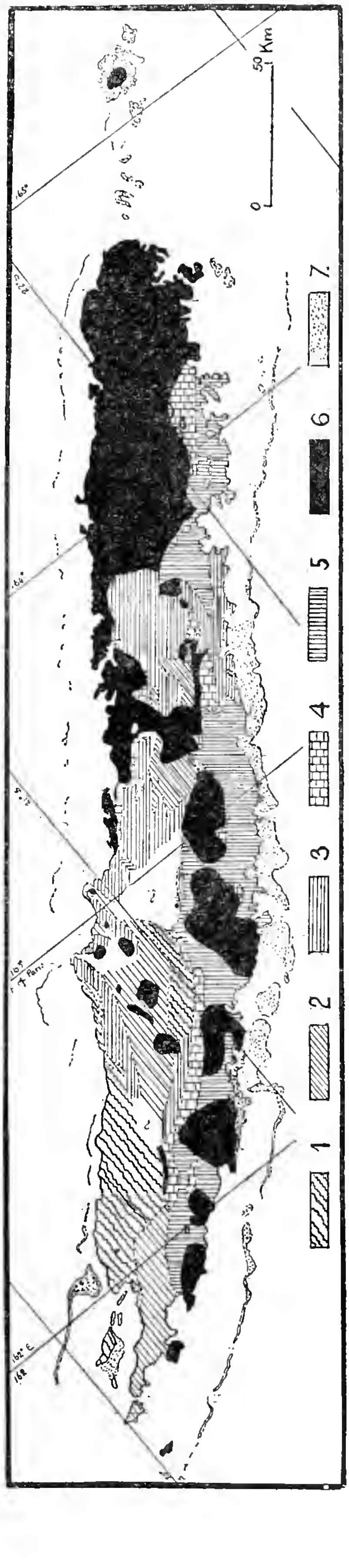

FIG. 12.—Geological map of New Caledonia. (After Piroutet.)

1. Gneiss and crystalline schist. 2. Sericite-schist and phyllite. 3. Triassic. 4. Late Jurassic and Cretaceous. 5. Eocene. 6. Serpentine. 7. Coral-reef.

that Glasser's conception of these rocks as part of a vast overthrust sheet is inadmissible. The peridotites have metamorphosed the adjacent sediments, often Eocene, and contain many large inclusions of them. The boundaries of the intrusions are sometimes vertical or inclined parallel to the dip of the invaded sediments. "Each of the massifs send out prolongations, almost always parallel to the strike of the beds. Besides these, numerous little intrusions in general elongated in bands in the same direction are excessively frequent, and are encountered almost everywhere." (Op. cit., p. 283 trans.) Other plutonic rocks occur in negligible amount; a few rolled pebbles of granite have been found, and a single dike of the same rock in the schist. Micropegmatite and diorite are equally rare, but a small massif of gabbro is known.

In New Zealand there was a long period of sedimentation, extending from later Paleozoic up into early Cretaceous times, the youngest sediments of the series having been shown to be Neocomian in age (Arber '17). Some authorities, and most recently Park ('21), have held that an important orogeny with plutonic intrusions interrupted this long period of subsidence and sedimentation about the close of Paleozoic times, and there seems reason to believe that minor breaks occur in the older Mesozoic sequence of beds. Some conglomerates and limestones occur in the series, but by far the greater portion consists of greywackes more or less argillaceous in character, and in Jurassic times especially interbedded with zones containing plant-fossils or even coal. Igneous rocks are rare. Melaphyres and basic breccias occur in the lower portions at Nelson (Marshall '11), and are more widespread intercalated in the Upper Triassic strata. Folding occurred directly following the deposit of the Neocomian beds (it had perhaps commenced before then), and was felt with varying intensity over the whole region, producing highly compressed strata, overturned folds, and perhaps over widely extending regions metamorphic schists were formed. The ranges so produced were soon mantled with marine sediments, the first of which have been shown to be of Lower Utatur age, equivalent approximately to the Albian or Middle Cretaceous (Woods '17). There followed Upper Cretaceous (Senonian) and Tertiary sedimentation, the continuity of which, or separation into several series by minor crust-movements, is still a matter under investigation. It would seem, however, that a definite break separated the Senonian from the Middle Tertiary deposits in the northern part of the North Island. Extensive orogenic movements, however, occurred again toward the close of the Tertiary period, resulting both in block-faulting (the Kaikoura movements of Cotton) and the overthrusting of Tertiary deposits by Mesozoic rocks or schists, as exhibited at Nelson (Marshall '11) and on Lake Wakatipu (Park '09).[3]

The following brief descriptions will indicate the nature of the known occurrences of basic and ultrabasic rocks in New Zealand. In the extreme north there exists a complex of basic and ultrabasic rocks the relations of which to each other and to rocks of known age are not clear (Bell '09). Marshall ('07) has shown the existence of masses of olivine-norite at Ahipara a short distance to the south. Bartrum thinks this may be considered to be coeval with a group of epidiorites intrusive into the Trias-Jura greywackes of the Whangerei district, and, tentatively, that they were erupted during the Cretaceous orogeny. Perhaps, however, they should be grouped with a series of small intrusions of serpentine occurring between here and Aukland, namely near Wade (where troctolite also is present), Warkworth, Wainui, and Kaipara Flats, which invade the probably Senonian "hydraulic limestone," but are apparently older than the Oligocene-Miocene sediments and limestone. This hydraulic limestone is considerably dislocated and broken, but is not very greatly folded. It thus seems probable that the Tertiary crust-movements, which were so marked in New Caledonia, affected to a lesser degree the northwestern peninsula of New Zealand, and were there accompanied by a small amount of intrusion of peridotite, etc.[4] There is a small occurrence of serpentine on the Mokau River also, about 120 miles south of Aukland. This Henderson ('23) found to occupy a fault-plane, but its relation to the adjacent Tertiary limestone is obscure. Specimens from this mass, and from that of Warkworth, prove to be normal harzbergite-serpentine. In the South Island the most

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[3] For further details reference may be made to the writer's recent summary of the geology of New Zealand (Benson '21).

[4] For the above information the writer is indebted to a private communication from Mr. J. A. Bartrum.

fully investigated mass of serpentine occurs. It commences in D'Urville Island and continues intermittenly for many miles to the south-southwest, parallel to the general strike of the invaded Paleozoic and Mesozoic sediments. The most continuous patch includes the Dun Mountain, and extends for nearly 20 miles.[5] Its irregular outline suggests that it was formed by a series of coalescent sill-like intrusions of peridotite, now serpentinized associated with a little "rodingite" or grossularite-gabbro. (Marshall '11.) (Fig. 13.) While the general extension of the mass is thus concordant, the boundaries considered in detail usually transgress the bedding-planes of the invaded formation. The majority of the exposed rock is serpentine; harzbergite is common, but its distribution relative to that of the dunite has not yet been studied in detail. The dunite not infrequently contains a small amount of pyroxene, and the chromite is distributed somewhat streakily in it. Strain-phenomena are common in the crystals, but there is not an excessive amount of crushing. Masses of very coarse grained websterite also are present. The rodingite has been rightly compared with the garnet-rocks in New South Wales mentioned above, but in the writer's view (Benson '13, pp. 684–689, '18, p. 722) neither should be considered primary magmatic crystallizations, but produced secondarily, probably largely through the action of the concentrated magmatic water. Long sill-like masses of serpentine occur also in the Collingwood (Takaka) region to the northwest from Dun Mountain (Bell '07), where they form lenticular masses elongated parallel to the nearly meridional strike of the invaded Ordovician sediments against which the granite has strongly transgressive boundaries. Serpentines, often antigoritic, again form a group of narrow sills, rarely more than a mile in length, in the steeply folded schists and phyllites to the east of Hokitika (Bell '06), and similarly occur in the

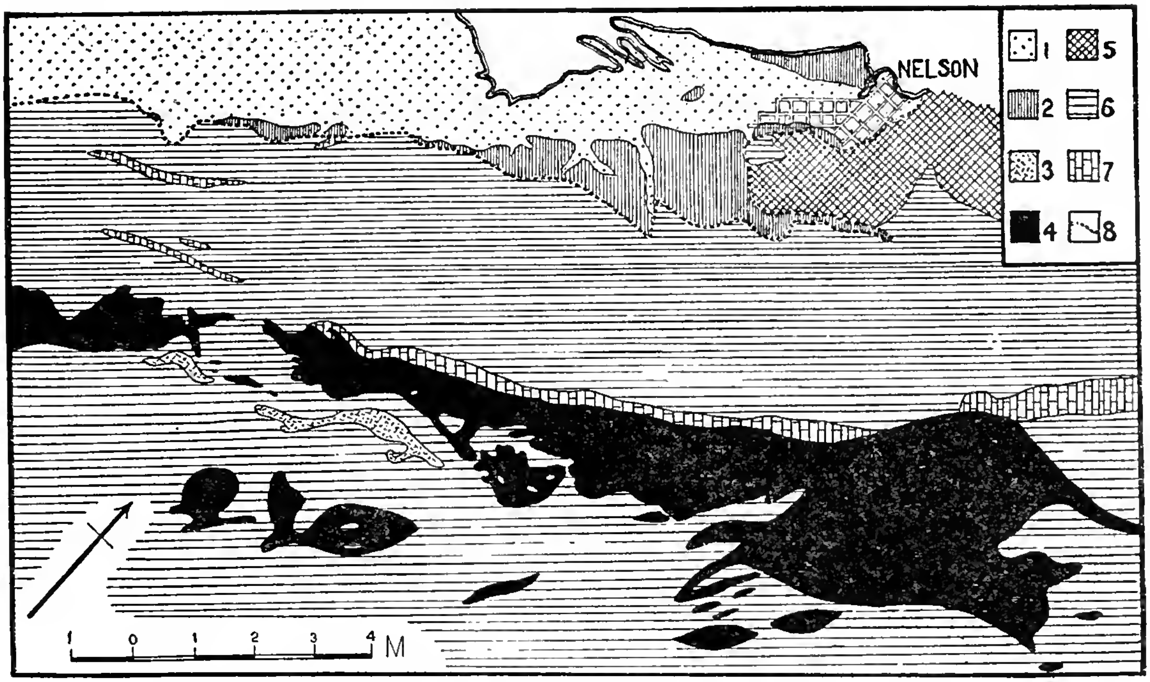

FIG. 13.—Geological map of the Dun Mountain District, New Zealand. (After Marshall and others.)
1. Alluvium.
2. Tertiary.
3. Rodingite.
4. Peridotite and serpentine.
5. Mesozoic (?) basalts, etc.
6. Mesozoic and Permian greywackes.
7. Permian limestone.
8. Fault-lines.

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[5] This is the occurrence whence the typical dunite was first obtained by Hochstetter (65) in 1859.

southwesterly continuation of the same zone of schists in the adjacent survey-district. The sections published indicate that in one region it seems to invade a broken anticline, slightly overturned toward the west. The upper limit of the possible age of these beds is fixed by the occurrence of pebbles of serpentine in the "Miocene" beds overlying the ancient rocks (Morgan '08). The occurrences were especially mentioned by Suess (IV, p. 566) when discussing the origin and significance of the green-rocks. Their relationship to the adjacent masses of gneissic diorites is not yet quite clear. Some authorities (Morgan '22) have considered that the latter are probably pre-Ordovician, but there is a strong petrological similarity between them and the gneissic diorites of the southwestern portion of the island, with which are associated a series of ultrabasic intrusions. During the last decade there ultrabasic and accompanying basic intrusions have been generally considered to have been injected during the late Mesozoic orogeny, but more recently Park ('21) has declared his belief that they were injected during the early part of the Triassic, accompanying the orogeny he believes to have occurred then, and he considers that all the other occurrences in the South Island are probably of the same age. The following are the known masses of basic and ultrabasic rocks in this southwestern development:

North of Big Bay and Milford Sound a large mass of peridotite occurs as a lenticular patch within the gneisses, forming the Olivine Range more than 8 miles in length and over 2 miles in width (Park '86). In the vertically-dipping schists at the Cow Saddle, northwest of Lake Wakatipu, Marshall ('06) found a laccolitic complex of which the eastern half consisted of lherzolite, with a small nucleus of dunite near its western side. This was immediately followed passing to the west, by pyroxenite, gabbro, and diorite in succession. Unfortunately, he was prevented from examining in detail this interesting mass which thus bears a very considerable resemblance to the complexes in the Urals. Not far from this are the masses of mica-norite in the Bryneira and Darran ranges, the former also associated with gabbro and serpentine. These occur in the northern portion of the great batholith of diorite which forms the southwestern portion of the island or "Fiordland." This mass is gneissic on its western margin where it contains bands of amphibolite, and invades more or less concordantly, a series of schists which pass westward into Ordovician slates etc. On the east it is less gneissic or is even massive, and invades Permian or Lower Triassic greywhackes. It is in turn veined by aplite or pegmatite often garnetiferous, and by massive granite. (Speight '10, Benson '21, Park '21.) Gneissic norites occur on the western margin at Bligh Sound, and at the entrance to Milford Sound (Anita Bay). Marshall ('05) observed among the schists a mass of peridotite containing much magnesite, and at times completely crushed. Southeast of the main batholiths are smaller outlying masses of norite such as that at Orepuki (Farquharson '10) and at the Bluff at the extreme south of the island. The last mass is associated with amphibolite (Wild '12), while that of Orepuki invades greywackes of probably Permian age. The southernmost occurrence of serpentine known in New Zealand is the small sill near Cromwell which invades mica-schist (Park '08). Concerning the age of this schist opinions have varied between those which claim for it an Archaean, or Paleozoic age, and that which would place it among Mesozoic formations.

Southward from here we may note the occurrence of gabbro in the Auckland (Speight '09) and Campbell Islands (Marshall '09). In South Victoria Land the dominant feature of the igneous geology is the occurrence of an immense series of sills of quartz-dolerite very like those of Tasmania (David '14, Benson '16), and cutting obliquely across the almost horizontally-bedded sandstones of Permo-Carboniferous and possibly Devonian age. The intrusion was not apparently associated with faulting, and the supply-channels for the sills have not been noted (Ferrar '07, David '14). Some gabbros were found, but not *in situ,* and were almost certainly derived from the folded complex beneath the sandstone.

Chapter VII.

THE BASIC AND ULTRABASIC INTRUSIVE ROCKS OF AFRICA.

The basic and ultrabasic intrusive rocks of South Africa belong to several diverse series, of which the most ancient are those occurring in the schistose complex forming the foundation-rocks of the northern part of South Africa, and termed the Swaziland series. Of this the sedimentary portion consists of slates and phyllites, quartzites, and conglomerates, passing into mica-schists. It was invaded by a group of massive basic igneous rocks, which in turn were invaded by granites, now more or less gneissic. The basic rocks form long narrow belts, the structure-planes of which are approximately parallel to those of the associated sediments, and among these the belts of serpentine appear to be intrusive into the hornblende- and chlorite-schist with which they are associated. The whole complex seems to give evidence of primary gneissic structure, due to intrusion under pressure. The granitic masses have invaded this transgressively. The relationships are clearly indicated at Barberton in the eastern Transvaal (Hall '18), near Pretoria (Kynaston '06), probably also near Vryburg (Du Toit '05a), and in Southern Rhodesia (Zealley '14).

The Swaziland series of sediments is followed by the Witwatersrand system of shales, quartzites, and conglomerates with interbedded diabase, which are unconformably overlain by the Ventersdorp series of acid and basic lavas, occasionally with pillowy structure (Du Toit '05), breccias, tuffs, and conglomerates, and these again are followed by the Transvaal system of conglomerates, dolomite, and the Pretoria series of slates and quartzites with abundant sills of diabase. Grits and sandstones of the Waterberg system (of possibly Devonian age) follow more or less unconformably upon these, the two formations being separated over wide areas by the intrusive rocks of the Bushveld complex. Probably intermediate in age between the Bushveld and Swaziland igneous rocks are those of the Palabora complex to the extreme east of the Transvaal. No detailed account of the tectonic relationship of these can be given; the complex appears to be intrusive into the older Swaziland granites and to consist of granite and syenite, the latter passing by imperceptible gradations into a felspar-less pyroxenite (Hall '12).

The Bushveld plutonic complex is one of the most remarkable assemblages of igneous rocks known. (See fig. 14.) Briefly it consists of a great oval mass, 250 miles in length east to west, with a mean width of 60 miles. Its central portion consists of granite, and its marginal portions are largely of norite. All around it the rocks of the Pretoria series dip in toward the center at low angles, while above it the Waterberg rocks lie with comparatively small disturbance, and show that they were invaded by the granites. Molengraaff ('01) interpreted the whole as a vast gravitationally differentiated laccolite thrust in between the Pretoria and Waterberg systems. While this conception is fundamentally that now generally accepted, modern work has modified it in many respects. Of this the following is a brief résumé:[1]

The abundant sills of dolerite in the Pretoria system beneath the complex are genetically connected with it. Over the greater part of the circumference of the complex, the norites, etc., pass into dolerites of an exactly similar character which form the fine-grained chilled selvage of the complex (often of considerable width) within which the more slowly cooled magma differentiated (Humphrey '10, Hall '05, Kynaston '04). While the base of the complex is approximately concordant with the stratification of the Transvaal system, if a broad view be taken, a

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[1] Grout ('18) considers this complex may be compared with the Duluth and Sudbury complexes to which he has applied the term "lopolith" to indicate a generally concordant lenticular mass, with a sunken center, of which the mechanism of intrusion is presumed to be different from that of a laccolite. See p. 53 and also postscript on p. 78.

detailed study shows that it cuts successively across the different members of the Pretoria series, breaking some up into detached fragments and following others for some distance. In places it even comes into contact with the old granite (Kynaston '08, Humphrey '10). The contact-metamorphism produced by this intrusion is very great and indicative of high pressure, which is more marked in the east than in the western region, where the laccolite was comparatively shallow (Hall '09, Humphrey '10). There is also a marked schistosity in the norite, and more basic rocks throughout the whole marginal zone of the complex, which is of the nature of primary gneissic structure, for no sign of crushing appears in the rock itself. The differences in composition of the successive bands so produced are such as to cause occasionally a regular cuesta-topography, the dip of the bands being precisely parallel with that of the adjacent Pretoria series (Hall '09). The norite is closely associated with pyroxenite, the one passing into the other without sharp separation, and sharing the same general foliation, while also bands of peridotite may appear (Humphrey '11, Kynaston '11). On the other hand the norite may

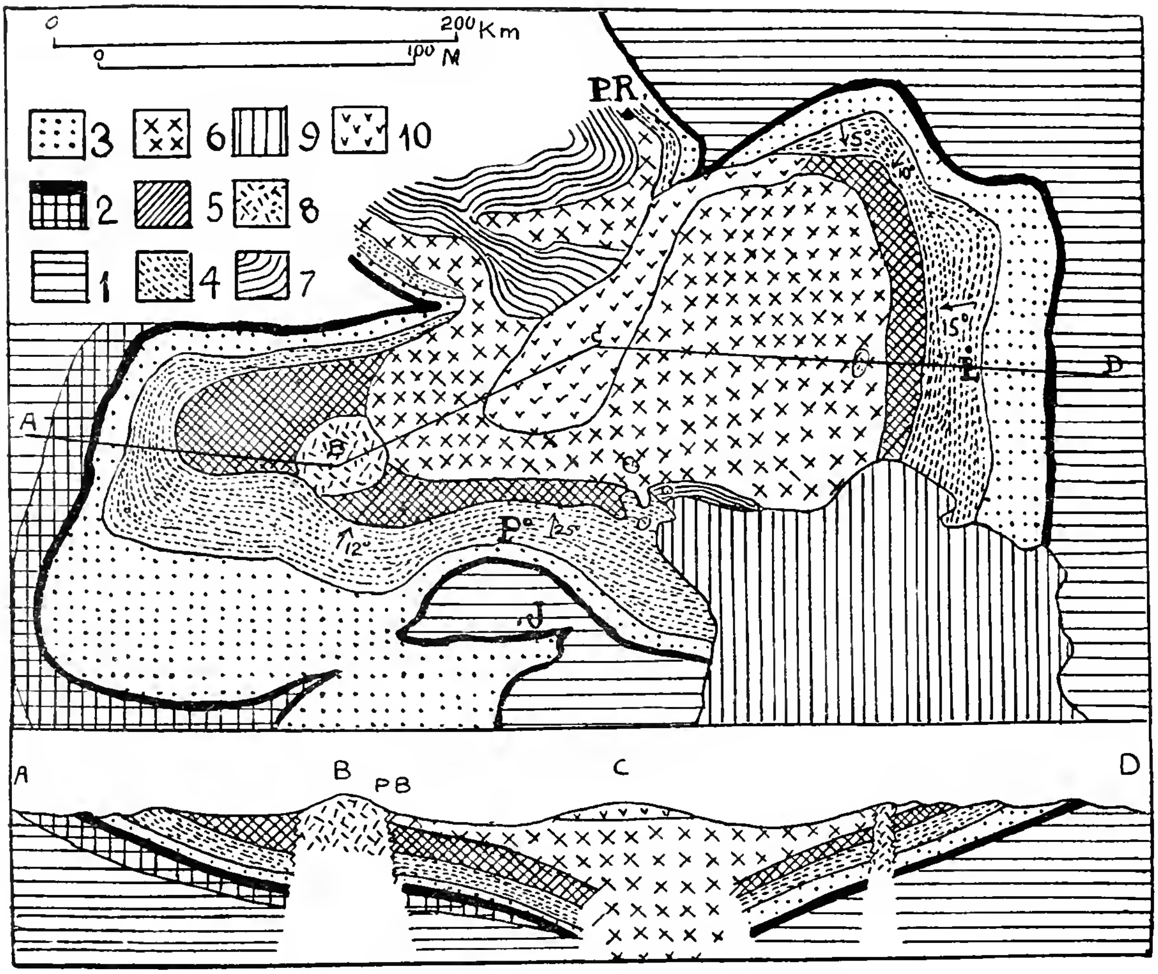

FIG. 14.—The Bushveld complex. (After Molengraaff and others.)
1. Pre-Cape complex.
2. Black Reef series.
3. Great Dolomite.
4. Pretoria series.
5. Pyroxenite and norite.
6. Red granite.
7. Waterberg series.
8. Nepheline syenite.
9. Karroo sediments.
10. Amygdaloidal lava.

grade into gabbro. Bands of magnetite, and to a less extent of chromite, occur in the norite and pyroxenite, running parallel with the general foliation, and are especially marked on the eastern margin of the complex, where they may be associated with a narrow underlying zone of highly felspathic norite, grading down into the normal rock (Hall '05, '09, Humphrey '11).

The granite lies above the norite, the contact zone being sometimes so distinct that hills of granite isolated by circumdenudation are seen to rest upon the norite (Hall '10). The relationship of the granite to the norite is generally an intrusive one, a contact-zone of norites veined by granite having been seen in a number of cases, (Kynaston '08, Hall '09, Humphrey '11, Wagner '12), though there is not necessarily any great age difference between the two. Along the southern margin there appear regions where it is claimed that a continuous passage between the two rocks occurs (Kynaston '08, Hall '03). In some cases the description of the supposed passage-rocks strongly recalls the characters of the marscoite hybrids of gabbro and granite occurring in Skye.[2] The lowest portions of the granite show very constantly a narrow zone of ultra-acid rock which has sometimes been mistaken for an included mass of quartzite. Hall ('10) states that its general dip is parallel to the schistosity of the underlying norites and of the Pretoria series. It consists of coarsely granular quartz with more or less mica and grades into a type containing orthoclase. Biotite, magnetite, ilmenite, and rutile are occasional accessories. Setting aside the suggestion that the rock may be of the nature of greisen, he holds that it resulted from differentiation in the marginal portions of the granite adjacent to the norites, where its power of differentiation was retained for the greatest length of time, having been elsewhere restricted by the increasing viscosity of the magna due to increasing acidity and decreasing temperature. Hall ('13) also describes a remarkable group of quartz-augite-monzonite porphyries, representing a "differentiation of the granite magma, resulting in a thin basal layer of less acid types which, in contact with the cooler floor of norite and other more basic rocks, assumed a finer texture."

The "red granite" above the basic zone is thus by no means a uniform mass. Locally granophyres of comparatively fine grain occur in it, and Mellor ('08) and Kynaston ('09) show that further complexity appears when we attempt to determine the relationship of the granites to the Waterberg system. It would seem that several intrusions occurred, derived from the same source. Bowlders of tourmalinized rocks and of granites in the Upper Waterberg conglomerates, point to the intrusion of granites into the Lower Waterberg rocks and their subsequent exposure by denudation in pre-Upper Waterberg times, but the invasion of Upper Waterberg sediments by further masses of red granite similar to that of the rest of the complex shows the continuation of the plutonic activity.[3] The invasion of the granites was followed in some places by a further development of diabase sheets in the granite and Waterberg sandstones which tend to grade into more acid felsitic rocks (Mellor '03). Felsitic and allied volcanic rocks are intercalated with the lower shales, etc., of the Waterberg series, and their possible magmatic relationship to the Bushveld plutonic rocks has been variously discussed.

The alkaline rocks which occur especially abundantly in the Pilandsberg, but also in a number of other areas near the margin of the norite and gabbros, were originally supposed to form an intermediate zone of differentiation (Hatch and Corstophine '05). The work of Brouwer ('10, '17) and Humphrey ('11) proved that the Pilandsberg rocks were the plutonic core of a series of alkaline volcanic rocks resting directly on an eroded surface of the norites and granite without any intervening Waterberg sediments. They are therefore of a date subsequent to the erosion of the Waterberg sandstones and the exposure of the Bushveld plutonic complex. There is no evidence to determine their age relative to the Karroo system, but Humphrey ('11) thinks they are probably much newer than the Waterberg system. Wagner ('12), on the other hand, points to the lengthy succession of granitic rocks from the Bushveld, some of an age subsequent to the exposure of the earlier granites of the complex, and holds it premature to decide

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[2] E. g., "The transition from coarse-grained norite to the more fine-grained reddish granite is complete in a distance of about 30 to 40 yards. The granite is mottled with green ferromagnesian constituents which are seen to be made up of a little augite together with very much corroded hornblende" (Hall '03, pp. 35–37; cf. Harker '04).

[3] Attention should be called to this recurrence of plutonic activity, after its apparent cessation and the intervening of a period of sedimentation. An analogous feature is seen in New South Wales (p. 38) and perhaps in Scotland (p. 12). See postscript, p. 78.

that they are entirely unconnected with the Bushveld plutonic complex, with which they are so closely associated. Bowen's ('15) conception of the origin of alkaline rocks from a normal magma by extreme gravitational differentiation would suggest that they might have formed the last phase of Bushveld igneous activity except for the difficulty that they do not rest directly upon the granites only, but also upon the norites, and the very long duration of plutonic activity involved. Smyth's ('13) hypothesis, on the other hand, the application of which is open to a similar objection, might lead us to regard gaseous concentration of alkalies into the residual magma of the Bushveld complex, as the essential mechanism of differentiation producing the alkaline series of igneous rocks, in support of which may be cited Brouwer's ('17) emphasis upon the abundance of fluorine in the rocks. Daly ('14) again would look to an interaction between the magna and the dolomite beneath the Bushveld complex as a probable factor in the genesis of the Pilandsberg rocks while Shand ('22) has described his hypothesis of the origin of the alkaline rocks as "a synthesis of the views of Bowen, Smyth, and Daly."

Possibly the next in age of the basic intrusive rocks in South Africa is the great dike of Southern Rhodesia described by Mennell ('10), Zealley ('11, '15), and Wagner ('14). It is 300 miles in length and about 4 miles in width, and is composed of rocks resembling the basic rocks of the Bushveld complex. It invades the older granite and schists of the Swaziland series, especially following the margin of the two. It is a highly differentiated mass composed of felspathic norite, enstatite-rock and harzbergite and occasionally dunite, all forming elongated strips or wedges, lying parallel to the edge of the intrusion, the less basic and finer grained portions occurring in the interior. The rock is, however, not foliated, though schlieren-masses of chromite are present. Small bosses and dikes of granite occur, never passing beyond the basic mass, also aplitic and pegmatitic veins, quartz-veins, and those composed solely of acid plagioclase. Mennell thinks this mass an intrusion into a gently inclined thrust-plane; Wagner holds it to be a very elongated asymmetric laccolite. Zealley believes it to be a dike. The gentle dip of the bands of the differentiates and of the schlieren-structure urged in support of the first two hypotheses, Zealley thinks explicable on other grounds.

The next great series of intrusions are of an age between the Jurassic beds of the upper portions of the Karroo series and the Upper Cretaceous Umtavuna beds in which they occur as bowlders. They invade the whole immense area of the unfolded Karroo sediments but are absent from the folded Karroo rocks of southern Cape Colony. The rocks are dolerites, forming sills and dikes, the latter clearly the feeding channels of the former. They are for the most part ordinary dolerite of a purely calcic character, but olivine dolerite is not infrequent. Acid veins of a granophyric character are by no means uncommon and are generally a few inches only in width. These intrusions run for very long distances concordantly in the stratification of the sediments but sometimes traverse them obliquely either with gentle or steep inclination, though the invaded beds may be quite horizontal. In the Queenstown district there is a great tendency for a single intrusion to form a highly undulating sheet in horizontal strata which on being denuded gives rise to annular outcrops or pseudo-laccolitic masses (Du Toit '05). The regularity of the intrusions may be broken by numerous splits and offshoots from the main mass, while new sills make their appearance in the strata farther away from the main intrusion, these being generally connected with the latter either directly or underground, so that the mass of sediments is penetrated by a plexus of sheets in the most complicated manner, but without affecting appreciably the dip of the strata. A remarkable series of intrusions occur in Griqualand, Pondoland, and Natal, which, though doubtless derived from the same magma as the dolerites, develop much thicker masses, and are plutonic in petrographic character. The Insizwa mass forms a huge dike of gabbro and norite which spreads as it rises and gives off on either side several flatter and diverging sheets thus forming a roughly fan-shaped mass in which the metamorphosed sediments occur between the inclined sheets of igneous rocks. (See fig. 15.) These are sometimes undulating, forming pseudo-anticlines and synclines in the horizontal mudstones (Du Toit '10).[4] The Tabankulu mass adjacent to the latter shows the presence of gravitational

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[4] See also Goodchild ('17).

stratification much more clearly. Its lower surface forms an elongated basin, and it reaches a thickness of about 2,000 feet. The upper portion is a feldspathic norite of specific gravity, 2.915, while it graded down into coarse-grained olivine-gabbro and "picrite," reaching a specific gravity of 3.275. Banding due to the presence of layers of different mineral composition is a frequent feature. Light colored, lenticular streaks of norite, free from olivine, occur conforming to the gentle inward dip of the banding in the gabbro, and these as well as the gabbro and picrite are traversed by occasional veins and bands of diorite and micropegmatite. The banding, when present in the upper portion, is only feebly developed. Beneath the part of the picrite is a wedge of gabbro, possibly injected at the base of the complex during or just after the differentiation of the more basic lower portion. It loses its characteristic texture about three-quarters of a mile from the picrite, then gradually becomes ophitic in texture and may be traced into an inclined sheet of coarse dolerite of the normal type which doubtless formed a feeding channel for the main mass. Adjacent to this is the Tonti mass, a gigantic sill up to 2,500 feet in thickness of gravitationally differentiated gabbro splitting into many narrower sills of dolerite (Du Toit '12). The Ingeli mass, which is fed by an uprising sheet on either side, consists of a gravitationally differentiated mass of olivine-norite and picrite, the latter forming a lens-shaped mass at the base of the norite which covers it to a depth of nearly 3,000 feet in places. The range of specific gravities is from 2.98 in the higher parts of the mountain to 3.29 near the base, where the rock closely resembles harrisite (Du Toit '13). In all three of these regions, pyrrhotite, chalcopyrite, and sometimes pentlandite occur in the basic margins.

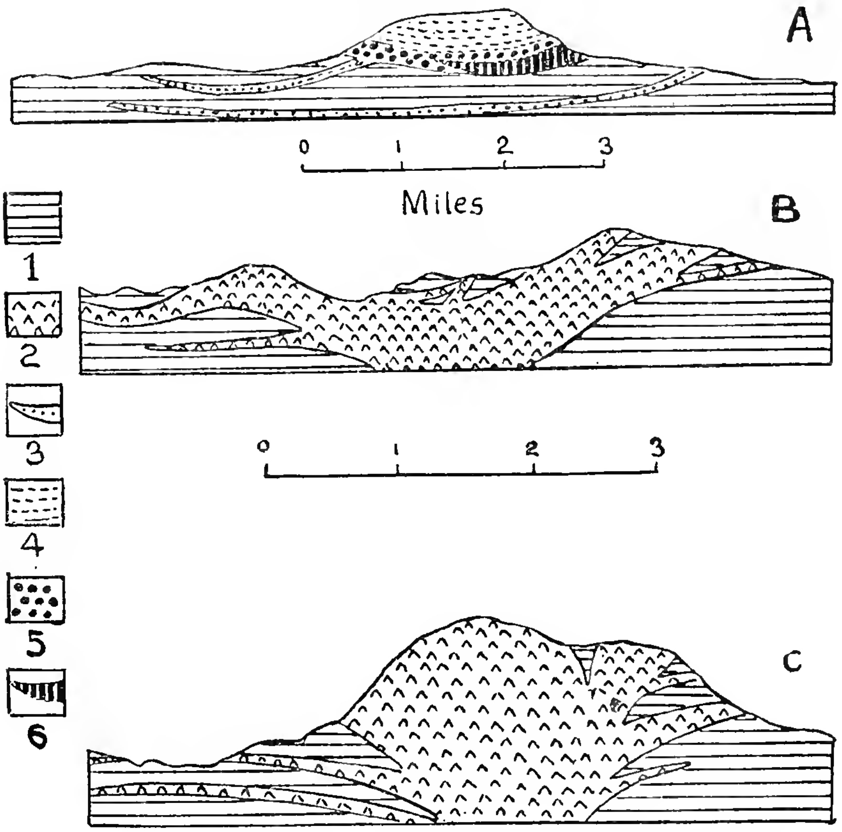

FIG. 15.—Differentiated intrusive masses in South Africa. (After Du Toit.)
A. Tabankulu mass. B and C. Insizwa mass at Brook's Nek (B) and Nolangeni Mountain (C).
1. Horizontal sediments. 2. Gabbro, lower part olivinic. 3. Dolerite.
4 and 5. Gabbro-norite poor (4) and rich (5) in olivine. 6. "Picrite."

These three mountain masses were parts of a single undulating sheet of abnormal thickness. Erosion has severed the continuity of the body, and the "domes" between them have been removed, so that these relics represent the lower basin-shaped parts of this great basin intrusion, which originally covered not less than 700 square miles. The volume of the gabbroidal matter involved probably exceeded 300 cubic miles. The lofty chain of Nolangeni (fig. 15c) marks the fissure up which the bulk of the eruptive matter ascended. (Du Toit '20.)

Immediately beneath the gabbro of the Insizwa mass the hornfels is full of little veins and stringers of granite and quartz-diorite, mostly vertical, and sometimes several inches in width; the boundaries of these are ill defined in the hornfels fading away into the body of the latter, while patches characterized by abundant feldspar occur near the contact showing the extreme impregnation and veining of the hornfels by the igneous material, which also formed small granitic veins in the base of the gabbro. The sulphide-minerals of the gabbro also occur in these and in veins in the hornfels (cf. p. 55, and Tolman and Rogers '16) and Goodchild ('18)). The olivine-free rocks toward the upper edge of the sheet become somewhat coarser in character, with a tendency to carry coarsely crystalline and pegmatitic veins associated with quartz-feldspar-micro-pegmatite.

This vast assemblage of doleritic or gabbroidal sheets totaling originally 100,000 cubic miles is found in various horizons in the Karroo system, being distributed through a range of over 10,000 feet of strata. Du Toit ('20) considers that the higher masses were injected first, and were followed successively by those lower and lower in the series. The differentiation is described as due to "fractional crystallization combined with sinking of crystals so formed in a body cooling from above downwards." As crystallization *en masse* extended downward from the roof, the cake of nearly solid gabbro would be resting on a "lens" of partly fluid ultrabasic matter, the consolidation of which had been deferred by its higher temperature, the presence of mineralisers, and interstitial sulphides. From this the residuum was squeezed out and we may note that the dioritic and granitic veins and lenticles which are absent in the higher levels are most characteristic of the basal zone, and even penetrate the underlying floor. With these are associated the sulphide-ores, the formation of which is described by Goodchild ('18). The production of the gneissic structure in the ultrabasic rocks is explained in the manner suggested by Bowen ('19).

We may perhaps class with intrusive basic rocks the series of volcanic pipes filled with "kimberlite" which is so marked a feature of South African geology. There has been a great deal of discussion concerning these, some authorities holding that the rock is a porphyritic consolidation from a peculiar type of ultrabasic magma, like our "alkaline peridotite" but the official geologists in South Africa are in accord with the view put forward by Dr. Bonney ('99), that the rock is a breccia composed of ultrabasic constituents, though holding that the rounding of the fragments is due to attrition in the vent (Rogers '05). Du Toit considers that the breccia consists of material of a threefold origin. Its minerals and rock-fragments are derived from (*a*) gneisses and schists; (*b*) gabbros and ultrabasic rocks, also eclogites; and (*c*) ultrabasic rocks, possibly limburgite, which as a lava brought up the fragments and became itself consolidated and completely brecciated in the process. In addition fragments of Mesozoic rocks that have fallen from higher levels are found in the pipes (Du Toit '06). Carvill Lewis's ('97) view of the original presence of a magma allied to melilite-basalt, the brecciated products of which are incorporated in kimberlite is supported by the occurrence in a pipe at Sutherland Commonage of massive melilite-basalt with xenocrysts and xenoliths of the same characters as in kimberlite (Rogers '05). Near Prieska dikes of lamprophyres allied to monchiquite, melilite-basalt, (alnoite) and perhaps camptonite occur (Du Toit '08). Lacroix ('98) found nepheline in place of melilite in one instance. The necks or dikes of kimberlite-breccia were formed in probably Cretaceous times, apparently without any accompanying folding or faulting, except the marginal subsidences around the great continental block of South Africa. Possibly we may compare these pipes with the "volcanic embryos" and melilite-basalt-intrusions in Southern Bavaria, though the analogy is not a very close one (Branca '94, Schwarz '05).

In the absence of information concerning conditions of intrusion we need here merely mention the occurrence of gabbro and peridotite in British Central Africa (Prior '03) (Bull. Imp. Inst. '04), of gabbro in Togoland (Koert '10), and of gabbro-peridotite series of French Guinea (Lacroix '11) to which probably belongs the enormous noritic intrusion of the peninsula of Sierra Leone (Dixey '21). The basic rocks of northwestern Africa (Atlas Mountains) have already been described.

In the southeast of Egypt Ball ('12) has noted among the schists of the Red Sea Hills a group of granites associated with gabbros and serpentinized ultrabasic rocks which cover more than 200 square miles. There is little evidence of the conditions of their intrusion.

Chapter VIII.

THE BASIC AND ULTRABASIC INTRUSIVE ROCKS OF AMERICA.

EASTERN NORTH AMERICA.

Pre-Cambrian.—The numerous brilliant investigations of the ancient rocks adjacent to the Great Lakes permit us to continue our studies of the development of basic rocks back into the earliest periods of geological history. At the same time they are so extensive and varied that a brief review must be very inadequate. The Keewatin lavas, the oldest igneous rocks known, are a series of basaltic and andesitic rocks with some interbedded acid flows and show when least metamorphosed marked pillow-structure. They are associated with tuffs and agglomerates, and also with diabase-sills and locally (Rainy Lake, Lawson '13) are invaded by gabbro and anorthosite, and in one region (Lake Abitibi, Wilson '13) by diorite and quartz-porphyry also. They are generally of normal basaltic composition, and are more or less deeply altered, passing into amphibolites and chlorite-schist. The "plagioclase," though originally basic, has not infrequently been changed to albite by pneumatolytic action (Van Hise and Leith '11, Wilson '13). They are associated with fine-grained sediments of considerable thickness, indicating, perhaps, deposition during a geosynclinal depression. This was followed by a period of intense folding, accompanied by the formation of huge batholiths, bosses, stocks, and dikes of acid chemical composition, with minor amount of basic rock and peridotite at Marquette (Van Hise '97). The movement may have been universal, or, as Blackwelder suggests ('14), comprised movement at several periods. This movement was the Laurentian revolution.

After extensive planation the deltaic Sudburian sediments were laid down upon the eroded surface of these ancient rocks (Barrell '15) and with them were formed a small series of contemporaneous basic pillow-lavas and pyroclastic rocks, with a minor amount of rhyolite. The majority of the analyses of these recorded by Clements ('99) show them to be of normal composition, but in the case of two of the more felspathic rocks the small amount of lime and relatively high percentage of soda suggests that some albitization and removal of lime has taken place. This period of sedimentation and outpouring of lavas was followed by a second period of crust-folding (the Algoman revolution), accompanied by immense plutonic intrusions chiefly of more or less gneissic granites. In Wisconsin, however, Weidmann ('07) recognizes as probably belonging to this period intrusions of gabbros, peridotites, and diorite, followed by granite and nepheline-syenite.

After a further planation, Algonkian sedimentation followed, mostly deltaic, with succeeding widespread marine depositions in shallow basins, associated with extensive eruptions of basic intrusive and extrusive rocks with breccias, the associated post-volcanic activity giving rise to the immense iron-ore deposits of Michigan. Approximately coeval with these, there were a similar series of eruptions near Hudson's Bay (Leith '10). After slight elevation and erosion shales, sandstone, and conglomerates were deposited subaerially, associated with an increasingly abundant series of lava-flows, the Keweenawan series, chiefly basalt or diabase with subordinate amounts of rhyolite and volcanic ash, all quite normally subalkaline in composition. These were probably derived from fissure-eruptions. Faulting and some folding occurred during the eruption of these lavas, for the lower portions are more steeply folded than the upper.

Among these were injected the immense Duluth mass of plutonic rocks, 100 miles in diameter, which has invaded beyond the Keweenawan lavas into the Archaean complex. "It spread at or near the base of the flows, and along the unconformity at the base of the Keweenawan sediments a little below the flows." Generally the mass is regarded as a laccolite, but a recent study by Grout ('18) has led to the conception of a somewhat different form of intrusive mass which he terms a "lopolith." The nature of this is illustrated in figure 16. The detailed petrological study of this mass has been summarized by Winchell ('11) and Grout ('18c). We are here concerned with the disposition of the various types of rock within the mass. The following comments are based chiefly upon Grout's recent papers ('18, '18a, '18b, '18c). It is estimated that over two-thirds of the gabbro mass at Duluth consists of olivine-gabbro, varying only slightly from the average. Such average rocks are scattered from top to bottom, the gabbro-mass being over 3 miles thick. The intrusion of the gabbro occurred in two or more events, for chilled contacts and apophyses of the newer gabbro in the subordinate and more feldspathic older gabbro are clear in some regions. Specialized rock-types have a more limited range. The peridotite occurs only near the base; the equally heavy magnetite-gabbro is near the center. The anorthosite ranges from the center toward the top, and is in the thin earlier intrusion. Very locally at the base of the early gabbro there is an apatitic hypersthene-gabbro. A red granophyre occurs mostly near the top and in a sill at a higher horizon. Grout points to the surprising uniformity of the composition of the feldspar (bytownite) throughout the complex and argues that this indicates a continuous adjustment of the composition of the (unzoned) feldspar, and, in consequence, the absence of any settling out of plagioclase more basic than the average feldspar content of the magma. Only in the upper portions are zoned or more acid feldspars known. Nor does the specific gravity of the rock diminish regularly toward the higher portion of the mass. Indeed one of the heaviest rocks described is well above the center. Weinschenk ('16) is of the opinion that this is the general rule for the segregation of magnetite, part of which remains molten till a late stage in magmatic consolidation (Grout '18c). (Compare Duparc and Pearce '05 and, for a volcanic instance, Jensen '16.) Nor is there any long series gabbro-diorite-syenite-granite; nor gabbro-quartz-diorite-granite, as Bowen's hypotheses seem to suggest. On the contrary, rocks of intermediate composition are markedly absent (as also in the case of the Bushveld complex) and the frequency of this feature has been emphasized by Dr. Harker ('16). The separation of the basic and acid types is so sharp as to suggest to Grout that the upper portion of a granophyric composition separated as an immiscible liquid from the underlying gabbro. In the field this change comes with surprising abruptness after the monotony of slightly varying gabbro-bands. In a few feet after the reddish tinge of granophyre is seen in the interstices of the gabbro, none of the gabbro-minerals are visible in the rock. The chief outcrops of the granophyre are irregular patches at the top of the main gabbro and apophyses into its roof;

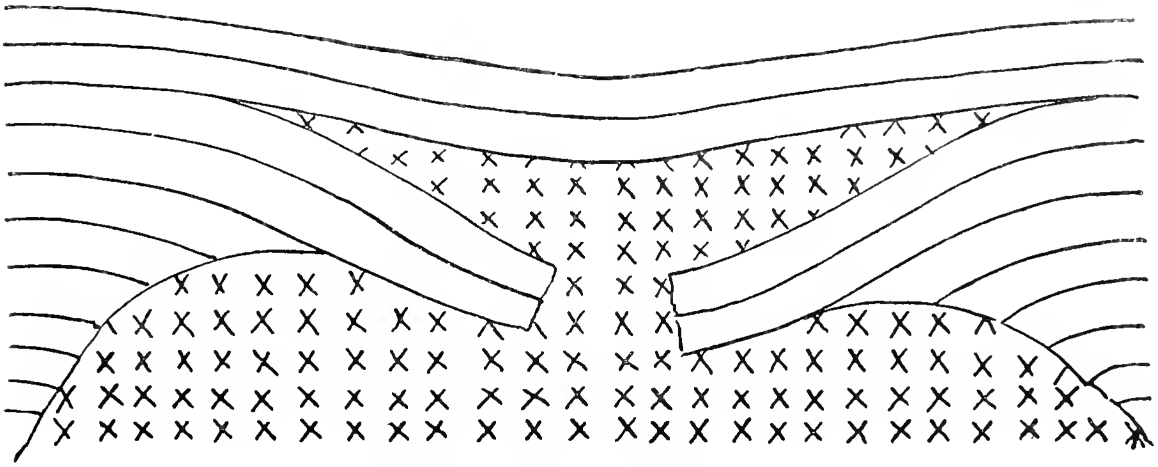
FIG. 16.—Relation of a lopolith to invaded sediments. (After Grout.)

it occurs also near the top of the earlier feldspathic gabbro, in a large sill close above the gabbro and in some small disks near the bottom of the gabbro. In a sill near Duluth there is a remarkable example of perfect gradation from diabase to granophyre. The sill is 1,500 feet thick, but the zone of gradation from black diabase to intensely red granophyre is less than 50 feet thick. The granophyre is sugary with miarolite cavities. Grout believes that the granophyre contains too much alkali for it to be considered a syntectic of gabbro and acid sediments [1] and holds that it was concentrated at the top of the magma chamber by the action of water and other vapors, the magma so produced becoming immiscible with the underlying less hydrous gabbro-magma. This latter is strongly banded in zones parallel to the margin of the intrusion, which structure Grout considers to have been produced by the action of convection-currents in the crystallizing magma.

Bowen's ('19) alternative explanation of this complex is of interest. The experimental evidence against immiscibility of liquid magmas is strongly urged. It is held that the Duluth laccolite may have originated from "a gabbroid magma, wholly liquid, injected into its present place." Gravitational separation of olivine and pyroxene gradually accumulated on the floor of the laccolite a thick layer of crystals, which at the base were packed together almost to the exclusion of molten matter, but higher up a crystal-mesh contained interstitial magma. The bulk of the iron-ores did not separate from the magma till crystallization was well advanced, and therefore sank to rest not on the floor of the magma, but above much of the layer of olivine and pyroxene. Intermittent deformation developed a series of lenticular openings which instantly filled with liquid from the interstices of the weakly-knit crystal-mesh. "The crystals that became detached during the shearing would naturally become aligned in the liquid filling the lenses, so that fluxion-structure would be a natural accompaniment. Moreover, in the larger lenses developed, a gravitative sorting of these detached crystals would take place under particularly favorable conditions, and bands showing the extreme contrast of monomineralic types might thus be formed." (Bowen '20.) Thus banding as a primary feature was produced as this process was repeated many times by continuous warping. The conditions favorable to its accomplishment are present when the magma contains from 50 to 65 per cent crystals. When the upper limit had been passed and the whole mass approached complete crystallization, it was able to withstand compression until the accumulated lateral force exceeded its power of resistance and produced an upward squeezing of the residual liquid, thus interrupting the course of regular differentiation outlined in the earlier paper (Bowen '15) and accounting for the sharp separation of basic from acid rock. The differentiation would be markedly discontinuous the later differentiate would have an intrusive relation into the earlier in some places, and a rather abrupt transition in others, and yet the relations would not indicate successive intrusion in the ordinary sense of the term. In so far as this action is incapable of occurring before a certain degree of crystallinity has been attained, there should be a tendency to fairly constant contrast between the two differentiates. On the other hand there is no necessity for the constant relative proportions in their amount. "The gabbro-granophyre association fulfils every requirement." The uniform composition of the plagioclase is not, according to Bowen, inexplicable in terms of his hypothesis.

The Duluth gabbro is similar in many ways to the Bushveld complex, in which, however, the acid differentiate is much more abundant, so far as the areal extent may indicate, and we have therefore discussed it at some length; the further comment on Bowen's hypothesis as applied to the Bushveld complex will be made later.

South of Lake Superior, in the Penokee area, the Bad River laccolite is possibly a continuation of the Duluth mass. South again of it is a group of intrusions ranging from granite to peridotite, invading the not very folded Animikiean sediments (Clements '99).

East of Lake Superior, rocks are found with a similar nature to those at Duluth. The Keewatin lavas are sometimes ellipsoidal and are invaded by Laurentian gneisses including

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[1] The composition of the feldspar in the granophyre is exactly the same composition as that of the uncrystallized interstitial residuum at this stage of crystallization of a gabbroid magma (Bowen '19).

nepheline-bearing and analcitic alkaine rocks. At Sudbury the pre-Animikiean micronorites' show pillow-structure, and are associated with greenstones and altered tuffs. In Keweenawan times was formed the Sudbury complex, which is similar to the Duluth complex though smaller, and has probably had an essentially similar origin. Coleman ('05, '07) followed by Daly ('14) considers it to be a clear instance of a gravitationally differentiated laccolite bent into a spoon-shaped syncline. A remnant of the sediment under which it was injected remains in the center of the trough. The lower portion of the mass is a dark-gray, coarse-grained norite grading up into pale gray or flesh-colored quartz-norite, followed by grano-diorite and granite which forms the upper portion, the;total thickness being about 6,500 feet. Barlow ('04), however, believed that the granite is intrusive into the norite and Dr. Harker ('16) remarks on the occurrence of hybrid rock types between the norite and granite, which otherwise appear rather sharply separated. The basal portion of the norite contain nickeliferous sulphides, veinlets of which project into the underlying schists, etc. These sulphides have been thought to be basal gravitational differentiates from a magma with which their miscibility was limited, but are now thought to be later perhaps hydrothermal concentrations (Tolman and Rogers '16). An elaborate discussion of their origin from a metallographic point of view has been given by Goodchild ('18).[2]

In Eastern Canada the Archaean rocks have been divided into two series, the Grenville and the Laurentian gneisses. The Grenville series consists of limestones, quarzites, etc., and amphibolites and some gabbros. The amphibolites are in part the hornblendic alteration products of tuffs and basic flows derived from centers of eruption near the occurrences of the gabbros, which are sometimes considerably differentiated into felspathic, ilmenitic, and pyroxenic phases. In opposition to Daly's ('14, p. 327) view, Adams and Barlow ('06, p. 154) hold there is no regular arrangement of rock-types observable. The whole area is greatly folded and invaded by domed batholiths of gneissic granite, fringed with nepheline-syenites along the lines of contact with the limestone. (See Dr. Harker's ('17) explanation of this.)

In the Hastings district and still further to the east masses of anorthosite and other basic igneous rocks appear among the basic lavas, which, like the above, may belong to the Keewatin series, and these masses are believed by Daly ('14) to be essentially laccolitic in character. The Chibougamou mass, for example, which is extensively differentiated, consisting of gabbro, norite, pyroxenite, and iron ores, makes concordant contacts with the invaded greenstone-schists (Barlow '11). Other masses are found in eastern Canada in the Saguenay and Morin areas, and in the latter they are associated with probably consanguinous but rather later intrusions of syenite. These occurrences Bowen ('17) believes to be analogous with those of anorthosites in the Adirondacks. He pictures the last as the middle member of a differentiated laccolite. The lower concealed portion consists presumably of gabbro, the upper of syenite which, though produced by gravitational differentiation *in situ*, has been occasionally thrust intrusively into the underlying anorthosite. The margin of the laccolite shows a cooling-selvage of gabbro. The assumed mechanics of differentiation are however peculiar. After the consolidation of the cooled gabbroid selvage "the femic crystals separated by gravity from the gabbro-magma, and the plagioclase, then bytownite, remained practically in suspension in the melt. When the liquid had become distinctly lighter, having attained a diorite-syenite composition, the plagioclase crystals, now labradorite, accumulated by sinking and give masses of anorthosite, at the same time leaving the liquid out of which they settle of a syenitic or granitic composition." Cushing ('17), while accepting Bowen's general conclusions as to the form and origin of the intrusion, holds that the syenite is distinctly subsequent to the anorthosite, though consanguinous, and that it consists of a number of separate intrusions, and did not form a single sheet beneath a roof of chilled gabbro, which separated from the parent magma of the anorthosite, supposed by Bowen to form a continuous sheet-laccolite, underlying the whole Adirondack region. Bowen in a rejoinder ('17) suggests that these apparently isolated masses of syenite may occupy marginal irregularities in the laccolitic-roof. Miller ('18) inclines more to the view of Cushing. He

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[2] This important paper came to the writer's notice too late to be considered in the preparation of the present article.

holds that the anorthosite is the residual after the separation gravitationally of the femic minerals from the gabbro-magna *in situ*. The anorthosite was not *ab initio* a collection of crystals, but molten, as shown by the evidence of some heterogeneity, and of primary (fluxional) banding, though some granulation occurred in the late stages of consolidation. The syenite was a distinctly later product, does not show gradual passage into the anorthosite, but is clearly intrusive into the gabbroid margin and the anorthosite, from which it is separated either sharply or by a narrow zone of gneissic hybrid rock.

Paleozoic.—Very different, however, are the intrusions of peridotite and serpentine in the eastern portions of Canada and the United States. Those of New Brunswick and New England are usually referred to folding in pre-Cambrian times (Van Hise and Leith '09) and so also are some of the intrusions of the eastern townships of Quebec (Dresser '13), but the evidence of age is often obscure. Extending down the highland zone from Newfoundland into North Carolina there is a series of lenticular masses of more or less altered peridotites among schist, some of the peridotites being possibly pre-Cambrian, others Paleozoic, such for example as the serpentines of Broughton in the eastern townships of Quebec in which the intrusion may have occurred between Cambrian and Ordovician times. After the apparently unbroken Ordovician, Silurian, and Lower Devonian sedimentation, the Thetford series of peridotites, pyroxenites, and gabbro were intruded, according to Dresser ('13), during a period of elevation. Harvie ('13) states that they form more or less concordant intrusive sheets, in which peridotite, pyroxenite, gabbro, and diabase pass by gradual or rapid transition into one another. In places the diabase at the outer edge passes into hornblende-granite and aplite which forms indistinctly bounded segregation veins, etc. (cf. Dresser '21). These are arranged in order of decreasing basicity and density in sheets from the base upwards, and in batholiths from the center outwards. According to more recent work cited by Bowen ('20), however, the basic rocks are in synclinal sheets, and the granite "batholiths" in the anticlines. A valuable summary of the whole belt of intrusions is given by Lewis and Pratt ('05). (See fig. 17.)

> Beginning in Tallapoosa County, Alabama, where the gneisses and crystalline schists emerge from beneath the Cretaceous and later formations lying farther south, and passing northward one finds that small disconnected peridotite-outcrops occur at short intervals forming a narrow belt that extends approximately N. 50° E. passing near Atlanta, Asheville, Lynchburg, Washington, Trenton, Baltimore, and Philadelphia to New Jersey, where the crystalline rocks again pass under younger formations. With the reappearance of the crystallines at Hoboken, New Jersey, and on Staten Island the peridotites are again represented by large masses of serpentine. A number of other outcrops of serpentine, and, in some cases unaltered peridotites, occur through Connecticut and Rhode Island, and Massachusetts and again form a continuous line through the crystalline belt of central Vermont and its continuation through southeastern Quebec, approximately parallel to the St. Lawrence River, into the Gaspé Peninsula. Large areas of serpentine are known in western Newfoundland and as these are doubtless a part of the same series, the belt of outcrops is extended to a length of over 2,000 miles * * * Systematic petrographers often classify the peridotites as subordinate facies of gabbro, but in North Carolina and in some other portions of the belt this relation is reversed, the gabbros occur only in small masses forming insignificant local facies of the peridotites. * * * In the majority of cases the outcrops are found to have lenticular or elliptical outlines with their longer axes conforming to the direction of lamination of the inclosing gneisses * * * Occasionally a nearly uniform width of outcrop can be traced to relatively great length, indicating sheet-like masses * * * In several instances the lenticular masses are distinctly bifurcate * * * Narrow, fingerlike, or curved and irregular apophyses branch off through the gneisses. The lamination of the gneisses almost invariably follows the outline of the peridotite-mass. The few instances where they have been found to meet the boundaries at a perceptible angle are quite exceptional * * * These relations are what would be expected from the intrusion of a molten magma into a highly laminated rock. That these rocks occupy planes of weakness in the gneisses along which subsequent movement has taken place is strongly suggested by the universal development of schistose secondary minerals about the borders of the peridotites.

It will be noticed that with the omission of the word "subsequent" a striking agreement with Suess' generalization is here adopted. It is not clear, however, that such movement is necessary to develop schistosity. It may have resulted from movements during consolidation though later movements undoubtedly took place.

The data are not sufficient exactly to determine the age of these ultrabasic rocks. The zone was one of movement in several epochs. Lewis and Pratt consider "the principal period of intrusion was closely associated with the great orogenic movements of the revolution at the close of the Ordovician period * * * . The latter Appalachian disturbances at the close of the Carboniferous would account for the widespread lamination developed in the peritodites, and would give occasion for the minor later intrusions." This is not, however, offered as a final conclusion on the subject, and possibly the earlier age suggested for the Broughton series of intrusions will stand. A still greater age is claimed for the serpentines more or less associated with the gabbros of the neighborhood of Philadelphia. Miss Bascom ('09) states that these are limited to the region of pre-Cambrian rocks and are probably of pre-Cambrian age, either peripheral to the gabbro, or injected into spaces left by contraction of these rocks. These gabbros occur in greater or less amount associated with the serpentines. They are subordinate in the south but in the region about Philadelphia they distinctly predominate over the serpentine. They generally have a laccomorphic type of development and are elongated following the strike of the country. A gravity-stratification is sometimes suggested (e. g., Loughlin '12). McCallie ('19) also considers the ultrabasic rocks of Georgia, in the southern part of this zone, are pre-Cambrian. That some of the plutonic complexes of this zone containing ultrabasic and

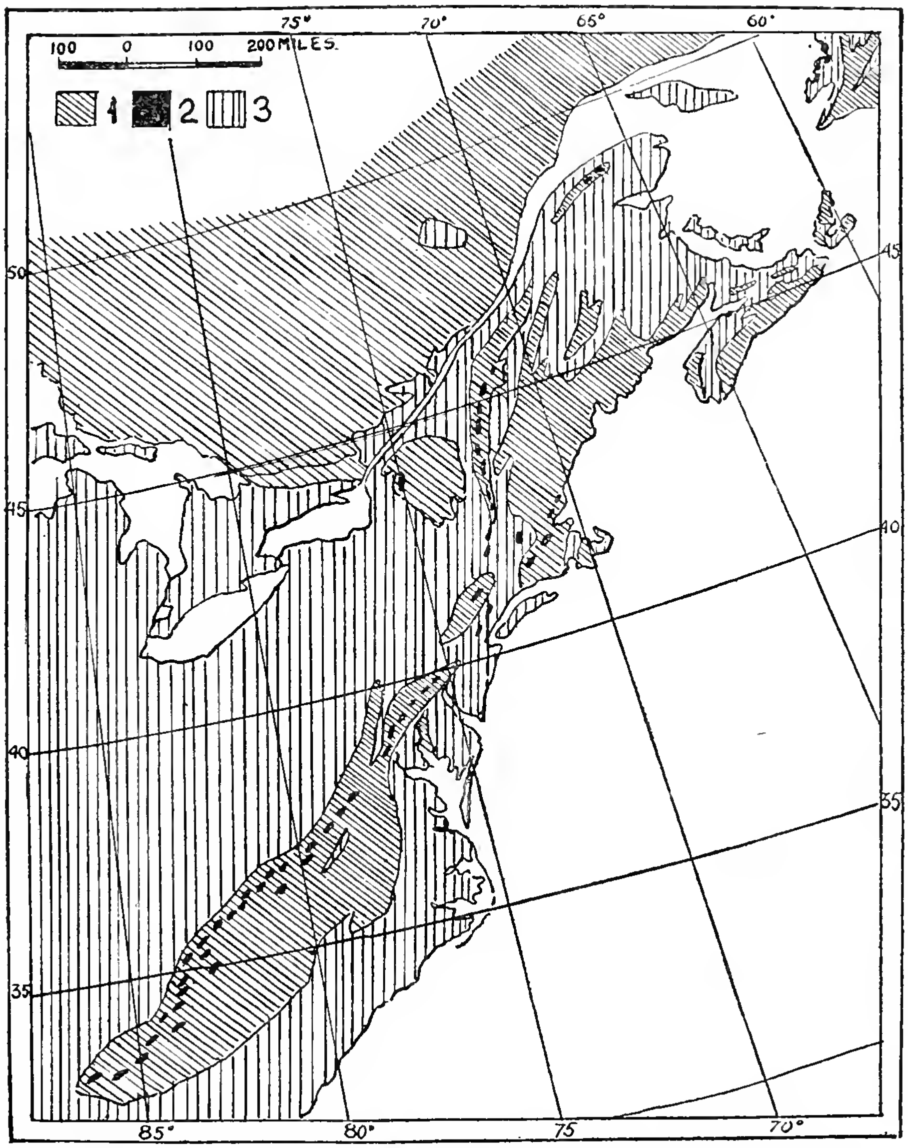

FIG. 17.—The distribution of peridotites, etc., in eastern North America. (After Lewis and Pratt.)
1. Schist and gneiss. 2. Peridotites and other magnesian rocks. 3. Paleozoic and later sediments.

basic rocks are intrusive into Paleozoic schists is the opinion of Iddings ('13) and as such he described the gabbro-diorite complex of Salem, Mass., which was erupted during the folding at the close of the Ordovician period. Clapp ('21) considers that the period of intrusion of these subalkaline rocks may even have been Devonian and that gravity controlled their differentiation. He believes that a long period of erosion intervened between this early intrusion and the development of the possibly Carboniferous alkaline lavas and plutonic rocks. Essexitic hybrid rocks were formed, however, as a result of the action of nepheline-syenite-magma on the relatively cold gabbro.

The Cortlandt series, "probably of late Paleozoic age" invades schists and limestone. (Rogers '11, '11a). They prove to be more complex than Williams first supposed ('86, '87, '88). The main mass is norite, with olivinic, augitic, hornblendic and quartzose varieties, exhibiting gneissic banding as the result of movement under pressure during consolidation. These are flanked by pyroxenite, the intrusion of which immediately preceded that of the norites. Diorites invaded these, and granite forms a more isolated intrusion. Bowen ('15) suggests that these may result from differentiation of a magma during which earth-movements destroyed the evidence of gravitational control. Similar rocks appear again in Pennsylvania (Bucks County norite invading limestone) and in various parts of Maryland (Iddings '13, p. 394).

Complexes in which gabbros and syenites occur together are not uncommon, examples being given by Tripyramid Mountain, a marginally differentiated laccolite, in which after the separation of a marginal gabbroid ring there was an access of magma bringing up the inner monzonitic portion, while similarly the upper syenitic appeared last of all (Pirsson and Rice '11), (or, as Bowen might hold, a chilled margin of gabbro about a gravitationally differentiated core) and the Ascutney Mountains (Daly '03), where there are three stocks of gabbro-diorite, alkali-syenite, and granite, respectively. This last is also of late Paleozoic age. Other complexes occur containing granites, diorite, gabbro, and rarely peridotite and are referred to various periods of Paleozoic time by Iddings ('13, pp. 374–390). The literature concerning most of these the writer has not yet studied. Though nepheline-syenites are believed to belong to the same series as granites, diorites, and gabbros, they do not generally occur in juxtaposition with the strongly calcic numbers of the series.[3]

Mesozoic.—During Triassic times there was deposited in New Jersey and Connecticut an immense thickness of sandstone and shale as terrestrial sediments, within which are interstratified lavas, and an extensive sill obliquely truncating the stratification, while fissures were filled with dikes some rising obliquely from the great sill. This is best known by its exposure on the Palisades on the Hudson where it shows some gravitational differentiation (Lewis '08). No folding accompanied these eruptions and intrusions, but extensive fracturing and tilting of fault-blocks immediately followed (Lewis and Kummell '15).

The States of New York, Pennsylvania, Kentucky, and Arkansas afford the most widespread instances of the occurrence of dikes of mica-peridotites (or, better, alkaline peridotite), which are entirely distinct from the mica-peridotite of the Kaltenthal or cortlandtite, but are frequently porphyritic olivine-pyroxene-biotite-perofskite-bearing rocks, sometimes containing melilite, more allied to limburgite, and especially alnöite. Their closest analogy is with the mica-peridotites of South Africa and India, which have already been described. They invade "the almost undisturbed Paleozoic strata lying to the west of the Appalachian upheavals" (Kemp and Ross '07). Williams ('87a) found the rock in narrow dikes invading the Onondaga salt-formation at Syracuse, and in the adjacent region about Dewitt, a further instance was found to contain fragments of the crystalline country-rock (Darton and Kemp '95). Smyth ('93, '02) observed melilite in these rocks. Farther south at Ithaca, similar dikes were found invading the Upper Devonian Portage sandstones (Kemp '91), which are not here greatly disturbed. Matson ('05) has argued (in a manner the writer does not find convincing) that

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[3] Attention may be called to an interesting series of albitic rocks perhaps possessing the petrographic characters of the "spilitic suite" occurring near North Haven, Maine. Their associations are not known to the writer. (Iddings '13, p. 376.) A further example of the association of gabbro, diorite, granite, and alkaline syenite occurring near Portsmouth has recently been described by Wandke ('22).

since the gentle folding of these rocks can be traced with increasing intensity into the Appalachian folds, the small amount of shearing visible between the various beds of sandstone must have occurred during the Appalachian folding, and concludes that as the ultrabasic dikes have been moved by this shearing they must be of pre-Permian age. Kemp and Ross ('07) comment on the strongly marked contact-effect of a dike of this rock which invades the coal measures of southwestern Pennsylvania, which is in accord with Holland's observation ('95) in India. In Crittenden County, Kentucky there is a large dike of this rock more than 20 feet wide. (Most of the dikes range from a yard to less than an inch in width.) This dike occupies the plane of a fault which throws Carboniferous rocks a distance of 800 feet. In Elliott County, a narrow dike of a similar petrographical nature invades almost horizontal coal-measures and contains fragments of shale. Diller ('87) remarks that "the very slight disturbance suffered by the strata through which the peridotite reached the surface suggests that the extrusion may not have been connected with great orographic movements at the close of the Carboniferous period, but rather with subsequent dislocations * * * which occurred at a much later date."

In Pike County, Arkansas, similar peridotite occurs forming a small stock 2,000 by 1,600 yards in dimensions. It was originally described by Branner and Brackett ('89), whose report is cited in full by J. F. Williams ('90). The stock lies within Carboniferous formations, but adjacent to it is a dike of peridotite invading the Lower Cretaceous sandstone, which lies horizontally, and this dike contains abundant inclusions of Paleozoic and Mesozoic rocks. Branner suggested that the subsidence in Tertiary times is in some way connected with the intrusion of these rocks, while Williams adds that it is evident that the time of their intrusion was not far removed from that of syenitic and monchiquitic rocks of other parts of the State. Purdue ('08) has found other pipes of the peridotite near Murfreesboro, in Arkansas, which, like the South African rocks of this character, are associated with diamonds. Recent observations by Glenn ('12) lead to the belief that the period of intrusion occurred between Lower and Upper Cretaceous times.

Thus the rocks of this group throughout the United States form narrow dikes or small stocks in horizontal or slightly folded, though not unfaulted, sediments, a mode of occurrence utterly distinct from that of normal gabbros and peridotites. We have seen that similar associations hold in India; they also hold in South Africa. For this reason Sacco's ('05) classing of these rocks with the normal ophiolitic group can not be supported.

Probably consanguinous with these are the series of igneous rocks forming the alkaline complex of Magnet Cove. Washington ('00) interprets this as a thick complex laccolite, but Dr. Harker ('02) suggests that it may consist of two thin laccolites bulged quaquaversally subsequent to their consolidation. The rocks are very varied, foyaite, and such basic and ultrabasic types as ijolite and jacuipirangite being present. They were injected without notable folding in late Cretaceous times, for the bulk of the Cretaceous strata in this region are horizontal.

We may here mention two other alkaline complexes: The Monteregian Hills near Quebec consist of essexite and nepheline-syenite with a series of diverse alkaline dike-rocks. Adams ('03) considers they are laccolitic and have been thrust through horizontal Devonian rock.

In North Greenland Steenstrup ('84) describes a sill of picrite-porphyry 120 feet thick invading the Kome beds which are flat-lying "Miocene" or Cretaceous sediments. It consists almost entirely of olivine, lying in a yellow or pale-green clear base. These last three occurrences would be appropriately classed with our "alkaline-plateau" group of intrusions. Possibly the occurrence of ultrabasic rock in Greenland figured by Daly ('14, p. 447) should be included here. A comprehensive illustration of these rocks, also due to Arnold Heim, is that given in *La Face de la Terre* (Tome iii–4, 1918, p. 1525) but the literature concerning this and other interesting complexes in Greenland is not accessible to the writer. In particular may be mentioned the magnesian rocks of Ellesmere Land described by Bugge ('10).

THE WESTERN CORDILLERA OF NORTH AMERICA.

Blackwelder's ('13) convenient sketch-map of the Rocky Mountain orographic elements and Idding's ('13) summary of the distribution of igneous rocks therein allow us to comment briefly on the tectonic surroundings of the various types of igneous rocks developed, the characteristics being indicated more clearly if we do not confine our attention to basic and ultrabasic rocks only. East of the Rocky Mountain zone there is a region of laccolitic hills rising with local upturning of the strata from an almost unfolded terrain. Commencing in Arkansas, where the series to be described is linked with the complex of Magnet Cove, we have the nepheline-syenites and associated alkaline rocks of the Fourche Mountains, probably of late Cretaceous age; nepheline-syenites in the Apache Mountains of West Texas; the strongly alkaline complex of Pikes Peak on the eastern flank of the Front Range; the post-Cretaceous alkaline laccolites of the Black Hills of South Dakota and Wyoming, containing mostly rocks of a moderate basicity, but also strongly basic rocks (ijolite, nephelinite, fourchite, etc.); and the laccolitic region of Central Montana, in which the alkaline facies is not always so strongly developed, though very distinct in the laccolites and stocks of the Highwood and Bearpaw Mountains. Among the first of these is the well-known gravitationally differentiated laccolite of Shonkin Sag. A monzonitic series occurs in the Little Belt Mountains, and a mixed facies of diorites and gabbros associated with shonkinites and other alkaline types in the Elkhorn and Crazy Mountains. In the last region the alkaline rocks form a marginal zone of intrusions about the central stock of subalkaline rocks, which invade upturned Eocene sediments. This recalls the distribution of the subalkaline intrusions in areas of local compression and the regional development of rocks with a "subdued alkaline character" in Skye and Mull. (See p. 13.) Alkaline rocks also occur in the Kootenay region and continue across the border into Canada.

West of this zone there is the continuous zone of open folds and faults extending from Yellowstone Park to Colorado. In these the petrographic characters of the rock are less uniform. In Yellowstone Park andesitic laccolites were formed at the end of the Laramide orogeny and later basaltic volcanoes have cores of gabbro and diorite. Among the effusive rocks of the Tertiary period alkaline and subalkaline types occur. They are also present in flows and dikes, accompanying generally monzonitic or dioritic stocks in Colorado. In the Front Range and the Sangre de Cristo Mountains the pre-Cambrian schists, etc., are invaded by dikes of granite, monzonite, diabase, gabbro, pyroxenite, and peridotite, and there is also a large gabbro batholith (Animas Valley).

To the west of this we have in the south the vast plateau of Utah, with laccolitic intrusions generally of andesitic characters, but with gabbros, diorites, etc., and only exceptionally strongly sodic types. To the north is the region of compressed folds and overthrusts in western Montana and Idaho, where there are the subalkaline Idaho and Boulder batholiths of quartz-monzonite with granitic, dioritic, and gabbroid facies and the quartz-diorite of Marysville. The intrusion of these probably followed the commencement of Laramide folding.

We turn now to the western portion of the cordillera. The northernmost mass of ultrabasic rock of which the writer possesses information is that described by Martin and others ('15) in the Kenai Peninsula of Alaska, where peridotite invades a highly disturbed series of Paleozoic or possibly Mesozoic greywackes, cherts, limestones, and basic igneous rocks. In the less metamorphosed terrain in the southwestern portion of the peninsula there are Triassic limestones and contorted cherts with pillow-lavas.

Southward from this stretches the Coast Range batholith for nearly 850 miles, with a width of about 60 miles in one place. It is made up of a number of separate batholiths ranging in age from early Jurassic to early Cretaceous. It varies in composition from gabbro to acid granite, but the prevailing type is a granodiorite usually massive, but often with a primary gneissic structure. McConnell ('13) and Bowen ('15) state that the smaller outlying intrusions to the west of this in the Prince of Wales Islands are of gabbro. Norite and gabbro also appear as marginal facies in Queen Charlotte Sound, and orbicular gabbro is recorded. Hornblendite locally forms a marginal ultrabasic modification (Bancroft, '13). The features here described recall in some degree those of the southwestern portion of New Zealand. In the southern end of Vancouver Island (Clapp '12, '13, '14, '17) shows that an extensive series of Lower Mesozoic andesite and basaltic lavas were invaded during the Jurassic folding by gabbro-diorite-gneiss, diorite, and granodiorite, with a series of later dykes. Resting on an eroded surface cut from these are a series of Cretaceous conglomerates and sandstones, followed by very much altered (usually albitised) pillow-lavas, agglomerates, and cherty tuffs, which were strongly folded and invaded by gabbro which passes upward through a transitional zone, 1 to 3 feet in width, into granite. In one area described by Cooke ('19) an oval mass of greatly varied, and peripherally gneissic, olivine-gabbro has a marginal zone of augite-gabbro, and these pass up into small masses of granite and anorthosite, the several rock-types being sharply separated or linked by transitional zones, usually a few inches in width. The intrusion of gabbroid and granite dykes and the production of hornblendite and aplite were the last events in the consolidation of this mass. Camsell ('13) has described a further development in the Tulameen area of British Columbia. Here intrusive into Mesozoic argillites and limestones, with intercalated basic effusive and clastic rocks of submarine origin, there is a roughly lenticular mass of pyroxenite and peridotite 7 miles long and 2 miles wide; the central portion is dunite, the envelope pyroxenite. Segregation-veins of biotite-olivine rock occur in the dunite, and hornblendic pegmatites in the pyroxenite. The margin of the intrusion conforms to the strike of the invaded rock, into which several sheets of the pyroxenite have been thrust. Locally "augite-syenite" with a gabbroid facies has been injected, followed by granodiorite, while Cretaceous rocks lie upon an eroded surface of the granodiorite. Evidently the complex may be grouped with the series of intrusions which accompanied the main Rocky Mountain folding at the close of Jurassic times. The special point of interest in regard to this mass of peridotite is the occurrence in it of some diamonds. This has led Camsell to correlate it with the peridotite of Pike County, Arkansas, but the correlation is not justifiable on tectonic or petrographic grounds. The intrusion of the Arkansas peridotite was not accompanied by noteworthy folding, and it contains melilite and perofskite and much greater amounts of lime, alkalies, and titanium, and a lower percentage of magnesia (25 per cent) than are normal for peridotites or occur in the Tulameen peridotite, of which the composition is quite a normal one for a peridotite and contains 40 per cent of magnesia. Compare with this the occurrence of diamonds in normal peridotite in Tasmania (p. 37).

Daly's ('12) study of the cordillera along the forty-ninth parallel shows an extremely complex series of igneous events. Commencing on the east, in the Purcell Mountains, the sandstones forming during pre-Cambrian times were interbedded with basaltic lavas and a little rhyolite and invaded by a series of composite sills composed of gabbro, generally forming the whole or the lower portion of the sill and granophyre forming the upper, and in one occasion the middle portion of the sill, while a rock of intermediate composition separates the two types of rock. Daly considers these result from gravitational differentiation of a magma acidified by absorption of the overlying siliceous sediment, but Schofield ('14) gives weighty criticisms of this view and concludes they arose as intrusions from an intercrustal reservoir containing a differentiated magma. Comparison should be made with the composite sills described by Harker ('04) in Skye. The Rossland volcanic series consists of an older and possibly Carboniferous series of basaltic and andesitic lavas and tuffs, now partly schistose. Newer than these, but difficult to separate from them, are further basalts, andesites, and latites, invaded by a monzonite which merges locally into a hornblende-peridotite. This was injected probably during the Jurassic orogeny. Gabbros, with peridotitic facies, occur in the same region, and a porphyritic harzbergite or picrite occurs (possibly as a sill) in the volcanic rocks, which are intersected by a dike of dunite. In the Columbia Mountains highly metamorphosed basic volcanic rocks of Paleozoic or Mesozoic age have been invaded by small masses of serpentine. In the Okanagan Mountains a long series of plutonic intrusions occur. Upper Paleozoic and possibly Triassic sediments and basic volcanic rocks were invaded, perhaps at the close of this period, by gabbro and peridotite. During the intense deformation in Jurassic times granodiorite-batholiths formed, and these in turn were dislocated by Laramide orogeny. Intrusions of nepheline-syenite and its associated differentiates followed, and were succeeded by sodic hornblende-gabbros of Tertiary age and later granites of a more acid character. The concluding events were the intrusion of dikes of basalt and andesite. Daly ('12) has offered an explanation of this series in terms of the theory of assimilation, in which the nepheline-syenites are looked upon as a peculiar though initial member of a second group of chiefly granitic intrusions, derived in large measure by the further differentiation of the refused granodiorite which formed the latest member of the earlier series. The discussion of this suggestion is however, outside the scope of this paper.

Southward in the State of Washington (Mount Stuart and Snoqualmie quadrangles) serpentine occurs intrusive into what is probably a Paleozoic series, and is overlain by Eocene sediments, in which serpentine pebbles occur. Unconformably upon these, are Miocene basalts and andesites, and the whole sequence has been invaded by granodiorite (Smith '04, Smith and Calkins '06).

Southward from here we may conveniently recognize two main zones of intrusions of ultrabasic and basic rocks, namely, those in the Sierra Nevada and those in the Coast Ranges, though these are much the same in age. These have been studied in considerable detail, and an excellent series of maps are included in the folios of the Geological Atlas of the United States. The more easterly series passes through the following quadrangles: Bidwell Bar, Downieville, Smartsville, Colfax, Nevada City, Truckee, Sacramento, Placerville, Pyramid Peak, Jacksonville, Big Trees, and Sonora, which have been mapped and described by Becker, Lindgren, Ransome, and Turner. The main formations throughout this region are a series of highly altered Paleozoic rocks, the Calaveras formation, on which lies the less-altered but still highly crushed Trias-Jura Mariposa formation, which is largely slaty, containing intercalated basic lavas and breccias. Into this have been injected long bands of serpentine and gabbro, which in some areas have irregular transgressive boundaries, but in others, especially in the Sonora quadrangle (fig. 18), the boundaries are very concordant with the strike of the invaded formations. Dioritic and granitic intrusions accompanied these invasions, but the sequence of the intrusive masses is not always clear. Dioritic and diabasic dikes frequently occur in the serpentines. The age of these intrusions is fixed by the fact that in the Truckee quadrangle they are overlain by Upper Cretaceous (Chico) sediments. An interesting feature is the presence of albitic dike-rocks associated with the serpentine in the Bidwell Bar, Jacksonville, and Sonora districts. These are nearly white rocks, with minute faint blue mottlings. The chief constituent is albite, and the mottling is due to the presence of tufts of slender crystals of amphiboles, with a little aegyrine, apatite, and zircon. Biotite is present in one of these dikes. Sometimes the dike is a type of soda-granite, containing albite, quartz, muscovite, and a little sphene. The largest of these masses has a length of 6 miles and a width varying up to 100 yards. It was injected between the serpentine and the inclosing hornblende-schist. Though such rocks seem rare, the writer has described several occurrences in association with serpentine from New South Wales and has pointed out other recorded instances in Cornwall and Akmolinsk (Benson '13, '18, '18a). They seem to be formed according to some general scheme of paragenesis. (Cf. Dresser ('21) and the footnote on p. 32.)

Structurally the Klamath Mountains of Oregon should be grouped with the Sierra Nevada, but as they form a link between the latter and the Coast Range series of ultrabasic intrusions they are considered here. Detailed investigations have been made by Diller in mapping the Roseburg ('98), Redding ('06), Coos Bay ('01), and Port Orford ('03) quadrangles; while the geology of the whole region has been more recently summarized by Diller ('14), and Smith and Packard ('19). In the Devonian and Carboniferous periods there was a transgressing sea of varying depth, in which were deposited about 10,000 feet thick of argillites, tuffs, and sandstones, with lenses of limestone and frequent beds of radiolarian chert. With these are associated an abundance of andesitic lavas, rich in pyroxene. In some places they are vesicular, and associated with fragmental deposits due to explosive volcanic action. These were folded and uplifted during the close of the Paleozoic period, and were invaded by peridotite, gabbro, and diorite. Triassic marine sedimentation was only local, but further volcanic eruptions then broke out, with products similar to those described above. These were continued into Jurassic

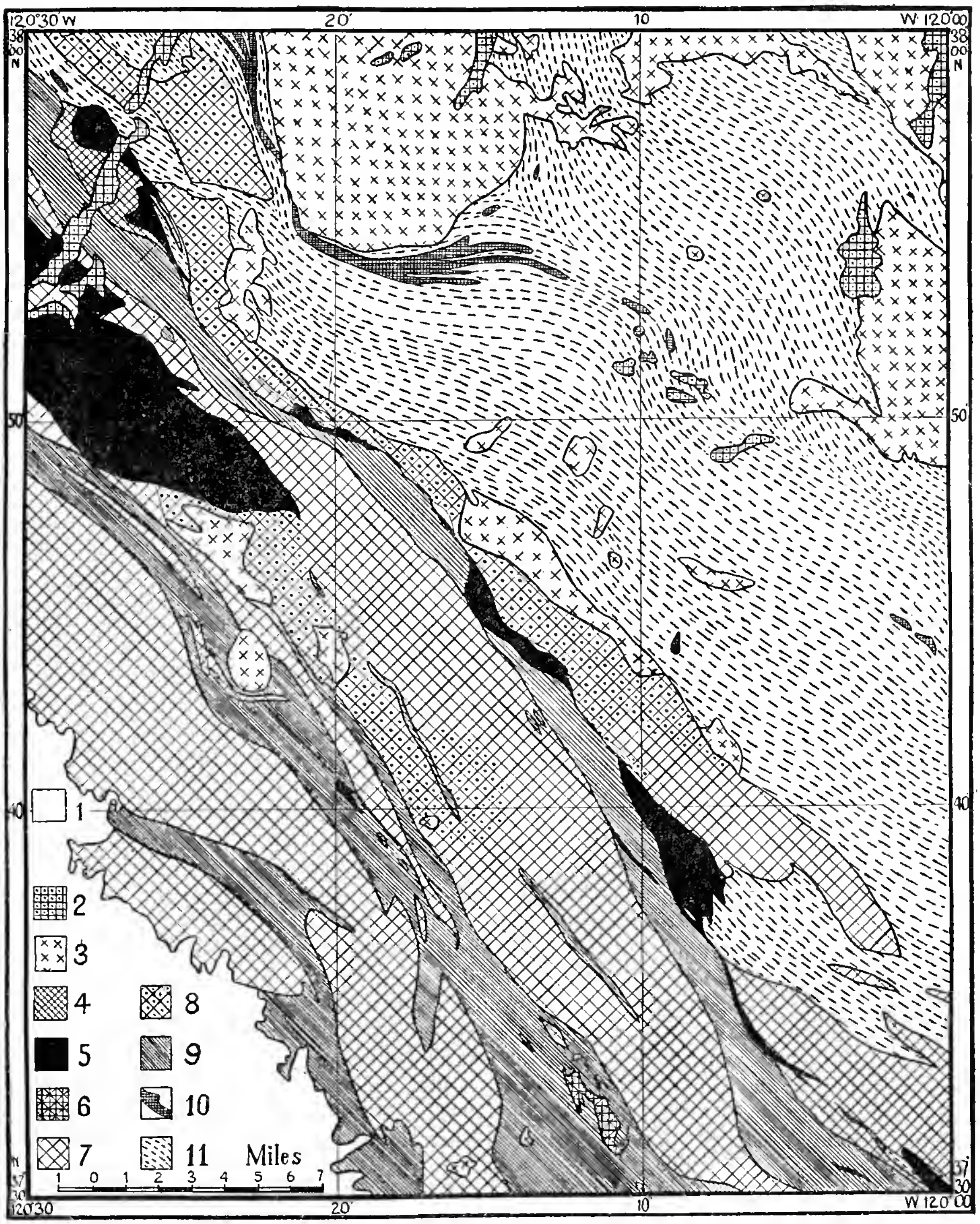

FIG. 18.—Geological map of the Sonora Quadrangle, California. (After Turner and Ransome.)
1. Tertiary sediment. 2. Tertiary basalt. 3. Granodiorite. 4. Soda-syenite. 5. Serpentine. 6. Diabase.
7. Porphyrite. 8. Amphibolite. 9. Trias-Jura sediment. 10. Limestone. 11. Carboniferous sediment.

times, when marine sedimentation recommenced, shales and sandstones with some conglomerate and a little chert being the chief deposits; the upper portion seems to be continued in the Franciscan series farther to the south. In intercalated fresh-water beds an extensive flora is preserved. The Jurassic epoch closed with profound folding and faulting, with the intrusion of extensive masses of greenstone followed by peridotite, gabbro, granodiorite, and dikes of dacite-porphyry. The concordant sill-like character of the basic intrusions is most clearly seen in the map of the Galice-Kerby-Waldo region (Diller '14) where a single mass of serpentine follows the strike of the country unbroken for over 40 miles. Erosion succeeded, and further marine deposition followed during Lower Cretaceous (Knoxville), continuing into Middle (Horsetown) and Upper Cretaceous (Chico) times. The Laramide orogeny followed, and minor intrusions of pyroxenite and gabbro accompanied this folding.

Southward the serpentine belt passes into northern California, where the serpentines have been studied by Kramm ('10). The most elaborate investigations are, however, those of San Francisco and La Cruz, respectively, by Lawson ('14), Branner ('09), and their associates. Here, resting on an eroded surface of granite intrusive into ancient sediment, lies the Jurassic (?) Franciscan series[4] of sandstone and conglomerates, shales, and a little limestone, with abundant interlaminated radiolarian chert, intercalated vesicular basaltic rocks, and irregular intrusive masses of pillow-lava (Ransome '93), generally invading sandstones and especially radiolarian rocks. Some of these have a more or less alkaline nature, e. g., fourchite (Ransome '94), a feature which may recall the sodic character of the spilites. The folding at the close of Jurassic times was accompanied by the development of laccolites, sills, and dikes of serpentine following the general strike, which greatly metamorphosed the Franciscan sediments, radiolarian, and otherwise, with the formation of glaucophane-schists. "This metamorphism occurred before the deposition of the Knoxville formation, and indeed before the erosion-interval that followed Franciscan time, so that the intrusion of the peridotites and ellipsoidal basalts must have occurred so soon after the deposition of the Franciscan strata that they may be with propriety referred to Franciscan time" (Lawson '14). Indeed the occurrence of pillow-structure in the basalt suggests that they may have been intruded into unconsolidated sediments. (Cf. Lewis '14.) The schistose nature of the metamorphic rock produced is, however, a very remarkable feature, though its sodic character suggests that the metamorphism may be a phase of that chemical process which produced the adinoles about the Devonian diabases of Germany and S. W. England or the albitic marls by the Tertiary diabase of Italy. The Lower Cretaceous (Knoxville) shales and the Upper Cretaceous (Chico) conglomerates and sandstones (here concordant) were deposited on a peneplain cut from the Franciscan sediments and igneous rocks.

The region of La Cruz, immediately to the south of the San Francisco area, gives a like series of events, and the unconformity between the Franciscan and Knoxville formations is emphasized by the occurrence of pebbles of the Franciscan rocks in the latter (Branner '09). Nutter ('01) has traced the line of serpentines for nearly a hundred miles farther to the south, along the Salinas Valley. Fairbanks ('04) has described the San Luis Obispo region still farther south, where again Knoxville beds occur unconformably overlying the Franciscan series, which here also, though chiefly of shallow water origin, contain many thin lenticles of radiolarian chert altered to glaucophane-schist where in contact with the basic intrusive rocks of the older series. These are the greatly altered amygdaloidal and pillowy basaltic rocks, the pyroxenite and peridotites which were erupted at the close of Jurassic times. A later series of diabases, serpentines, and gabbros invaded the Knoxville but not the Chico rocks, there being an unconformity between the two formations here. The long period of Neogene sedimentation was followed by a further folding in which was developed intrusions of olivine-dolerite and augite eschenite.

The close association between pillow-lavas, diabases, serpentines, and radiolarian rocks, which is thus a marked feature of the Jurassic intrusions of the west as well as the eastern border of the Pacific, suggests at once the features of alpine occurrences and the "green rocks" of Lower Paleozoic age in Scotland, as Steinman ('05) pointed out. This similarity is strengthened by Fairbanks's description ('96) of the rocks of Point Sal, south of the San Luis Obispo. Here

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[4] Reference should be made to Davis's recent descriptions ('18, '18a) of the Franciscan Series.

the complex relation of Jurassic (?) igneous rocks to one another are well exposed in cliff-sections. There are two main areas of these; the one consists of pillow-lava, showing an extraordinary assemblage of highly scoriaceous rock, sheet-like masses of elliptical basalt, sometimes sodic and apparently decalcified (see analyses cited and cf. Termier '98), together with veins of coarse gabbro of normal calcic composition. The other stratiform intrusive mass shows an extraordinarily intimate mixture of peridotite and flaser or banded gabbros, in which it is difficult to say which is the older. These are cut by diabase. The descriptions remind one strongly of what may be seen in some parts of the Lizard Peninsula in Cornwall (Flett and Hill '12, pp. 81–101). This region differs from all other parts of the coast in the large amount of gabbro that is present.

Again to the southeast there are intrusions of serpentine and diabase into supposedly Knoxville rocks in the San Rafael Mountain (Fairbanks '96), and near San Diego in the southwestern corner of California, Lawson ('04) noted an orbicular gabbro doubtless occurring in the same series as the norites, gabbros, diabase, and more acid plutonic rocks which Fairbanks ('93) found to invade the crystalline metamorphic rocks in this region. Further south the succeeding occurrences of such basic rocks in the Islands of Cedros, Santa Magdalena, and Santa Margarita off the end of the peninsula of Lower California are associated with highly altered schists and amphibolites (Lindgren '93).

In his interesting summary of the petrographic provinces in North America, Iddings ('13) remarks that the differences between the congenetic series of rocks in different regions are sufficient to distinguish them as representatives of different petrographic provinces, though sometimes they are so slight that there seems to be what Pirsson terms a regional progression of types. "The data already to hand suggest the existence of ill-defined zones traversing the North American Continent along the lines of its chief physiographical features, but they also indicate the petrographic complexity of these zones, and the probability of their being separated into many petrographic provinces and into innumerable petrographic districts." As may be seen from the foregoing summary there is in the relationship of the distribution of petrographic type to that of the tectonic features of the western cordillera, a very considerable degree of concordance with the generalizations of Dr. Harker.

CENTRAL AND SOUTH AMERICA.

Passing farther to the south we note that though there are abundant evidences of immense folding-movements in Mexico, as for example the great recumbent folds of the Cretaceous limestones of the Sierra Madre Occidentale, there are no ultrabasic intrusions, so that here, as in much of the Pyrenean and Carpathian Ranges and many other parts of the world, folding has occurred without the injection of ultrabasic rocks; or if these were present, they have not been yet exposed by erosion. The volcanic rocks, which form the bulk of the present tabular ranges have been poured out from fissures formed in the underlying folded range, and no precursors of these eruptions appear in the form of volcanic tuffs embedded in the older sediments (Suess IV, 437–442).

Suess traces the trend-line of the great Andean folds from the south of Mexico into Guatemala, where it leaves the southeasterly trend and turns into an east-north-east direction into the Sierra de las Minas, on the north side of which, according to Sapper ('99) runs a band of serpentine, and on the south side another band extends along the River Motagua for 225 kilometers. It is regarded by him as younger than the Upper Carboniferous and older than the Middle Cretaceous. Nevertheless, a recent report by Powers ('18) has thrown doubt on the presence of this serpentine, remarking that "the belt mapped as serpentine coincides with a belt of very good quality white crystalline marble which composes the south flank of the mountains." The more metamorphosed rocks, considered to be ancient schists by Sapper (but not by Powers), extend in a range south of the River Motagua and end in the islands of Ruatau and Bonaca, the latter consisting of serpentine and phyllite. The continuation of this tectonic axis is in Jamaica. Cuba, however, appears as an inserted axis, a virgation of the main line, and in this extended island there is a long zone of serpentine forming the main watershed of the island, though of no great height. It occurs in a complex of metamorphic and igneous rocks, diorites, etc., with which it is closely united. This is overlain by Cretaceous *Rudistes* limestones, at the base of which is an arkose of fragments of granite and serpentine derived from the basement complex. No age can therefore be assigned to the basement rocks. They may be the equivalent of the late Jurassic rocks of the western United States or much older (Hayes '01). Steinmann ('05), citing observations by Gabb ('73), Kloos, and Martin, believes that radiolarian chert occurs with diabase, variolite, and serpentine in San Domingo. In several other Antillean islands schistose basement-rocks occur, but ultrabasic rocks are apparently not present, though in the continuation of the tectonic axes through the Lesser Antilles, gabbros occur as inclusions in the volcanic ejectmenta (Lacroix '04), and a series of plutonic rocks ranging from granite to peridotite occur in the crystalline complexes exposed in the inner curve of islands. Högbom's ('05) statement concerning the rarity of potash in these rocks enables Suess (IV, p. 464) to correlate them with the granodiorite masses of the Andean system. Högbom concludes that in spite of their plutonic habit they are Cretaceous, occurring among tuffs and breccias of that age.

Passing into South America we find a continent unique in the rarity of ultrabasic and basic plutonic rocks. The Andean zone swings into northern Venezuela, and opposed to it is the foreland of Brazil and Guiana. The massif, which is composed of ancient gneisses and schists, in British Guiana, is covered by sandstones resembling those of the Triassic in New Jersey, but, owing to the occurrence of certain fossils in its extension into Venezuela and Brazil, a Cretaceous age has been suggested. It is invaded by huge flat-lying sills of quartz-dolerite like that forming the Palisades on the Hudson, and therefore correlated with them by C. Brown, though Harrison ('09) is inclined to correlate them with Tertiary eruptions for rather indefinite reasons. Somewhat similar sills are associated with basaltic lavas in the Trias-Jura sandstones, etc., of Southern Brazil (White '08).

Following round the massif of Brazil, and as its marginal folds, is the Andean chain. Some serpentines have been found in the crystalline massif itself in Brazil (Hussak '17), and in French Guiana (Lacroix '98), but Steinmann ('05) has commented upon the absence of such rocks of post-Paleozoic age from the greater part of the Andean chain, though in Columbia some serpentines and gabbros have been found (Iddings '13), and a small mass of norite in southern Peru invades the Mesozoic andesites. Though there was considerable folding and intrusion of granodiorites at the close of Jurassic times, the general absence of basic and especially of all ultrabasic plutonic rocks seems to stand in definite relation to the structure of the range. "Throughout the Peruvian Cordilleras, inverted folds are the exception rather than the rule, and great zones of overthrusting appear to be entirely wanting. Any directional movement of the folding, moreover, is hard to determine" (Douglas '20). Farther south, however, near Aconcagua, Schiller ('07, '12) has indicated the presence of overfolding and overthrusting of the Jurassic sediments and lavas directed toward the west, and on the eastern side of the range in the north of the Argentine, Keidel ('16) has described overfolds directed toward the northeast, involving Cretaceous rocks. Older than these in the Argentine, a complex of diorites, norites, gabbros, and peridotite, occurs chiefly in the ancient schists but also in the Paleozoic rocks of the pre-Cordillera chains east of the Andes (Romberg '94, Steiglitz '11). These rocks occur as pebbles in the overlying Mesozoic sandstone, and are therefore pre-Mesozoic (perhaps Altaid). In Patagonia, Quensel ('12) describes an interesting series of intrusions on the eastern ranges and foothills of the Andes. The former consist of laccolitic masses, probably of very early Tertiary age. These contain a varied series of plutonic rocks from subalkaline gabbros and diorites, to orthoclase-gabbro, monzonite, and aegyrine-syenite. In one laccolitic mass the rocks may be strongly differentiated, while in an adjacent one they may be almost uniform. One may show alkaline features, another, though widely differentiated, may show no relationship with the alkaline rocks. Apparently there was extensive differentiation before intrusion, and some differentiation also occurred *in situ*. In the eastern foothills (pre-Cordillera) there is a more uniformly alkaline character, the rocks being essexites, and these are believed to antedate the rocks of the eastern flank of the cordillera. They invade the Cretaceous calcareous marls. Iddings's ('13) remarks on the presence of gabbro and granodiorite in Patagonia, and Chrustchoff ('88) obtained a pebble of peridotite from the shores of Magellan Straits. Possibly these were all connected with the Andean granodiorites forming the western portion of the ranges. If so, some analogy might be drawn between the distribution of alkaline and subalkine rocks in Patagonia and Montana (see Harker '09, p. 95). Quensel, however, while drawing attention to the analogy with North America pointed out by Suess (IV, p. 485), inclines to follow Daly's view in explaining the alkalinity of the eastern rocks by the absorption of the associated calcareous marls.

An interesting application of petrology to the study of tectonic conditions is suggested by recent investigations in South Georgia. (Tyrrell, '14, '15, '16, '18, and Ferguson '15.) Here there are a series of highly altered shales, sandstones, and gritty trachytic tuffs containing radiolaria which, from the suggestion of obscure fossils, are possibly of Ordovician or Silurian age. Less altered than these are a series of similar sediments with a greater abundance of tuffs which appear to be of Mesozoic age. A very definite suite of spilitic rocks occur also with albite-dolerites and soda-felsites. Thus the petrographical evidence seems to the writer to oppose the suggestion that South Georgia was portion of an ancient continental land (Gregory '15, Tyrrell '18), but favors instead the view that it is the folded remnant of what was the offshore region of subsidence and sedimentation about such a continental mass.

Very similar rocks occur in the South Orkneys, greywackes, slates, etc., which are of Silurian age, and spilites (Tyrrell '15); and the islands of the west coast of Graham Land again contain slate radiolarian jasper and tuffs. On the mainland are Jurassic sediments invaded by the typical Andean series of plutonic rocks ranging from granite to gabbro, while to the east are nearly horizontal Cretaceous and late sediments, comparable with those of Patagonia. Thus there is a tectonic, and as Nordenskjöld ('13) urges, a strong petrographic affinity between Graham Land and the Andean chain. This has been supported recently by Ferguson ('21) and Tyrrell ('21).[6]

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[6] Attention may be directed to a recent study by Baeckström ('16) of the basalts of south Patagonia and the islands along the trend-line we have traced. These show a general association of alkaline and subalkaline types, except those in the South Sandwich Islands, which are entirely subalkaline.

Chapter IX.

DISCUSSION AND CONCLUSIONS.

In bringing these studies to a close we must comment upon certain problems which have arisen in connection with the features we have described.

THE GREEN-ROCKS OF THE ALPINE TYPE.

Great difficulties still remain in regard to this series of rocks and the reconciliation of their diverse characters. Considering first the chemical characters of these rocks we find that the Italian analyses (all "inferior" according to Washington '03, '04) indicate that the green-rocks are all of normal alkali-calcic composition, with the exception of a mica-teschenite (Verri '00). Strong sodic solutions were, nevertheless, emitted from them, for the marls have been extensively albitized along their contact with the diabases, and in one instance a radiolarian cast was found preserved in a crystal of albite (Issel '90). In some Swiss types, more soda is present. The rocks of the Bagnetal, if they are rightly considered in this connection, are in composition intermediate between basalt and trachydolerite, soda and titanium being noteworthy (Woyno '11). Those near Brig (Preiswerk '07) and in the Julier Pass (Upper Engadine) (Cornelius '12), show a higher content of soda, some types approaching the composition of keratophyre, while Grubenmann ('09) has called attention to the "essexitic" character of those of the Lower Engadine. Thus, particularly in the occurrence near Brig, there are chemical features which are comparable with those of the spilitic suite, though in some analyses cited by Grubenmann there is a suggestion of a secondary alteration of composition comparable with that investigated by Termier ('98), an elimination of lime with some addition of soda. How far this process may have affected the whole series is not clear. These alkaline characters are seen in the diabasic types, including some coarse-grained specimens referred to gabbros in the Brig area (see p. 27), but they are generally absent from the gabbros proper, the gabbro-schists, and allalinites.

In regard to the mode of occurrence, while no indubitable volcanic rocks are known [1] (Suess IV, p. 134) the pillow-lavas indicate rapid chilling, and may have resulted from intrusion into unconsolidated submarine sediments. On the other hand the peridotites and schistose gabbros are clearly plutonic in petrographic character. Considering first the finer-grained types apart from the gabbros, the Italian geologists believe them to be flows interbedded with the Eocene marls in the Apennines showing intrusive features owing to the unconsolidated nature of the sediments over which they flowed.[2] The Piedmontese *pietre verdi* are believed to be flows of various ages between Permo-Carboniferous and Jurassic. Termier ('98) considers the greenstones of Pelvoux Triassic flows, and Zaccagna ('87) so explains the variolite and spheroidal diabase of Monte Viso. Schmidt and Preiswerk ('08) found the green-rocks of the Simplon area to appear as if they were interbedded flows on either side of the boundary between the Triassic dolomite, and the Jurassic calc-phyllite, quite unconnected with the folding. The same conclusion was reached by Seidlitz ('06) in the Engadine and Meyer and Weber ('10) in the Tauern. Other workers in the Engadine have come to different conclusions. Cornelius ('12) held that the green-rocks of the Julier Pass were injected into their present position during the Tertiary folding. Lorenz ('02) has similarly explained the green-rocks of the southern

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[1] "It still remains to be determined by extensive research whether a true volcanic action was associated with the intrusion of the ophiolites, whether there were produced as a result of submarine extrusion the peculiar features like pillow-structure, and the peripherally vesicular character of the pillows, and how far the dislocations have obliterated the originally effusive character" (Steinmann '05, p. 57). At Monte Genèvre, Cole and Gregory ('90) believed tuffs were developed, and Woyno ('11) considers the prasinites and glaucophane-schists of the Bagnetal have resulted from the metamorphism of lavas and tuffs in the Mesozoic calc-phyllites. For a recent discussion of the significance of pillow-structure see Lewis ('14).

[2] See also Stefani ('13). Sacco ('05) and Steinmann ('05) contend the marls and radiolarite are not Tertiary but Cretaceous or older.

Rhaetikon, which he held to be clearly associated with lines of thrust (a conclusion challenged by Von Seidlitz '06). Paulcke ('04) so explains the green-rocks of the Antirhaetikon, and Becke ('03) the peridotites of the Tauern, which invade calc-phyllites and green schists which are in part Mesozoic. Unfortunately the writer has not seen Staub's ('15) discussion of this problem to which reference should be made. Similar rocks in California are held to be intrusive.

Steinmann ('05) basing his view chiefly on the features of the Engadine, is opposed to this conclusion. In general, he urges, there is no association between the occurrence of the green-rocks and the great recumbent sheet-folds, but they are confined to the Rhaetic sheet only, and were carried forward passively when this was folded up. The root-region belongs to the inner zone of the Alps and was probably the Ivrea zone. In the Rhaetic sheet there occur radiolarian cherts and clays, which he assumes are of abyssal origin, and these are overlain by shallow-water Cretaceous sediments. There must therefore have occurred an uplift of the sea-floor to the extent of ten or fifteen thousand feet in early Cretaceous times. The association of Jurassic radiolarite and shallow-water Cretaceous deposits occurs in no other region of the Alps, and we may therefore consider that the extrusion of the ophiolitic rocks accompanied or followed closely after this great uplift, and that they are for this reason confined to the Rhaetic sheet. It was in the later intense overfolding of Tertiary times that they were carried forward into their present position and were strongly metamorphosed. "Thus the circumstances of their intrusion were different from those of granite and diorite massifs and dike rocks, and we may conceive that under the great sea depths basic magmas collect, and are injected during the folding of these abyssal regions, while more acid magmas rise into the foundations of the continents and the regions of shallow seas" (Steinmann '05, p. 59). This hypothesis, therefore, depends on the necessarily abyssal character of the radiolarites of the Alps, and this assumption is also made by Suess, though he calls attention to an area in the eastern Alps (Suess IV, p. 190) (also discussed by Uhlig '11), where they are very intimately associated with littoral sediments. There is an increasing body of evidence put forward by Lawson ('95), Walther ('97), David ('99), Martin ('07), Dixon ('11), and most recently by Davis ('18), which makes it clear that radiolarian cherts are frequently formed under shallow-water conditions, this being notably the case in California, which was considered by Steinmann to illustrate his hypothesis.

Suess ('04, IV, pp. 248, 564) objects to Steinmann's hypothesis because of other evidence of the development of green-rocks in folded mountains, where deep-sea conditions are inadmissible, namely the occurrence of green-rocks as sills in the shallow-water Mesozoic rocks with the gypsiferous and saline Triassic beds of the Pyrenees, Morocco, and Tunis, and holds instead that they "form sills in dislocated mountains, which sometimes follow the bedding planes and sometimes the planes of movement," believing that the intrusion actually accompanied the dislocation. (Suess IV, p. 561–567). The fact that they are confined to the Rhaetic sheet in the Alps is explained by reference to the nature of its component rocks. In the case for example, of the Simplon area, as soon as they had reached the upper limit of the gneiss they discovered the planes of least resistance in the Triassic limestones and the Jurassic calc-phyllite, generally the bedding-planes, and spread out in them. For this reason they are intercalated in the Mesozoic sediments one above the other. Ascending dikes are rare (ibid., pp. 134). So also they were injected into weak structures in northern Africa, and were brecciated by later movements (ibid., p. 222). Probably the alpine green-rocks were rooted in the Ivrea zone of intrusions, which were developed during movement on the sole-plane, along which the Dinarides were thrust on to the Alps, but it is possible that this question can never be settled by observation, for the connection with the south has now been destroyed (ibid., pp. 154, 564).

It is very clear from many instances we have described how correctly are the basic and ultrabasic rocks described as concordant sills in dislocated mountains, developed during the crust-movements, and so far Suess's conclusion is confirmed, but its application appears to be carried too far when it is sought to include all the alpine green-rocks. In particular, it does not seem permissible to regard the finer grained green-rocks, such as those of the Simplon area, which are not associated with clearly plutonic rock types, or those elsewhere with pillow-structure or possibly of tuffaceous origin, as products of the crystallization of a magma thrust into consolidated Jurassic sediments during folding, and under a thick cover of Upper Jurassic, Cretaceous, and possibly Eocene deposits. Under such circumstances plutonic and hypabyssal features only would occur. It seems, therefore, preferable to accept the views of those who consider such masses as approximately contemporaneous with the associated sediments being intrusions into unconsolidated material or even submarine flows, and to note, moreover, the geosynclinal conditions of their development and their often spilitic chemical character. Where, however, such rocks are intimately associated with plutonic types, other considerations may be noted. Plutonic intrusions of peridotite and gabbro are not infrequently followed by dikes of diabase, and in a strongly dislocated region the three types might become intermingled and their relations obscured. We may conceive it to be possible that the basic magma rising along a plane of shearing in a geosynclinal zone may be pressed out at the surface in front of the advancing overthrust anticline or crust-flake, and may consolidate in the form of submarine volcanic rock, massive or tuffaceous, and as the movement continues, these may become over-ridden by the advancing sheet; the magma passing along the thrust-plane may now be injected into the previously formed volcanic rocks, and thus a plutonic series of intrusions, with possibly some differentiation may invade volcanic rocks, perhaps rendered more or less schistose by the later movements. The plutonic rocks may later be invaded by a few dikes. In this way, perhaps, we may explain the features of the Italian and Californian green-rocks, with pillow-lavas, peridotite and gabbro invaded by diabase or even locally by veins of granite, and on the other hand, the agglomerates and breccias with serpentines, etc., of Cretaceous age, which surround the Indian massif, though it must be recognized that in the case of those to the west of India, the descriptions and diagrams given by Vredenburg ('09) do not lend much support to such a suggestion. The difficulties in the problem of the origin of such associations of igneous rocks are so great, that the above-suggested explanation, which embodies some features of Steinmann's hypothesis, is put forward with much diffidence. Kober's ('21) remarks on the eruption of the green-rocks in the alpine orogenic regions during intermittent folding and over-thrusting in Mesozoic and early Tertiary times seems to be largely in accord with this suggestion. His terse phrase (p. 279) which contrasts these rocks from those considered below may be translated thus: "The orogenic vulcanism in the time of great mountain-building, leads to the formation of metamorphosed volcanic rocks, among which the green-rocks play an important rôle. All the rocks of this orogenic phase appear to be of Pacific types. In sharp contrast to these stand the rocks of the geosynclinal phase, the time of quiet sedimentation in the geosyncline. There the Atlantic magma appears." While this seems too sweeping in its assertion of sharp contrast, the fact that it is often difficult to draw the line between the two tectonico-petrographical groups, does not appear to the writer to render any less real the tendency of the rocks developed to vary systematically with the tectonic conditions in the direction indicated. From the very nature of the case, rocks of intermediate characters could be expected.

THE SPILITIC ROCK-SUITE.

The reality of this suite as a definite tectonico-petrographical group has been challenged by Daly ('14, p. 388). He points out the difficulty in drawing a clear distinction between the normal basalts and diabases in Germany, and those which show alkaline characters, which we have already indicated, and we might also refer to the apparent similarity in history of the strongly albitized rocks in the southwest of England and the much less frequently albitized rocks of Germany, though the latter are also included in the spilitic suite by Flett and Dewey ('11). In place of the explanation put forward by these authors, which is accepted by Harker ('17), who holds the spilitic suite to be a special division of the alkaline branch of igneous rocks, Daly adopts and extends Bowen's ('10) suggestion concerning the origin of albitic rocks. The albitization is not the result of the post-volcanic replacement of originally basic feldspar by juvenile solutions rich in soda, as is held by Flett and Dewey ('11) to have occurred in the same manner but on a much greater scale than the albitization studied by Bailey and Grabham ('09); it is, on the contrary, the result of the action of resurgent water. The rising magmas must pass through wet sediments, and the water contained therein enters the magma, and assists in the transfer of soda from the underlying normal basaltic magma to the upper portions which accordingly become albitized. "Water must play an important rôle in modifying the magma in the vents, and it seems impossible to doubt that occasionally the upper part of the magma-column, and also some of the extrusive lava will become albitized." "As usual, special emphasis is laid on the testimony of the sill," and Daly cites certain instances where the uppermost portions of dolerite-sills are enriched in soda, though the bulk of the rocks are of normal composition. It is not, however, shown that the instances quoted were formed under conditions comparable with those specified by Flett and Dewey; and the "testimony of the sill," when applied by the writer to a region in New South Wales, where the tectonic conditions of extrusion were exactly as specified for the development of spilitic rocks, fails to support Daly's contention. (See p. 38.) A great sill of dolerite about 1,500 feet thick is uniformly albitic from top to bottom. Moreover, the spilitic suite is not throughout of basaltic habit, as Daly infers ('14, p. 339), but the spilites are associated with other sodic rocks such as keratophyre, and in New South Wales as in Britain these form large independent masses which are composed predominately of albite, or acid oligoclase (with a little quartz, augite, and magnetite) and are comparable in size with the dolerite-intrusions themselves in some localities (Benson '18). There is clear evidence of strong pneumatolytic action in connection with these rocks, which has converted large amounts of the associated argillites into ferruginous jasper, and has affected the keratophyres themselves, but this injection occurred after the argillites had become compacted (with elimination of much of the contained water) and is usually found along lines of local fracture and small displacement (Benson '15, '15a; cf. the Victorian "spilitic" jaspers, p. 37). The unfavorable conditions for concentration of soda by resurgent water, the absence of evidence of such concentration in thick dolerite-sills, and the occurrence of large independent intrusions of highly sodic keratophyre supports the view that the immediate parent-magma, from which these New South Wales rocks were derived was an unusually sodic one. The writer ('18) is, indeed, of the opinion that some of the albite in the dolerites may be of primary origin, though dolerites of normal composition are occasionally present, but recognizes the abundant evidence of the post-volcanic activity of solutions in connection with the associated keratophyres. The New South Wales region may therefore be held to exemplify the conclusions of Flett and Dewey.

In those regions where the alkaline character of the rocks as a group is less clearly marked or a mixed series of types is present, it seems possible that the "typical alkaline rocks" may be extrusions from local magmas derived by a lengthy differentiation from the original magma (see Harker's ('17) adaptation of Bowen's researches), and are intercalated with those of less specialized magma-basins. Possibly as conditions of slow geosynclinal subsidence changed toward those of orogeny, new drafts of the primitive would be raised into activity near the surface, as a result of increased lateral pressure at depth, with the consequent development of a mixed or transitional assemblage of rocks, as in the case of the Upper Devonian and Lower Carboniferous igneous rocks in the Ural Mountains and in New South Wales. Bowen's work would point also to the probability that conditions favoring the retention or escape of the volatile constituents from the magma would exercise considerable effect in determining the apparent "alkalinity" of the rocks developed. Perhaps in some obscure difference in the course of regional differentiation of the subcrustal magmas in the Hercynian areas of southwestern Britain and Germany may be found the explanation of the somewhat less markedly alkaline character of the Devonian rocks of the latter region. Both series were erupted as extrusions and intrusions under a thin cover of sediments that were then being deposited in subsiding offshore regions. In both regions, also, this crust-sagging was the prelude to a great period of lateral compression and orogeny. Hence the igneous rocks and sediments are highly dislocated. In this they differ from the characteristic essexitic-theralitic rocks, with their picrites, which in the majority of cases show clearly that they were erupted during block-faulting of the crust, unaccompanied by strong lateral compression. The absence of such compression, perhaps even the tension in the one case and the steady downward sagging of the crust in the other, may be conditions so far analogous as to accord with the grouping of the spilitic suite as a special class of the alkaline rocks, as has been done by Harker. We may therefore look upon the picrites (paleopicrites) which sometimes form sills clearly comagmatic with rocks of the spilitic suite, as comprising a definite tectonico-petrographic group of ultrabasic intrusions.

THE ALKALINE PLATEAU-GROUP.

The picrites that accompany the essexitic-theralitic eruptive rocks are not distinguishable petrographically from those of the spilitic suite, and we have already indicated above the reason for considering that these two groups are closely allied in tectonic as well as petrographic features, but that, nevertheless, they are sufficiently different to form distinct subdivisions of the alkaline branch which are not, however, necessarily sharply separated. In the case of the rocks of this group, therefore, the conditions under which crystallization occurred have been an absence of effective lateral pressure associated with an unusual abundance of volatile constituents in the magma; so that here circumstances have been especially favorable for the development of gravitational differentiation, and the production of such complexes as the Shonkin Sag laccolite or the recently described Lugar sill in Ayrshire (Tyrrell '16). From such magma-chambers also, picritic lavas may be poured out. It is clear, however, that ultrabasic rocks developed in such an association have a very different significance from those which occur in the normal peridotite-gabbro-granite complexes. (Cf. Daly, '14, p. 451.)

THE ALKALINE-PERIDOTITE DIKES.

In considering the peculiar dikes of mica-peridotite in India, South Africa, and in the United States, we have recognized yet another group of ultrabasic intrusions of definite tectonico-petrographical characters, having been developed under much the same regional tectonic condition as the last-mentioned series, though forming not sills but dikes and rarely small stocks. In Arkansas these mica peridotites are probably coeval with the alkaline complex of Magnet Cove, and occur in the same tectonic province. We may consider them to be specialized members of the alkaline plateau group. Adding to the series we have mentioned above, the dikes of melilite-basalt in Tasmania, and the diamond-bearing "pipe" at Minas Gereas in Brazil, Du Toit ('20) points out that these all occur in the foreland-regions of great folded arcs, and suggests that they may be derived from the ultrabasic differentiate of dolerite-magma still remaining in the subcristal reservoir, into which it had been thrust out from the folding-zone in the manner described below.

THE DOLERITE-SILLS.

Du Toit ('20) shows that the dolerite-sills of the Karroo occur in the foreland of the great east-west belt of compression, part of which forms the southern margin of Africa. In this foreland subsidence had continued since Lower Devonian times up into the Rhaetic. He suggests that consequent on the sagging of the crust, or else causal thereto, a huge volume of subcrustal matter was bodily transferred outwards and upwards into the undisturbed regions beyond the zone of corrugation, penetrating the strata and leading to their upheaval. The injected magma in the foreland, and the effusions arising therefrom, represent a fraction only of that squeezed forward in advance of the folding. The order of intrusion from above downward is explained as the result of the strengthening of the crust by the early extrusions and intrusions of shallow depth, and the consequent necessity for the magma, rising later, to find a path of least resistance in the fissile sediments below these intrusions. On the assumption that a submerged zone of folding, possibly the continuation of that south of the Karroo, lies between Tasmania and Antarctica (an assumption made also by Kober '21 on other grounds). Du Toit would explain similarly the origin of the dolerite-sills in these two localities, and also applies the hypothesis to the explanation of the dolerite-sills of Brazil and New Jersey, and the development of the Jurassic Rajmahal basalts of India.

THE LACCOMORPHIC COMPLEXES.

These are most fully illustrated by the discussions of the Duluth, Sudbury, and Bushveld complexes. We may consider several hypotheses explanatory of the mode of differentiation of these. Coleman ('07), Daly ('14), and Bowen ('15) consider these are resulting from gravitative differentiation *in situ*, "with some movements during consolidation resulting in a certain amount of injection of one type into another. * * * In some localities more than one principal intrusion of basaltic magma took place, and therefore two or more interlocking gabbro-granite sequences may exist with resultant irregularities in the order of succession" (Bowen '15, p. 55). Grout ('18a) urges that there is not a regular sequence of differentiated types in these complexes, but that the acid upper portion is sharply distinct from the lower basic zone, which latter is often strongly banded. He suggests that the granite may have been separated gravitationally from the gabbro and become immiscible with it, due perhaps to the concentration of water within it, while the gabbro becomes banded, as a result of convection-currents. Bowen's ('19) alternative explanation has been given above (p. 54), and is based on the relative movements of solid and liquid in the crystallization of single originally uniform gabbroid magma, which by warping permits the accumulation of liquid residue in the planes of tension in a crystal-mesh, leading to the formation of a banded structure parallel to the floor of the intrusive mass, while a moderate amount of lateral compression when the rock is almost completely crystallized determines the separation of the upper layer of granitic material by the squeezing upward of the last residue of interstitial liquid from the crystal-mesh. This liquid can not apparently be more than 35 per cent of the whole magma, and is probably much less. "It is suggested that the various kinds of filter-press action (discussed) probably can not take place before the mass is 80 per cent crystalline."

We may now apply this conception to the case of the Bushveld complex. First it must be noted that though the thickness of the granite mass, and therefore its total bulk, can not be determined, its areal extent in proportion to that of the basic rocks is very much greater than in the case of the relation of the areas of acid and basic rocks in the Duluth region, though the compositions of the rocks are analogous. We must, however, note Bowen's remark ('19, p. 408) that there is no necessity for the constant relative proportion of their amounts. The basic lower portion of the complex is strongly banded, and yet over wide areas these bands, which are parallel to the floor of the complex, are so nearly horizontal that it seems rather heroic to attempt to explain their origin as the result of repeated warpings of the floor during the crystallization of the magma. Much more inadequate seems the hypothesis of convection-currents. Again after the acid portion had become completely solid, was exposed by erosion, and covered again by sediment, plutonic activity was resumed, and granite of the same nature as previously, rose through the earlier granite and invaded the new formed sediments. It is difficult to conceive it possible that this came from within the Bushveld complex; it must be considered to have come from below, where the old parent-magma remained at least potentially molten. We have already pointed out such long suspensions of activity in a single cycle of vulcanicity in Scotland (p. 12) and New South Wales (p. 38) and the long duration of the potential activity of a deep-seated magma is thus apparent. It may, therefore, be permissible to inquire whether the first granite could not also have come from these deeper levels after the basic rocks, and "slid in on top of its forerunner." Thus Brouwer ('17) thinks "we could explain the facts in a rather satisfactory way if we admitted effusion (of acid volcanic rocks) and several intrusions from a deeper-seated mother-magma." The question is not one that can be answered here from a review of the literature only, but it may be noted that the fact that the chilled margins at the base of the laccolite and the smaller associated sills are doleritic, accords with the view that the first magma to enter the laccolite chamber was normal basaltic magma" and that some differentiation occurred in *situ*. (See postscript, p. 78.)

THE CORDILLERAN COMPLEXES.

Laccomorphic complexes occur where there is no dominating lateral pressure, and gravity-control of the differentiation may appear more or less clearly, but as lateral pressure increases differentiation by deformation becomes the controlling factor in the way Dr. Harker and Dr. Bowen have described. Where the pressures were irregular "a wholly random spatial arrangement" of the several differentiates may be brought about, but where they are more uniform in direction the various rock-types in the complexes tend to become arranged in a definite manner, and largely to consist of separate intrusive masses. The basic and especially the ultrabasic rocks tend to form concordant sheet-like masses, the more acid, possibly as a result of the power of stoping possessed by their lighter magmas, making bosses with transgressive boundaries; but in cases of very great lateral pressure even these from more or less concordant intrusive masses. The possibility of differentiation of these *in situ*, of the limiting of the effects of such differentiation according to the size of the itrusive mass, and the formation of chilled basic marginal phases, have been discussed by Daly, Bowen, and others, and need not be considered here. Both with these and the laccomorphic complexes dikes of ultrabasic rocks may occur among the latest members of the retinue of subsequent minor intrusions.

THE ERUPTIBILITY OF PERIDOTITE.

Bowen ('15, p. 31) has indicated that in a magma from which olivine crystals were settling, the total composition of the basal portion might become lherzolitic while it still contained nearly 50 per cent of liquid, so that it would still be eruptible, but a pure olivine-magma (or a pure anorthosite-magma) could not be developed by differentiation from a normal basaltic magma (Bowen, '17, '19). He further states that the facts of serpentinization adduced by the present writer do not indicate the presence of such an *excessive* amount of water in the ultrabasic magmas as could warrant the assumption that a magma, which could crystalize completely as dunite, could be so fluxed, though the presence of some water does seem to be indicated, notably in the case of the peculiar veinlets of serpentine in the stubachite of Weinschenk (Benson, '18, p. 718). Hence Bowen ('20) considers that a sill or dike-like mass of dunite might result from crystallization from normal basaltic magma, where by subsequent movement the residual magma has been squeezed out, connoting the probable association of such ultrabasic masses with granitic differentiates in the widened portions of the same intrusive body. The question is best investigated in the Tertiary complexes, for in the older and more deeply eroded masses of igneous rocks the lighter differentates might have been completely removed. In Rum, minutely described by Dr. Harker ('08 p. 68) no evidence of fluxing by magmatic water can be recognized, but the gneissic structures present do seem to accord with those which might be expected in rocks crystalllized from magmas containing a large proportion of crystals at the time of their injection, though the presence of later and more acid differentiates of the primitive magma successively below this, seems to show clearly that the peridotite was not formed by differentiation *in situ* during deformation, but resulted from the completion of crystallization in a periodotitic magma injected as such into its present position, the first of the fractional magmas drawn off from the immediate parent reservoir below. Again in the case of New Caledonia, where there is an area of 2,600 square miles of peridotite, more or less serpentinized, and intrusive into Eocene rocks, Piroutet has shown that it forms massives of varying size, which send out numberless sills and apophyses. Card's ('00) description of a few specimens from this locality shows that they are composed of olivine and enstatite, though some dunite is present. The writer also has noticed that of a collection of serpentines from here the greater part were derived from harzbergite or lherzolite. Gabbro occurs in a few masses only, and rare scattered pebbles, derived doubtless from small inconspicuous intrusions, form almost all that is known of the more acid rocks. There can be no doubt that here great masses of peridotitic magma rose as such into the upper portions of the earth's crust, and its differentiation *in situ* was confined to the separation of the different types of peridotite and dunite from one another. It was not a mono-mineralic intrusion, but one doubtless explicable on the first of

Bowen's suggestions mentioned above. The presence of so huge a mass of peridotite injected as such into Tertiary rocks seems to show the possibility that such intrusions have been much more frequent than recent discussion of peridotite might suggest, and thus supports Dr. Harker's hypothesis of successive intrusions of decreasing basicity.

A WORKING HYPOTHESIS OF TECTONIC PETROLOGY.

This leads us to further speculation. It is manifest that no general petrogenic hypothesis can be well founded that is not supported by a study of the tectonic and other conditions accompanying the extrusion and intrusion of all types of igneous rocks, at least as complete as is here attempted for the ultrabasic and basic intrusive rocks only. The writer has not made so extensive a study, yet since the further discussion of the problem of the tectonic conditions accompanying the intrusion of basic and ultrabasic rocks can not be advanced without a general petrogenic application, we may here outline tentatively a working hypothesis for the purpose of grouping available facts into some significance. It will be obvious that most of the conceptions therein are due to others.

A very general conception is that of batholiths as essentially stratiform masses of magma rising from a potential magma-zone at great depth in a more or less oblique course, and aided in some degree by "overhead stoping" (Harker '09, Iddings '14). From these "cupolas" may arise and extend laterally into great laccolitic masses. While the magma in the stratiform reservoir or in the laccolite, if present, remains undisturbed, gravitational differentiation may perhaps produce a series of associated rocks, stratified according to density. We must recognize that such occur among plutonic masses now exposed, though Harker ('16) and Cross ('15) concur in believing indubitable examples to be comparatively rare and generally indicative of special conditions of fluidity. Where small movements have occurred during consolidation, the appearance of successive intrusion may be produced, as argued by Daly and Bowen. Where greater displacements of the differentiates occur, the conditions pass into those of the drafting-off of successive fractions from the primary and perhaps secondary derived reservoirs. Whether such successive intrusions are closely associated or not—that is, whether they rose along similar or diverse paths—depended on the varying tectonic conditions, and the extent to which crystallization had blocked the channel followed by the preceding magma. The earlier basic and especially ultrabasic intrusions in any epoch of vulcanicity accompanying orogeny were generally injected into the planes of structural weakness, and form stratiform intrusions, often with marked flow-structure, perhaps caused by their being in very large measure crystalline at the time of their injection. Some gravitational differentiation may occur in these, with, perhaps, further development of banded structure in the manner described by Bowen ('19), and the production of an upper layer in which liquid predominated, and a lower of more or less closely knit crystals. If, in the absence of marked lateral pressure, further intrusion occurred shortly after the first, the path of least resistance would naturally be found in the upper layer, and the new magma injected into this might mingle more or less intimately with the upper layer of the older intrusion. If, as so frequently appears to be the case, the successive drafts of magma ejected from the subcrustal reservoir were increasingly acid, the appearance of gravitational differentiation would thus be produced as the laccolite swelled, being filled out with a series of intrusions. But if a pause occurred between successive intrusions sufficient to permit the formation of a strong crystal-mesh or complete crystallization in the upper layer and the feeding-channel, the latter magma may be injected below the "solidified cake" of the former intrusion, may envelope it, or may break through it in batholithic fashion, perhaps with the local production of hybrid types. On the other hand, if the injection of the magma resulted from "a single principal act" and was so rapid that no noteworthy differentiation occurred during its progress, the differentiation of the originally almost homogeneous magma, and the apparent passage or injection of the several differentiates into one another, might follow on the lines laid down by Bowen. In places, more than one basic-to-acid series of plutonic rocks are thus developed sometimes with associated effusive rocks and minor intrusions. Where lateral pressure is pronounced, and the tectonic conditions tend toward the formation of a folded cordillera, the successive intrusions are more or less separated from one another, and the more basic, earlier intrusions are more closely concordant with the structure of the country than the later more acid series of intrusions, the *mise-en-place* of which may have been more largely determined by stoping. This is perhaps part of the explanation of the processes that make Suess's statement that "the green-rocks form sills in dislocated rocks, which sometimes followed the bedding plane and sometimes the plane of movement," so frequently an accurate expression of the facts. The later acidic intrusions are batholiths, with strongly transgressive boundaries when considered in detail, though their major axes, or distribution, generally will conform to the structure of the country. The later Paleozoic plutonic rocks of northeastern New South Wales (fig. 10, p. 54) form a striking illustration of this. Moreover the sill-like ultrabasic rocks occur in the outer portion of the folded range, while the granites invade the central portion, as Suess also notes in connection with those of the younger mountain ranges (IV, p. 561). Similarly also we may note that the ultrabasic rocks of the complex of the Harz Mountains (fig. 6), a region in which the folding was directed toward the northwest, lie to the northwest of the granite massif, and extend in a southwest to northeast direction for the most part, i. e., concordant with the axes of folding. In the Taurus mountains also (fig. 8a), the thrusting of the ultrabasic and basic magmas to the outer portion of the folded range is very marked.

The hypothesis thus outlined seems also to be compatible with the occasional intrusion of granitic masses *beneath* the basic rocks, as in the west of Scotland (figs. 3 and 4), and with the possible development of hybrid rocks between the gabbros and granites in the Bushveld, Duluth, and Sudbury complexes. It does not involve any extensive assimilation of invaded rock, nor deny the possibility of a minor amount of such solution. It does not involve the assumption of immiscibility of magmas, and thus accords with the evidence of experimental research. It recognizes the occurrence of masses differentiated *in situ*. It is, perhaps, not incompatible with the explanation suggested by Bowen for the Tagil complex (fig. 5), though here we must notice that the proportion of acid to basic rock is immensely greater than that suggested in the discussion of the Duluth mass, so far as the areas of exposure afford an indication of relative volume, and that a reservation may be made concerning the acceptance of the pyroxenite as a "huge reaction-rim" about the peridotite. It seems also to give the opportunity for horizontal differentiation in response to lateral thrust, which, in a very broad sense, is required by the Harker-Becke hypothesis of the development of characteristic petrographical provinces, a differentiation, the mechanism of which has been greatly elucidated by the work of Smyth ('13) and of Bowen ('15). This same mechanism, carried to an advanced stage, might produce the association of alkaline with subalkaline rocks in regions, where, in the absence of dominating lateral thrust, gravity exercised the greater influence on the course of differentiation in the deep-seated magma-reservoirs, and may therefore explain the mixed character of the succession of rocks erupted during the sagging of the crust which precedes orogeny.[4]

SUBALKALINE AND ALKALINE PETROGRAPHICAL PROVINCES.

This discussion brings us to the question of the reality or significance of the separation of petrographical provinces into two types characterized by different tectonic associations. It is unfortunate that some criticism of this hypothesis does not appear to consider the essential feature in it. Thus there have been cited (Cross '10, '15) as examples of associations of rocks believed to be adverse to the hypothesis, the Tertiary alkaline rocks of the Bohemian Mittelgebirge, and the adjacent Paleozoic (or pre-Paleozoic) gneisses and calcic granites and gabbros,

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[4] Following the usual custom, we have in the foregoing referred to the "overthrusting" of folded strata. Hobbs ('14) has, however, argued that such movement is essentially underthrusting in an opposite direction to the movement usually assumed. This is not opposed to the conception of the thrusting out of residual magma in the direction of assumed overthrust. If we note the frequency with which dynamic metamorphism decreases in this direction, it seems probable that, whatever may be the distribution of forces at great depths, the lateral pressure at the depths where the intrusive masses of magma differentiate is perhaps the upper member of the folding couple of forces, and does decrease in the direction of assumed overthrust, with the resulting distribution of the fractions of the differentiated magma. Hobbs's suggestion, indeed, gives the added possibility, which should be kept in mind, that magma situated at still greater depths may be differentiated by the "filter-pressing" out of the residual magma in a direction opposite to that of the assumed overthrust.

with their associated lamprophyres minette, kersantite, etc., in the Erzegebirge; the alkaline Tertiary (and Devonian ?) rocks of Germany, and the "calcic" lamprophyres of Carboniferous age; the alkaline rocks of the Great Rift Valley of British East Africa, and the underlying complex of ancient paragneisses, and calcic gabbro-granite series; but the vast difference in age of the members of each pair of adjacent rock-series is not noted, nor that in each of the six (or seven) cases the requirements of the tectonico-petrological hypothesis are exactly fulfilled. The Tertiary alkaline rocks in all three regions cited were emitted during the blockfaulting of plateaux (and the semialkaline Devonian igneous rocks of Germany were developed during slow continuous crust-subsidence unaccompanied by folding). The German lamprophyres are obviously connected with the gabbro-granite intrusions that accompanied the Variscan crust-folding, and whatever age may be eventually assigned to the plutonic rocks in the gneisses of the Erzegebirge and East Africa, it can scarcely be doubted that strong lateral pressure accompanied their intrusion. It must, however, be recognized that there are some regions where there is an indubitable association of rocks of calcic and alkaline affinities within the same petrographical province and epoch of vulcanicity (Daly's collection of facts are useful in this connection), and we may share Cross's objection to the attempt to separate into two *sharply distinct* branches the various types of igneous rocks. The objection seems to be met by the following remark: "The doctrine of two classes of igneous rocks, alkaline and calcic, having a significant geographical distribution in relation to the great tectonic features of the globe, does not, of course, imply any sharp divisions, and perhaps the more philosophical conception is that of two opposite petrographic poles, toward which igneous rocks tend as a result of primary differentiation. There is naturally some complication introduced by subsequent processes, giving rise to the great diversity of igneous rocks known to petrographers; and these later processes may sometimes obscure, as regards individual rock-types, the primary characteristics" (Harker '17, p. lxx). Such associations, he says ('11) are to be found among the later derived types [5] referrable to prolonged or repeated differentiation, and are to be expected especially where the initial magma is not very strongly characterized as either calcic or alkaline. It seems thus reasonable to explain such petrographically diversified regions as those in which the subcrustal lateral separation of magmas, or tectonico-petrologic specialization was incomplete, and such regions must inevitably occur if tectonic movements exercise any control on the course of magmatic differentiation; since the crust movements themselves do not in reality fall into two distinct and separate groups. This association of diverse rock-types may well be particularly marked in such a region as the central Pacific island groups (Cross '15) where crustal instability (as shown by the recent investigations of geologists and biologists), but with absence of marked lateral pressure, seems to have long been the dominant tectonic condition.

The results of the experimental work in the Geophysical Laboratory at Washington, D. C., accord with the view that in those "regions of the earth's crust where tangential extension is the dominant expression of the forces acting (Atlantic structures), the development of alkaline rocks might be a prominent feature, though the conditions requsite to their formation would undoubtedly occur locally elsewhere" (Bowen '20). It is not, however, intended to assert here that differentiation during deformation is the sole process that may be involved in the production of alkaline rocks.

CONCLUSION AND ACKNOWLEDGMENTS.

Thus we may believe that the evidence here collected tends to the conclusion that each of the several morphological types of basic and ultrabasic rocks is very generally associated with as definite a set of tectonic conditions, and often with as definite a group of less basic igneous rocks. This appears to emphasize the importance of crust-movements in determining, not only the *mise-en-place* and form of intrusive masses of igneous rocks, but also in actually controlling, in some degree, the processes of magmatic differentiation.

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[5] See Bowen's reference ('15, p. 60) to Bergeat's discussion of the leucitic lavas of the Aeolian Islas, and compare the same with the occurrence of leucitic lavas in Celebes (Wanner '19) and in Java. (Verbeek and Fennema '96.)

In conclusion, the author desires to acknowledge his indebtedness to many geologists of whom he would specially mention five. The broad significance of the problem discussed first was made clear to him by Suess's great work. The writings and personal encouragement of Prof. Daly have been most stimulating, and the significance of Bowen's invaluable experimental work and discussions will be obvious. To his teachers, Prof. Sir Edgeworth David, of Sydney, and later Doctor Harker, of Cambridge, the writer's indebtedness can not be fully measured, but he desires gratefully to acknowledge that whatever of value may be found in the present work owes its inspiration very largely to their influence and encouragement.

POSTSCRIPT.

The manuscript of this memoir was finished in November, 1919, and was accepted for publication twelve months later, some additions being made in the interval. Further material was incorporated in order to bring certain portions more up to date, when the proofs were being corrected in September, 1922, but there was not the opportunity of considering fully the bearing on the subject of Bowen's reaction-principle which had just been published. (Journ. Geol. 1922, pp. 176–198.) Similarly there can not now be utilized the results of the recent revision of the geological features of the Bushveld Complex, though they are of great importance in this connection. (See Daly, R. A., and Molengraaff, G. A. F., Journ. Geol., 1924, pp. 1–35, and Wagner, P. A., Memoir 21, Geol. Surv. Union of S. Africa, 1924. Another memoir in this series dealing with the whole complex is being prepared by A. L. Hall.) Briefly, the facts announced show that the great mass of basic and ultrabasic rocks was injected into the upper portion of the Pretoria series, and not between this and the Waterberg series. (See pp. 47–49 and 73 above.) It was intimately associated with intrusive masses of syenite and granophyre, and with felsites that seem to have broken through to the surface, and was gravitationally differentiated approximately in the manner explained by Bowen in various papers, though a special explanation of the origin of the banded structure in this mass is suggested by Wagner. The red granite is clearly younger than the basic rocks which it invades, though older than the Waterberg sediments which rest on its eroded surface. Subsequent faulting has caused portions of the granite to project into these sediments and such were formerly accepted as being definitely intrusive apophyses.

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NATIONAL ACADEMY OF SCIENCES.

Volume XIX.

SECOND MEMOIR.

PARALLAXES OF FIFTY-SEVEN STARS.

BY

MILDRED BOOTH AND FRANK SCHLESINGER.

PARALLAXES OF FIFTY-SEVEN STARS.[1]

By Mildred Booth and Frank Schlesinger.

The determination of these parallaxes was carried out through the cooperation of several institutions. The photographic plates were secured with the Thaw photographic refractor of the Allegheny Observatory. They were measured and reduced at Yale Observatory under a grant from the National Research Council (Division of Physical Sciences) to the committee on stellar parallaxes of the American Astronomical Society. The measuring machine is one that was purchased several years ago with a grant from the Draper fund of the National Academy of Sciences. The authors desire to record their acknowledgments to all these agencies, especially to the National Research Council, without whose aid a long interval would have elapsed before these results could have been made available.

The measuring machine is an excellent one of the long screw type, made by William Gaertner & Co. from specifications supplied by one of us. It was intended (and has been extensively used) to measure 7 by 8 inch plates, somewhat smaller than the 8 by 10 inch parallax plates. A modification in the plate-holding device sufficed to permit the measurement of the larger plates.

The measurements and computations were carried out by Miss Booth. The methods employed are described in detail in the Publications of the Allegheny Observatory, volume 3, pages 1 and following. Whenever possible four comparison stars were employed, otherwise three. The average number for the present series is 3.8. The average number of plates for each region is 15.

A great many of the stars on the present list are double; for this reason or for some other, almost every object is one of more than average difficulty, the stars having in fact been selected on that account from a long list awaiting attention at Allegheny. In view of these circumstances the average probable error for a parallax, ″.0084, is very satisfactory.

To preserve the continuity with the parallaxes previously determined from Allegheny plates, the numbers 470 to 526 have been assigned to the present list.

A summary of the results appears on page 6. The magnitudes and spectra are taken from the Draper Catalogue. For the faint stars in the latter part of the list these were kindly communicated by Prof. Bailey in advance of publication. The parallaxes in next to the last column are relative. To get the absolute values, we should add ″.003. This quantity was determined with a probable error of about one-tenth of its value from a discussion of the proper motions of several thousand comparison stars.

The table following the summary gives information regarding the comparison stars. The coordinates give the position of each one referred to the parallax star in its field as origin. Positive coordinates correspond to large right ascensions and large north polar distances, respectively. In the fourth, seventh, tenth, and thirteenth columns are the dependences used in the solutions. In the last column appears a constant applied to the solution to obviate the use of large numbers. In next to the last column is the mean photographic magnitude of the three or four comparison stars in each field. This was determined from the photographic magnitude of the parallax star, allowance being made for the opening of the sector used to reduce the magnitude of the parallax star to apparent equality with the mean of the comparison stars.

Yale University Observatory,
November, 1921.

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[1] Read at the November, 1921, meeting of the National Academy.

SUMMARY OF PARALLAXES.

No.	Name.	α(1900)		δ(1900)		Durchmusterung number.		Visual magnitude and spectrum.		Total proper motion.	Relative parallax and probable error.		Probable error for one good plate.
		h.	m.	°	′	°				″	″	″	″
470	Σ 16	0	11	+54	6	53	31	7.5	A3	0.17	+0.012	±0.009	±0.022
471	10 Arietis.	1	58	+25	27	25	341	5.7	F5	.14	+ .021	10	28
472	9 H. Camelopardis	3	49	+60	49	60	768	5.0	K0	.017	+ .010	10	28
473	55 Tauri	4	14	+16	17	16	579	6.9	G0	.10	+ .043	6	19
474	OΣ 82	4	17	+14	49	14	690	7.1	G0	.10	+ .028	7	21
475	Piazzi 256	5	48	+31	41	31	1139	5.8	A3	.20	+ .021	5	17
476	74 Orionis	6	11	+12	18	12	1084	5.1	F5	.21	+ .039	6	20
477	Groombridge 1214	6	37	+40	44	40	1696	6.9	Ma	.17	+ .005	7	22
478	θ Geminorum	6	46	+34	5	34	1481	3.6	A2	.05	+ .021	9	27
479	15 Lyncis	6	49	+58	33	58	982	4.5	G5	.13	+ .005	6	19
480	Lalande 15394	7	49	+19	31	19	1869	7.9	K2	.47	+ .031	8	26
481	7 Sextantis	9	47	+ 2	55	3	2280	5.9	A0	.20	+ .003	9	24
482	ζ Leonis	10	11	+23	55	24	2209	3.6	F0	.027	+ .006	7	18
483	γ¹ Leonis	10	14	+20	21			2.6		.34	+ .004	11	32
484	γ² Leonis	10	14	+20	21			3.8		.35	+ .018	14	40
	Mean					20	2467		K0		+ .009	9	
485	88 Leonis	11	27	+14	55	15	2345	6.2	G0	.38	+ .026	7	18
486	Lalande 21947	11	29	+37	22	37	2195	6.3	K0	.18	− .019	12	30
487	61 Ursae Majoris	11	36	+34	46	35	2270	5.5	G5	.39	+ .105	8	23
488	44 Boötis	15	0	+48	3			6.1			+ .053	9	26
489	44 Boötis	15	0	+48	3			5.3			+ .078	9	28
	Mean					48	2259		G0	.41	+ .065	6	
490	Ψ Serpentis	15	39	+ 2	50	2	2989	5.8	K0	.17	+ .013	8	20
491	Σ 2052	16	24	+18	37	18	3182	7.1	K3	.51	+ .050	8	25
492	μ Draconis	17	3	+54	36			5.8		.11	+ .029	13	30
493	μ Draconis	17	3	+54	36			5.8		.11	+ .050	13	30
	Mean					54	1857		F5		+ .039	9	
494	Lalande 34496	18	31	+34	20	34	3239	7.8	F8	.27	− .005	8	21
495	Weisse 1339	18	45	+31	25	34	3326	8.4	F5	.22	− .001	9	22
496	11 Aquilae	18	54	+13	29	13	3841	5.4	A0	.12	+ .031	9	22
497	Σ 2481 BC	19	8	+38	37			8.2			+ .003	6	20
498	Σ 2481 A	19	8	+38	37			8.2			− .010	8	24
	Mean					38	3466	7.5	G5	.27	− .002	5	
499	Piazzi 233	19	35	+49	3	48	2922	6.5	G0	.14	+ .003	6	16
500	ο Aquilae	19	46	+10	10	10	4073	5.2	F5	.28	+ .046	10	27
501	Piazzi 306	19	47	+11	23	11	4019	6.2	K0	.46	+ .021	10	25
502	OΣ 389	19	48	+30	53	30	3779	6.9	A5	.00:	+ .024	8	18
503	Weisse 1190	19	49	+ 1	41	1	4134	8.5	K0	.30	+ .018	11	29
504	Weisse 1196	19	49	+ 1	41	1	4135	8.8	K0	.29	+ .049	15	39
505	η Cygni	19	53	+34	49	34	3798	4.0	K0	.05	+ .007	5	14
506	27 Cygni	20	3	+35	42	35	3959	5.5	K0	.49	+ .022	6	17
507	Lalande 38613	20	5	+16	30	16	4166	7.7	K0	.17	+ .015	7	18
508	Groombridge 3150	20	17	+66	32	66	1281	6.1	G0	.56	+ .050	7	21
509	1 Delphini	20	26	+10	34	10	4303	5.9	A0	.020	− .005	11	31
510	κ Delphini	20	31	+ 9	44	9	4600	5.2	G2	.32	+ .014	9	24
511	γ¹ Delphini	20	42	+15	46			5.5		.20	+ .019	6	15
512	γ² Delphini	20	42	+15	46			4.5		.21	+ .021	5	13
	Mean					15	4255		G5		+ .020	4	
513	OΣ 447	21	36	+41	16	41	4224	8.1	K0		.000	8	20
514	OΣ 447	21	36	+41	16	41	4225	8.7	K0		− .002	5	12
	Mean									.00:	− .001	4	
515	OΣ (App.) 226	21	51	+67	38	67	1370	9.6	A		− .005	9	23
516	OΣ (App.) 226	21	51	+67	38	67	1372	7.6	K0		− .019	7	17
	Mean									.05	− .014	5	
517	Lalande 43751	22	19	+38	4	37	4560	6.2	G0	.29	− .013	6	15
518	Fedorenko 4220	22	34	+72	22	72	1050	7.5	F5	.10	+ .034	10	25
519	Fedorenko 4222	22	34	+72	21	72	1051	8.3	G	.09	+ .032	9	21
	Mean										+ .033	7	
520	OΣ 478	22	40	+38	56	38	4855	6.1	K4	.016	+ .003	6	18
521	σ Pegasi	22	47	+ 9	18	9	5122	5.3	F0	.52	+ .028	9	23
522	π Cephei	23	5	+74	51	74	1006	4.6	G5	.030	+ .003	8	25
523	70 Pegasi	23	24	+12	13	11	5009	4.7	K0	.06	− .011	9	26
524	72 Pegasi	23	29	+30	46	30	4978	5.2	K0	.06	+ .003	11	28
525	λ Piscium	23	37	+ 1	14	0	5037	4.6	A5	.20	+ .027	12	29
526	Anonymous	23	37	+ 1	7			10:		.19	+ .018	9	22

THE COMPARISON STARS.

No.	Star 1.			Star 2.			Star 3.			Star 4.			Mean Magn. *Photogr.*	
	X	Y	Dep.	X	Y	Dep.	X	Y	Dep.	X	Y	Dep.		
	mm.	*mm.*		*mm.*	*mm.*		*mm.*	*mm.*		*mm.*	*mm.*			*mm.*
470	− 41	+66	0.287	−34	−60	0.291	+25	−62	0.213	+77	+56	0.209	11.0	−0.0294
471	− 74	+42	.312	−12	+50	.137	+22	−12	.267	+67	−60	.284	11.5	+ .1083
472	− 50	+56	.460	+38	−58	.366	+53	−24	.174				9.5	− .1257
473	− 64	−19	.305	−14	+33	.240	+30	−32	.308	+95	+51	.147	12.5	+ .0843
474	− 69	+55	.183	−25	−47	.127	+11	+31	.384	+38	−54	.302	11.5	− .0707
475	− 64	+38	.249	−48	−61	.214	+32	+15	.262	+65	− 2	.275	11.0	+ .0160
476	− 58	−12	.262	−43	+40	.345	+53	−63	.127	+88	−11	.266	10.5	+ .1220
477	− 63	+20	.214	−30	+52	.163	+12	−69	.318	+47	+30	.305	11.0	− .2725
478	− 72	−30	.116	−46	+43	.255	+12	+27	.325	+53	−54	.304	10.4	+ .1627
479	− 95	− 5	.306	+14	+24	.265	+52	−56	.250	+68	+52	.179	11.0	− .1524
480	− 62	+26	.280	−61	−36	.278	+67	−21	.221	+88	+32	.221	10.5	+ .0151
481	− 57	−25	.344	+27	+ 2	.398	+34	+28	.258				10.3	+ .0737
482	− 93	−34	.156	−17	+29	.249	+19	−57	.280	+42	+45	.315	10.3	− .1312
483	−100	+32	.287	+28	+52	.259	+47	−50	.454				10.7	+ .0473
484	−100	+32	.287	+28	+52	.259	+47	−50	.454				10.7	− .1911
485	− 74	+31	.286	− 2	−79	.281	+20	+ 8	.242	+88	+60	.191	11.0	.0000
486	−111	−74	.228	+22	−21	.209	+31	+52	.354	+45	+13	.209	11.4	− .1536
487	− 93	−69	.231	+ 7	+59	.201	+16	+20	.253	+50	− 3	.315	12.8	− .0380
488	− 70	+37	.291	+20	−69	.308	+25	+59	.148	+43	+ 6	.253	11.4	+ .3551
489	− 70	+38	.291	+20	−69	.308	+24	+59	.148	+43	+ 7	.253	11.4	+ .1146
490	− 69	−48	.320	− 7	+12	.234	+32	0	.270	+85	+72	.176	11.4	− .0667
491	− 66	−27	.352	+21	+46	.198	+26	+42	.198	+55	−31	.250	11.5	− .1736
492	− 92	+53	.126	−56	−12	.369	+58	+79	.122	+66	−32	.383	11.8	+ .0638
493	− 93	+54	.126	−56	−12	.369	+57	+79	.122	+66	−32	.383	11.8	− .0576
494	− 45	−36	.274	−25	+28	.223	+30	+ 9	.245	+43	+ 5	.258	12.0	+ .1088
495	− 41	−34	.266	−24	+66	.252	+33	+38	.236	+39	−66	.246	11.3	+ .0516
496	− 64	+38	.295	−11	+53	.198	+30	−59	.298	+56	−19	.209	10.0	− .2335
497	− 67	− 8	.275	−35	+74	.250	+39	−63	.254	+78	− 1	.221	11.2	+ .1557
498	− 68	− 8	.275	−35	+74	.250	+39	−62	.254	+78	− 1	.221	11.2	− .0205
499	− 87	−13	.214	−33	−68	.304	+22	+65	.192	+84	+38	.290	11.0	+ .0322
500	− 50	−54	.295	−10	+66	.254	+26	−43	.238	+53	+44	.213	11.0	− .0516
501	− 86	+ 1	.297	+ 9	+78	.255	+49	−38	.224	+56	−52	.224	11.2	+ .1304
502	− 70	+27	.240	−63	+32	.268	+61	−48	.212	+74	−17	.280	10.0	− .0347
503	−101	−24	.333	+21	+36	.046	+53	+10	.621				10.8	+ .0357
504	−112	−24	.272	+10	+36	−.007	+42	+ 9	.735				10.8	+ .0235
505	− 69	+36	.267	− 6	−72	.267	+11	+29	.233	+75	+12	.233	10.0	− .1447
506	− 75	+33	.228	−22	−72	.227	− 1	+66	.276	+84	−35	.269	11.0	+ .1148
507	− 54	+34	.275	−44	−43	.271	+53	−14	.227	+66	+23	.227	11.2	+ .1651
508	− 95	+85	.319	+37	−60	.351	+41	+82	.055	+55	−38	.275	11.7	+ .0958
509	− 57	−64	.240	−27	+28	.242	−18	+80	.242	+89	−38	.276	10.5	+ .0420
510	− 99	+21	.127	−61	−69	.319	+42	+ 5	.269	+73	+62	.285	11.2	+ .0349
511	− 46	+67	.333	−31	−77	.305	+67	+ 3	.362				11.5	+ .4182
512	− 45	+67	.333	−30	−77	.305	+68	+ 3	.362				11.5	− .3152
513	− 52	+46	.338	−29	− 7	.214	−10	−73	.163	+90	− 8	.285	10.5	+ .0941
514	− 54	+47	.340	−30	− 6	.184	−11	−71	.184	+88	− 6	.292	10.5	− .1250
515	− 80	+12	.196	− 6	−81	.175	+13	+31	.354	+44	+ 3	.275	10.7	+ .0655
516	− 85	+14	.166	−10	−79	.183	+ 8	+33	.310	+39	+ 5	.341	10.7	.0000
517	− 47	+46	.210	−31	−34	.260	+29	+62	.239	+37	−54	.291	11.8	− .2330
518	−100	− 7	.216	−10	+63	.262	+41	−42	.234	+50	−19	.288	10.4	− .0562
519	−102	− 9	.188	−12	+61	.293	+39	−44	.233	+48	−21	.286	10.4	+ .3227
520	− 46	+64	.268	−21	−47	.391	+57	−30	.249	+70	+92	.092	9.7	.0000
521	− 47	−45	.258	− 4	−61	.241	+ 6	+89	.267	+49	+10	.234	11.3	+ .0227
522	− 66	−14	.264	−20	+51	.225	+32	−74	.273	+55	+53	.238	10.2	− .2357
523	− 77	−35	.273	−38	+ 2	.193	+53	+17	.534				11.5	− .1704
524	− 52	+ 7	.341	−37	−45	.258	+59	− 4	.164	+74	+42	.237	11.2	− .0154
525	− 71	+33	.342	+23	−57	.362	+53	+31	.296				11.5	− .3618
526	− 81	+ 5	.332	+12	−85	.040	+42	+ 3	.628				11.5	− .2146

(470)

Σ 16, $0^h\ 11^m$, $+54°\ 6'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
10102J	1917 Aug. 16	−13	+0.59	−359	0.9	+0.0014	−0.025	
10126J	17	−19	+ .58	−358	0.8	+ 38	+ 10	
11512C	Dec. 14	+10	− .89	−239	0.8	+ 23	+ 16	
11538J	15	− 4	− .89	−238	0.8	+ 20	+ 12	
11635J	22	+ 7	− .90	−231	0.7	+ 49	+ 55	
13878J	1918 Aug. 6	+ 4	+ .71	− 4	1.0	− 4	− 25	
13905J	12	+ 7	+ .65	+ 2	0.9	+ 8	− 6	
14828J	Nov. 26	+10	− .79	+108	0.8	+ 5	+ 15	
14861T	27	+10	− .80	+109	0.9	− 20	− 20	
14930J	Dec. 2	+ 9	− .83	+114	0.9	− 49	− 61	
17632J	1919 July 28	+ 7	+ .79	+342	0.6	− 13	− 12	Two exposures.
17695h	Aug. 2	+ 7	+ .75	+357	0.9	0	+ 7	
17763D	14	+ 7	+ .63	+369	0.8	+ 33	+ 58	

$$\begin{array}{llll} +10.80\,c-\ 0.46\,\mu-0.22\,\pi=+\ 0.0074\text{ mm.} & c=+0.0007\text{ mm.} \\ \quad +67.19\quad +4.84\quad =-\ \ .0311 & \mu=-\ .00052. \\ \qquad\qquad +6.19\quad =+\ \ .0024 & \pi=+\ .00082. \end{array}$$

Probable error for unit weight, ± .0015 mm. =±″.022.
Annual proper motion in R. A., − ″.028 ±″.010.
Relative parallax, **+ ″.012 ±″.009.**

No other determination of this parallax has been published.

The ninth magnitude companion, distant 5″.6, shares the proper motion.

(471)

10 Arietis, $1^h\ 58^m$, $+25°\ 27'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
10195J	1917 Aug. 19	+ 7	+0.86	−375	0.7	− 0.0046	−0.050	
10209s	20	+16	+ .85	−374	0.6	− 13	− 1	Two exposures.
10256J	25	+ 5	+ .81	−369	0.9	0	+ 16	
11621T	Dec. 20	+17	− .77	−252	0.8	0	+ 9	
11645J	22	0	− .79	−250	0.7	+ 47	+ 77	Two exposures.
11707J	31	+11	− .86	−241	0.7	− 10	− 9	
11721T	1918 Jan. 2	+ 5	− .87	−239	0.8	− 27	− 34	
14008T	Aug. 22	+12	+ .84	− 7	1.0	+ 105	+ 45	
14037T	29	+ 9	+ .75	0	0.8	+ 48	− 39	
15474T	1919 Jan. 20	+10	− .92	+144	1.0	+ 31	− 79	
15551T	26	+12	− .92	+150	0.8	+ 93	+ 10	Two exposures.
15591h	27	+21	− .92	+151	0.8	+ 125	+ 55	Two exposures.
18030J	Sept. 5	− 2	+ .71	+372	0.9	+ 154	− 10	
18053D	6	−12	+ .71	+373	1.0	+ 174	+ 18	

$$\begin{array}{llll} +11.50\,c-\ 4.69\,\mu-0.24\,\pi=+\ 0.0625\text{ mm.} & c=+0.0064\text{ mm.} \\ \quad +80.62\quad +0.65\quad =+\ \ .1604 & \mu=+\ .00235. \\ \qquad\qquad +7.90\quad =+\ \ .0114 & \pi=+\ .00144. \end{array}$$

Probable error for unit weight, ± .0019 mm.=±″.028.
Annual proper motion in R. A., + ″.125 ±″.012.
Relative parallax, **+ ″.021±″.010.**

No other determination of this parallax has been published. Boss gives +0″.140 for the proper motion.

There is a companion two magnitudes fainter with which this star forms Σ 208. The two are now very close. The orbital period must be long.

(472)

9 Camelopardis, $3^h\ 49^m$, $+60°\ 49'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
190J	1914 Sept. 30	− 3	+0.77	−481	0.8	0.0000	−0.022	Two exposures.
256H	Oct. 7	−35	+ .69	−474	0.9	+ 30	+ 22	Four exposures.
1047b	1915 Jan. 8	+ 6	− .72	−381	0.6	− 33	− 50	Two exposures.
1063J	9	− 5	− .73	−380	1.0	0	− 1	Four exposures.
1145b	Feb. 4	−13	− .93	−354	0.4	+ 60	+ 89	One exposure.
3171T	Sept. 10	− 2	+ .93	−136	0.9	− 13	− 20	
3214H	12	−18	+ .92	−134	0.8	− 6	− 10	Two exposures.
3456D	Oct. 3	+ 5	+ .75	−113	0.5	+ 10	+ 16	Two exposures.
8678J	1917 Feb. 10	+13	− .95	+383	0.9	− 54	− 28	
8709J	14	+21	− .96	+387	0.9	+ 16	+ 73	
10622T	Sept. 25	+10	+ .82	+610	0.6	− 23	+ 13	
10693T	Oct. 1	+12	+ .76	+616	0.8	− 28	+ 7	
11880T	1918 Jan. 20	+15	− .83	+727	1.0	− 106	− 83	
11965J	Feb. 2	+11	− .92	+740	0.8	− 26	+ 35	
14232J	Sept. 27	+ 6	+ .80	+977	0.4	+ 3	+ 74	One exposure.
14249h	28	+24	+ .79	+978	0.5	− 69	− 29	Two exposures.

$+11.80\,c + 19.03\,\mu + 0.20\,\pi = -\ 0.0212$ mm. $\quad c = -0.0011$ mm.
$+332.70 \quad -7.07 \quad = -\ .1724 \quad \mu = -\ .00044.$
$+8.29 \quad = +\ .0086 \quad \pi = +\ .00069.$

Probable error for unit weight, ± .0019 mm. = ±″.028.
Annual proper motion in R. A., − ″.023 ±″.006.
Relative parallax, **+ ″.010±″.010.**

The spectroscopic determination of this parallax at Mount Wilson yields +0″.010. Boss gives +0″.003 for the proper motion.

There is an eighth magnitude companion at a distance of 2″ with which this star forms OΣ 67. The two have a common proper motion.

(473)

55 Tauri, $4^h\ 14^m$, $+16°\ 17'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
1170J	1915 Feb. 10	−11	−0.93	−579	0.8	−0.0121	+0.045	
1182J	16	0	− .96	−573	1.0	− 160	− 12	
1188H	17	+ 5	− .96	−572	0.8	− 164	− 18	
3296J	Sept. 15	+ 2	+ .95	−362	1.0	− 64	− 18	
3306H	16	− 5	+ .94	−361	0.9	− 93	− 60	
3425T	Oct. 2	+ 5	+ .82	−345	1.0	− 36	+ 23	
3458D	3	+ 7	+ .81	−344	0.9	− 51	+ 1	
6856J	1916 Sept. 11	− 2	+ .96	0	0.6	+ 53	+ 42	
6964h	20	− 5	+ .92	+ 9	0.9	+ 47	+ 32	
6971J	21	− 7	+ .91	+ 10	1.0	+ 27	+ 3	
8573T	1917 Jan. 23	+ 9	− .82	+134	1.0	0	+ 1	
8608H	28	+10	− .88	+139	0.7	− 10	− 13	
14190J	1918 Sept. 21	+ 3	+ .91	+740	0.9	+ 169	− 13	
15676h	1919 Jan. 31	− 3	− .88	+872	0.9	+ 164	+ 18	
15749h	Feb. 5	0	− .91	+877	0.6	+ 131	− 31	Two exposures.

$+13.00\,c - 6.10\,\mu + 1.24\,\pi = -\ 0.0145$ mm. $\quad c = -0.0004$ mm.
$+300.26 \quad -\ 5.06 \quad = +\ .6151 \quad \mu = +\ .00209.$
$+10.62 \quad = +\ .0200 \quad \pi = +\ .00293.$

Probable error for unit weight, ± .0013 mm. = ±″.019.
Annual proper motion in R. A., + ″.111 ±″.004.
Relative parallax, **+ ″.043±″.006.**

The spectroscopic determination of this parallax at Mount Wilson is +0″.023.

There is a companion two magnitudes fainter with which this star forms OΣ 79. The two are in moderately rapid orbital motion.

Plate 10493, taken 1917, September 17, was rejected for discordance. The residual was −0″.15, weight 0.7.

(474)

OΣ 82, $4^h\ 17^m$, +14° 49′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
1270J	1915 Feb. 20	+10	−0.97	−728	0.7	−0.0185	+0.018	
3370J	Sept. 24	+ 5	+ .90	−512	0.8	− 137	− 25	
3484T	Oct. 6	+11	+ .79	−500	0.7	− 126	− 9	
6973J	1916 Sept. 21	+ 5	+ .91	−149	0.9	− 73	− 34	
8711J	1917 Feb. 14	+ 8	− .95	− 3	0.9	− 40	+ 25	
8731T	15	+ 9	− .96	− 2	1.0	− 48	+ 10	
10458T	Sept. 16	+15	+ .94	+211	0.9	0	− 31	
10605J	24	− 7	+ .89	+219	0.7	+ 58	+ 54	
10625T	25	+10	+ .89	+220	0.9	+ 34	+ 18	
12016J	1918 Feb. 11	+12	− .95	+359	0.9	+ 40	+ 38	
15567T	1919 Jan. 26	+ 7	− .83	+708	1.0	+ 50	− 48	
15614h	28	+ 5	− .85	+710	0.7	+ 55	− 42	Two exposures.
15633h	30	− 9	− .87	+712	0.9	+ 85	+ 3	
15677h	31	− 3	− .88	+713	0.9	+ 74	− 13	
18265D	Sept. 25	+ 3	+ .89	+950	0.7	+ 202	+ 57	

$+12.60\,c + 26.08\,\mu - 1.38\,\pi = +0.0002$ mm. $c = -0.0038$ mm.

$+340.95 \quad -16.24 \quad = + \ .5319$ $\mu = + .00194.$

$+10.24 \quad = - \ .0067$ $\pi = + .00191.$

Probable error for unit weight, ± .0015 mm.=±″.021.

Annual proper motion in R. A., + ″.103 ±″.005.

Relative parallax, **+ ″.028±″.007.**

The spectroscopic determination of this parallax at Mount Wilson yields +0″.024. The companion is two magnitudes fainter. Comparatively rapid orbital motion is present.

(475)

Piazzi 256, $5^h\ 48^m$, +31° 41′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
3728J	1915 Oct. 21	− 3	+0.86	−716	0.6	+0.0080	+0.013	
3920H	Nov. 1	+ 7	+ .74	−705	0.8	+ 64	− 6	
7375J	1916 Oct. 14	+ 2	+ .91	−357	0.8	+ 57	+ 23	
8829J	1917 Feb. 28	+ 7	− .94	−220	1.0	0	− 3	
8861h	Mar. 6	+ 5	− .97	−214	1.0	− 6	− 12	
10724J	Oct. 2	− 3	+ .97	− 4	0.6	− 10	− 32	
10747G	6	−12	+ .95	0	0.8	+ 22	+ 15	
12091J	1918 Feb. 17	0	− .86	+134	0.9	0	+ 39	
12121K	21	− 4	− .89	+138	0.6	− 40	− 19	
14298h	Oct. 3	− 5	+ .97	+362	0.9	− 29	− 16	
14391T	14	+10	+ .91	+373	0.9	− 51	− 45	
15805J	1919 Feb. 6	+ 8	− .75	+488	0.8	− 31	+ 35	
15834T	10	+ 6	− .79	+492	0.8	− 66	− 16	
15869T	19	0	− .87	+501	0.8	− 37	+ 29	
16086h	Mar. 9	+10	− .98	+517	1.0	− 88	− 41	
18437D	Oct. 3	+ 8	+ .97	+727	1.0	− 33	+ 25	
18608J	21	+10	+ .86	+745	0.9	− 43	+ 13	

$+14.20\,c + 22.50\,\mu + 0.49\,\pi = -0.0214$ mm. $c = -0.0002$ mm.

$+305.35 \quad -3.67 \quad = - \ .2673$ $\mu = - .00084.$

$+11.49 \quad = + \ .0198$ $\pi = + .00146.$

Probable error for unit weight, ± .0012 mm.=±″.017.

Annual proper motion in R. A., − ″.045 ±″.004.

Relative parallax, **+ ″.021±″.005.**

No other determination of this parallax has been published. Porter gives −0″.051 for the proper motion.

(476)

74 Orionis, $6^h\ 11^m$, $+12°\ 18'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
1513S	1915 Mar. 14	+12	−0.98	−937	0.7	−0.0159	−0.020	
3704H	Oct. 20	0	+ .90	−717	0.9	− 44	+ 29	
10749C	1917 Oct. 6	− 4	+ .98	0	0.8	0	− 54	
12137T	1918 Feb. 22	+ 9	− .86	+139	0.9	+ 19	+ 16	
12156J	23	+ 8	− .87	+140	0.7	0	− 13	
12174J	26	+ 8	− .88	+143	1.0	+ 15	+ 10	
14436J	Oct. 16	+ 3	+ .93	+375	1.0	+ 74	− 22	
14463T	20	+11	+ .90	+379	0.8	+ 111	+ 32	
14520T	26	+10	+ .86	+385	0.9	+ 100	+ 18	
15910J	1919 Feb. 24	− 4	− .87	+506	1.0	+ 36	− 35	
15932J	26	+11	− .89	+508	0.8	+ 88	+ 42	
15997h	Mar. 1	+13	− .92	+511	0.9	+ 59	0	
18439D	Oct. 3	0	+ .99	+727	0.9	+ 166	+ 38	
18621D	22	− 2	+ .89	+746	0.9	+ 116	− 35	
18689J	Nov. 3	+ 6	+ .79	+757	0.6	+ 130	− 12	

$+12.80\,c + 32.40\,\mu + 0.81\,\pi = +0.0624$ mm. $c = +0.0012$ mm.
$+353.44 \quad +10.43 \quad = +.5591$ $\mu = +.00140.$
$+10.41 \quad = +.0432$ $\pi = +.00266.$
Probable error for unit weight, ± .0014 mm. = ±″.020.
Annual proper motion in R. A., + ″.074 ±″.005.
Relative parallax, + **″.039±″.006.**

The spectroscopic determination of this parallax at Mount Wilson yields +0″.046. Boss gives +0″.091 for the proper motion.

(477)

Groombridge 1214, $6^h\ 37^m$, $+40°\ 44'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
8834J	1917 Feb. 28	− 4	−0.86	−595	0.9	+0.0040	+0.029	
11029J	Nov. 4	−12	+ .82	−346	0.9	− 17	− 45	
11128J	7	− 5	+ .79	−343	0.7	+ 48	+ 48	
11202J	9	− 6	+ .77	−341	1.0	0	− 20	
12140T	1918 Feb. 22	+11	− .80	−236	0.9	0	− 6	
12177J	26	0	− .83	−232	1.0	− 29	− 48	
12218T	Mar. 3	0	− .88	−227	0.9	+ 23	+ 28	
14440J	Oct. 16	+ 6	+ .96	0	1.0	− 14	− 19	
14497T	23	+ 3	+ .93	+ 7	0.6	+ 46	+ 67	
14523T	26	+ 6	+ .90	+ 10	0.7	0	+ 1	
15913J	1919 Feb. 24	+ 9	− .82	+131	0.9	+ 6	+ 28	
15935J	26	+ 2	− .83	+133	0.8	+ 9	+ 31	
16041T	Mar. 3	+ 8	− .88	+138	0.8	− 13	0	
16079J	6	+ 4	− .90	+141	0.9	− 10	+ 4	
16124h	11	−15	− .94	+146	0.9	− 50	− 54	
18543D	Oct. 17	+ 3	+ .96	+366	1.0	− 15	+ 3	
18628J	23	0	+ .93	+372	1.0	− 19	− 1	

$+14.90\,c - 7.35\,\mu - 0.77\,\pi = -0.0025$ mm. $c = -0.0004$ mm.
$+112.95 \quad + 4.84 \quad = -.0461$ $\mu = -.00045.$
$+11.36 \quad = +.0020$ $\pi = +.00034.$
Probable error for unit weight, ± .0015 mm. = ±″.022.
Annual proper motion in R. A., − ″.024 ±″.008.
Relative parallax, + **″.005±″.007.**

Other determination of this parallax are: Jost, −0″.011±0″.026; Mount Wilson (spectroscopic), +0″.005. Porter gives −0″.017 for the proper motion.

(478)

θ Geminorum, 6ʰ 46ᵐ, +34° 5′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
1373H	1915 Mar. 1	−16	−0. 85	−736	0. 9	−0. 0033	0. 000	
1432H	9	+ 6	− . 92	−728	0. 9	− 36	− 4	
4174T	Nov. 17	0	+ . 71	−475	0. 7	0	+ 12	
4798T	1916 Mar. 3	+ 3	− . 87	−368	0. 8	− 13	+ 20	
8867h	1917 Mar. 6	− 4	− . 89	0	0. 9	− 41	− 23	
10822T	Oct. 13	+14	+ . 98	+221	0. 8	+ 45	+ 57	
10915s	27	+ 3	+ . 90	+235	0. 8	+ 7	+ 4	
11203J	Nov. 9	− 9	+ . 79	+248	1. 0	− 64	− 98	
12220T	1918 Mar. 3	+ 5	− . 86	+362	1. 0	0	+ 29	
14397T	Oct. 14	− 3	+ . 97	+587	0. 7	+ 39	+ 42	
14415h	15	+ 8	+ . 97	+588	0. 7	+ 34	+ 36	
14441J	16	+ 4	+ . 97	+589	1. 0	− 8	− 26	
15878T	1919 Feb. 19	+12	− . 75	+715	0. 8	− 12	+ 3	
16042T	Mar. 3	+10	− . 86	+727	0. 9	− 24	− 15	

$+11.90\,c + 16.70\,\mu - 0.20\,\pi = -0.0120$ mm. $c = -0.0012$ mm.

$+322.07 \quad +17.92 \quad = +.0446$ $\quad \mu = +.00012.$

$+9.23 \quad = +.0154$ $\quad \pi = +.00142.$

Probable error for unit weight, ± .0018 mm.=±″.027.
Annual proper motion in R. A., + ″.006 ±″.006.
Relative parallax, + **″.021±″.009.**

No other determination of this parallax has been published. Boss gives +0″.007 for the proper motion.

(479)

15 Lyncis, 6ʰ 49ᵐ, +58° 33′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
1617H	1915 Mar. 27	+22	−0. 99	−723	0. 7	−0. 0004	+0. 016	
1643D	30	+35	− . 99	−720	0. 6	− 35	− 28	Two exposures.
3926T	Nov. 1	+ 7	+ . 88	−504	0. 8	− 5	+ 1	
4815J	1916 Mar. 4	+ 2	− . 87	−380	0. 9	0	+ 16	
8904J	1917 Mar. 19	+ 4	− . 96	0	1. 0	− 44	− 53	
8927T	22	+16	− . 98	+ 3	1. 0	− 7	+ 3	
11130J	Nov. 7	+ 3	+ . 82	+233	0. 7	− 6	− 10	
11257T	10	− 6	+ . 79	+236	1. 0	+ 24	+ 35	
11282C	11	+ 3	+ . 78	+237	0. 6	− 12	− 19	Two exposures.
11335T	13	+ 7	+ . 75	+239	0. 8	+ 6	+ 9	
12281C	1918 Mar. 8	+ 5	− . 90	+354	0. 8	− 2	+ 3	Two exposures.
12324J	15	0	− . 95	+361	0. 8	+ 44	+ 73	
14539h	Oct. 27	+ 9	+ . 91	+587	0. 9	− 13	− 25	
14655J	Nov. 6	− 4	+ . 83	+597	1. 0	+ 7	+ 6	
14682T	7	+11	+ . 82	+598	0. 8	0	− 6	
15915J	1919 Feb. 24	+11	− . 79	+707	0. 9	− 14	− 18	

$+13.30\,c + 18.63\,\mu - 0.75\,\pi = -0.0046$ mm. $c = -0.0005$ mm.

$+278.92 \quad +17.79 \quad = +.0235$ $\quad \mu = +.00009.$

$+10.26 \quad = +.0058$ $\quad \pi = +.00037.$

Probable error for unit weight, ± .0013 mm.=±″.019.
Annual proper motion in R. A., + ″.005 ±″.005.
Relative parallax, + **″.005±″.006.**

Other determinations of this parallax are: At Swarthmore, +0″.023±0″.011; at Mount Wilson (spectroscopic), +0″.011.

This is a binary star, OΣ 159, the components of which differ by 1.1 magnitude and are now about 0″.8 apart. The above measures refer to the combined image. Boss gives +0″.006 for the proper motion in right ascension of the middle point between the two components.

(480) Lalande 15394, $7^h\ 49^m$, $+19°\ 31'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
9048h	1917 Apr. 3	+12	−0.97	−581	0.9	−0.0075	−0.016	
11264T	Nov. 10	− 3	+ .90	−360	1.0	+ 61	+ 63	
11342T	13	+15	+ .87	−357	0.9	+ 45	+ 41	
11427T	21	− 5	+ .80	−349	0.9	0	− 25	
12363T	1918 Mar. 16	+18	− .85	−234	1.0	0	− 4	
12500J	25	0	− .91	−225	0.9	− 34	− 57	
14636h	Nov. 5	− 2	+ .93	0	0.5	+ 89	+ 6	Two exposures.
14697J	9	+ 2	+ .91	+ 4	0.9	+ 44	− 60	
14747T	13	+11	+ .87	+ 8	0.8	+ 66	− 28	
16173T	1919 Mar. 12	+14	− .81	+127	0.6	+ 97	+ 36	
16252h	22	− 7	− .89	+137	0.9	+ 56	− 23	
16315T	24	+15	− .90	+139	1.2	+ 112	+ 57	
16384J	29	− 2	− .94	+144	0.9	+ 76	+ 6	
18783J	Nov. 8	+ 4	+ .91	+368	0.9	+ 158	+ 7	
18865J	13	+ 9	+ .87	+373	0.9	+ 145	− 13	

$$\begin{array}{rrrl@{\qquad}l} +13.20\,c- & 7.81\,\mu+ & 0.22\,\pi= & +\ 0.0721\text{ mm.} & c=+0.0065\text{ mm.} \\ & +107.35 & +\ 1.95\ = & +\ .1542 & \mu=+\ .00187. \\ & & +10.48\ = & +\ .0273 & \pi=+\ .00212. \end{array}$$

Probable error for unit weight, ± .0018 mm.=±″.026.
Annual proper motion in R. A., + ″.100 ±″.010.
Relative parallax, + **″.031±″.008.**

Other determinations of this parallax: At Mount Wilson (spectroscopic), +0″.052; at Dearborn Observatory, +0″.069±0″.010. Porter gives +0″.110 for the proper motion.

(481) 7 Sextantis, $9^h\ 47^m$, $+2°\ 55'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
1786H	1915 Apr. 13	+ 2	−0.81	−371	0.9	+0.0276	+0.034	
1814J	14	+23	− .82	−370	0.9	+ 227	− 35	
4129T	Nov. 15	− 9	+ .93	−155	0.4	+ 175	− 20	Two exposures.
4258D	27	+ 5	+ .91	−143	0.5	+ 220	+ 53	
4394J	1916 Jan. 3	+12	+ .62	−106	0.8	+ 149	− 34	
5137D	Apr. 17	+ 6	− .84	− 1	0.7	+ 143	+ 12	
5164J	18	+ 8	− .85	0	0.6	+ 176	+ 58	
8177J	Dec. 5	+11	+ .88	+231	0.6	+ 31	− 51	
8215H	6	+ 7	+ .87	+232	0.9	+ 65	− 3	
9170J	1917 Apr. 15	+ 8	− .83	+362	0.7	0	− 31	
11660T	Dec. 22	+12	+ .75	+613	0.7	− 51	+ 3	
11730T	1918 Jan. 2	−13	+ .63	+624	0.5	0	+ 86	
12697K	Apr. 13	+12	− .82	+725	1.0	− 117	− 36	
12723T	14	+ 9	− .82	+726	0.8	− 80	+ 20	Two exposures.

$$\begin{array}{rrrl@{\qquad}l} +10.00\,c+ & 17.61\,\mu- & 1.15\,\pi= & +\ 0.0817\text{ mm.} & c=+0.0138\text{ mm.} \\ & +185.33 & -0.89\ = & -\ .3422 & \mu=-\ .00315. \\ & & +6.63\ = & -\ .0115 & \pi=+\ .00023. \end{array}$$

Probable error for unit weight, ± .0017 mm.=±″.024.
Annual proper motion in R. A., − ″.168 ±″.007.
Relative parallax, + **″.003±″.009.**

At the Yerkes Observatory this parallax was measured as +0″.057±0″.008. Boss gives −0″.180 for the proper motion.

(482)

ζ Leonis, $10^h\ 11^m$, +23° 55′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
1815J	1915 Apr. 14	+ 9	−0.75	−598	0.8	−0.0068	−0.045	
1836D	15	+18	− .76	−597	1.0	0	+ 54	
1852J	17	+ 1	− .77	−595	0.9	− 47	− 16	
4452J	1916 Jan. 7	+ 3	+ .64	−330	0.5	− 6	+ 1	
4523J	17	− 9	+ .52	−320	0.5	− 14	− 12	
5134H	Apr. 15	+ 3	− .77	−231	1.0	− 13	− 16	
5248T	30	0	− .88	−216	1.0	+ 24	+ 36	
8152H	Dec. 2	+ 3	+ .91	0	0.8	+ 19	− 9	
8178J	5	− 4	+ .90	+ 3	0.8	+ 62	+ 54	
8217H	6	− 3	+ .89	+ 4	1.0	0	− 36	
9210T	1917 Apr. 20	− 3	− .81	+139	0.9	+ 41	+ 13	
9224J	22	+ 9	− .82	+141	0.9	− 7	− 57	
11691C	Dec. 26	+ 8	+ .76	+389	0.8	+ 70	+ 13	
12764T	1918 Apr. 19	+ 2	− .80	+503	0.9	+ 52	− 20	
12770J	23	0	− .83	+507	0.9	+ 89	+ 34	

+12.70 c− 9.05 μ−3.11 π=+ 0.0184 mm. c=+0.0022 mm.
+178.22 +7.01 =+ .1488 μ=+ .00093.
+8.22 =+ .0028 π=+ .00038.
Probable error for unit weight, ± .0016 mm.=±″.024.
Annual proper motion in R. A., + ″.050 ±″.007.
Relative parallax, + **″.006±″.009.**

Other determinations of this parallax are: Mount Wilson (spectroscopic), +0″.018; McCormick, +0″.005±0″.007. Boss gives +0″.024 for the proper motion.

This star is 5′ from 35 Leonis; the proper motions of the two stars indicate that there is no physical connection between them.

(483) and (484)

γ Leonis, $10^h\ 14^m$, +20° 21′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Brighter component.			Fainter component.		
					Wt.	Solution.	Resid.	Wt.	Solution.	Resid.
		min.				*mm.*	″		*mm.*	″
1790H	1915 Apr. 13	+ 7	−0.73	−599	0.7	−0.0481	−0.013	0.5	−0.0438	+0.053
1816J	14	+15	− .74	−598	1.0	− 407	+ 95	0.7	− 492	− 29
1853J	17	+ 7	− .77	−595	0.9	− 445	+ 35	0.6	− 403	+ 101
4291T	Dec. 2	+ 6	+ .91	−366	0.7	− 324	− 15	0.5	− 380	− 121
5167J	1916 Apr. 18	+ 4	− .79	−228	0.9	− 261	− 50	0.6	− 223	+ 7
5214J	28	+ 5	− .87	−218	0.8	− 237	− 23	0.6	− 259	− 55
8154H	Dec. 2	+11	+ .91	0	1.0	− 130	− 85	0.7	− 77	− 34
8218H	6	0	+ .89	+ 4	0.9	− 73	− 7	0.6	− 10	+ 61
8355J	25	− 5	+ .77	+ 23	0.7	− 66	− 12	0.5	0	+ 60
9225J	1917 Apr. 22	+11	− .82	+141	1.0	0	− 23	0.7	− 34	− 77
12771J	1918 Apr. 23	+ 3	− .82	+507	0.9	+ 255	− 4	0.6	+ 279	+ 25
14925T	Dec. 1	+16	+ .92	+729	0.9	+ 449	+ 57	0.6	+ 408	− 36
15010T	16	+18	+ .85	+744	0.8	+ 429	+ 16	0.6	+ 483	+ 61
15116J	18	+ 4	+ .83	+746	1.0	+ 447	+ 41	0.7	+ 442	− 1
16589h	1919 Apr. 21	+ 7	− .81	+870	0.8	+ 475	− 32	0.6	+ 501	− 3

BRIGHTER COMPONENT.

+13.00 c+ 11.22 μ− 0.33 π=− 0.0234 mm. c=−0.0075 mm.
+344.02 +19.33 =+ 2.1904 μ=+ .00660.
+ 9.00 =+ .1325 π=+ .00028.
Probable error for unit weight, ± .0022 mm.=±″.032.
Annual proper motion in R. A., + ″.352±″.007.
Relative parallax, + ″.004±″.011.

FAINTER COMPONENT.

$$\begin{array}{rrrrrl}
+9.10\,c+ & 8.17\,\mu- & 0.23\,\pi= & -\ 0.0056\text{ mm.} & & c=-0.0066\text{ mm.}\\
 & +243.18 & +13.31 & =+\ 1.5829 & & \mu=+\ .00666.\\
 & & +\ 6.26 & =+\ \ .0981 & & \pi=+\ .01280.
\end{array}$$

Probable error for unit weight, ± .0023 mm.=±″.034.
Annual proper motion in R. A., + ″.355±″.009.
Relative parallax, + ″.019±″.014.

The fainter component is hardly good enough to measure on these plates, the sector having been adjusted for the brighter. The mean by weight is **+0″.009±0″.009.** Other determinations, for the brighter: Mount Wilson (spectroscopic), +0″.044; Yale (heliometer), −0″.046±0″.030. For the fainter: Mount Wilson (spectroscopic), +0″.016. Boss gives +0″.305 and +0″.305 for the proper motions. Very slow orbital motion is present.

This pair is only 6′ from Weisse 10^h 234, a faint star with large proper motion. That there is no physical connection with γ Leonis is shown by the parallaxes, that of Weisse 10^h 234 being nearly 0″.2.

(485)

88 Leonis, $11^h\ 27^m$, +14° 55′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
2043D	1915 May 15	+ 7	−0. 83	−362	1. 0	+0. 0222	+0. 041	
4400J	1916 Jan. 3	+ 6	+ . 84	−129	0. 9	+ 92	0	
4566T	22	+ 6	+ . 69	−110	0. 9	+ 44	− 53	
5323H	May 9	+13	− . 79	− 2	0. 7	+ 3	+ 16	
5337J	11	+ 3	− . 81	0	0. 9	− 21	− 19	
8510J	1917 Jan. 16	+ 9	+ . 74	+250	0. 9	− 112	+ 15	
9338H	May 14	+ 3	− . 82	+368	0. 7	− 212	+ 3	Two exposures.
9364T	15	+10	− . 83	+369	0. 7	− 250	− 48	
11821T	1918 Jan. 15	+14	+ . 75	+614	0. 8	− 326	− 1	
11851T	19	−14	+ . 71	+618	0. 8	− 311	+ 28	
11894J	20	+ 9	+ . 70	+619	0. 6	− 316	+ 19	
12882T	May 8	+16	− . 90	+727	0. 6	− 422	− 4	
12917T	14	− 7	− . 83	+733	0. 6	− 416	+ 6	Two exposures.

$$\begin{array}{rrrrrl}
+10.10\,c+ & 23.95\,\mu- & 0.66\,\pi= & -\ 0.1299\text{ mm.} & & c=+0.0006\text{ mm.}\\
 & +187.91 & +0.98 & =-\ 1.0387 & & \mu=-\ .00561.\\
 & & +6.28 & =+\ \ .0048 & & \pi=+\ .00176.
\end{array}$$

Probable error for unit weight, ± .0013 mm.=±″.018.
Annual proper motion in R. A., − ″.299 ±″.006.
Relative parallax, **+ ″.026±″.007.**

The spectroscopic determination of this parallax at Mount Wilson yields **+0″.029.** Boss gives −0″.330 for the proper motion.

This star has a companion two magnitudes fainter and distant 15″ with which it forms Σ 1547. The two have the same large proper motion except for a small difference probably due to orbital motion. Boss's proper motion includes a part of this orbital motion.

(486)

Lalande 21947, 11^h 29^m, +37° 22′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
2030H	1915 May 13	+ 9	−0.81	−605	0.7	+0.0106	0.000	
2037J	14	− 3	− .82	−604	0.8	+ 108	+ 4	
2049H	16	+ 5	− .83	−602	0.8	+ 143	+ 55	
4530T	1916 Jan. 18	+12	+ .73	−355	0.9	+ 47	+ 15	
4567T	22	+11	+ .70	−351	0.8	+ 27	− 13	
5283D	May 7	+ 9	− .76	−245	0.9	− 36	− 102	
5303J	8	+ 8	− .78	−244	0.7	+ 17	− 25	
8470T	1917 Jan. 7	+ 7	+ .81	0	0.8	0	+ 50	
9374T	May 19	+17	− .85	+132	0.8	− 16	+ 34	Two exposures.
11853T	1918 Jan. 19	+10	+ .72	+377	0.8	− 154	− 67	
11893J	20	− 2	+ .71	+378	0.7	− 94	+ 19	
12919T	May 14	+10	− .82	+492	1.0	− 110	− 3	
12951J	15	+ 5	− .83	+493	1.0	− 87	+ 34	

$$\begin{array}{lllll} +10.70\,c- & 7.24\,\mu- & 2.50\,\pi= & -\ 0.0081\text{ mm.} & c=-0.0024\text{ mm.} \\ & +185.96 & +5.12\ \ = & -\ \ .3530 & \mu=-\ .00196. \\ & & +6.62\ \ = & -\ \ .0128 & \pi=-\ .00132. \end{array}$$

Probable error for unit weight, ± .0021 mm.=±″.030.
Annual proper motion in R. A., − ″.104 ±″.008.
Relative parallax, − **″.019±″.012.**

No other determination of this parallax has been published. Porter gives −0″.176 for the proper motion, which differs largely from the photographic. The comparison stars were measured on two early and two late plates in such a way as to bring out relative proper motions, but we found no motion large enough to account for more than a small fraction of the difference from Porter.

(487)

61 Ursae Majoris, 11^h 36^m, +34° 46′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
2038S	1915 May 14	+ 3	−0.80	−627	0.8	0.0000	+0.018	
2044S	15	+13	− .81	−626	0.7	− 22	− 15	Two exposures.
2053H	19	+14	− .84	−622	0.7	0	+ 19	Two exposures.
4531T	1916 Jan. 18	+17	+ .73	−378	0.9	+ 121	+ 44	
4568T	22	+15	+ .71	−374	0.9	+ 56	− 50	
5284D	May 7	+18	− .74	−268	1.0	− 17	− 1	
5360J	15	+11	− .82	−260	0.8	+ 8	+ 47	Two exposures.
8637J	1917 Jan. 30	−24	+ .62	0	0.9	+ 53	− 29	
9311T	May 10	+ 6	− .77	+100	0.8	− 67	− 55	
9339H	14	+ 6	− .80	+104	0.8	− 46	− 19	Two exposures.
11592C	Dec. 17	0	+ .90	+221	0.9	+ 88	+ 1	
12883T	1918 May 8	+19	− .89	+463	0.9	− 41	+ 10	
15017T	Dec. 16	− 3	+ .90	+685	0.7	+ 49	− 35	
15125J	18	− 7	+ .90	+687	1.0	+ 109	+ 53	
16734T	1919 May 14	+10	− .80	+834	1.0	− 53	0	

$$\begin{array}{lllll} +12.80\,c+ & 2.52\,\mu- & 1.86\,\pi= & +\ 0.0222\text{ mm.} & c=+0.0028\text{ mm.} \\ & +299.01 & +10.67\ \ = & -\ \ .0023 & \mu=-\ .00029. \\ & & +\ 8.29\ \ = & +\ \ .0513 & \pi=+\ .00719. \end{array}$$

Probable error for unit weight, ± .0016 mm.=±″.023.
Annual proper motion in R. A., − ″.015 ±″.005.
Relative parallax, + **″.105±″.008.**

The spectroscopic determination of this parallax at Mount Wilson yields +0″.072. Boss gives −0″.007 for the proper motion.

(488) and (489)

44 Boötis, 15h 0m, +48° 3′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Fainter component.			Brighter component.		
					Wt.	Solution.	Resid.	Wt.	Solution.	Resid.
		min.				mm.	″		mm.	″
1359J	1915 Feb. 28	− 6	+0.88	−480	0.8	+0.0422	+0.009	0.8	+0.0476	+0.003
1442H	Mar. 9	−16	+ .82	−471	1.0	+ 389	− 28	1.0	+ 427	− 54
1502H	13	− 9	+ .78	−467	1.0	+ 396	− 13	1.0	+ 439	− 29
2396S	June 26	0	− .71	−362	0.9	+ 320	+ 72	0.9	+ 315	+ 35
2414S	27	− 9	− .72	−361	1.0	+ 229	− 60	1.0	+ 293	+ 4
2440S	28	− 4	− .74	−360	0.9	+ 298	+ 41	0.9	+ 295	+ 10
2459D	July 2	0	− .77	−356	1.0	+ 229	− 53	1.0	+ 303	+ 31
4780H	1916 Feb. 29	+ 7	+ .87	−114	0.9	+ 164	+ 26	0.9	+ 153	− 20
4891T	Mar. 19	+ 7	+ .72	− 95	1.0	+ 134	+ 10	1.0	+ 203	+ 88
5686J	June 21	+ 4	− .66	− 1	0.9	+ 4	− 4	0.9	0	+ 13
5715T	22	+11	− .67	0	0.9	+ 49	+ 64	0.9	− 19	− 12
5766T	26	0	− .72	+ 4	1.0	0	− 3	1.0	− 24	− 12
9062h	1917 Apr. 3	−24	+ .53	+285	1.0	− 161	0	1.0	− 225	− 57
9655J	June 27	+14	− .73	+370	0.9	− 279	− 13	0.9	− 367	− 63
9695J	30	+12	− .76	+373	0.9	− 290	− 26	0.9	− 332	− 4
12008J	1918 Feb. 10	+ 9	+ .95	+598	0.9	− 397	− 31	0.9	− 401	+ 35
12192J	Mar. 1	+ 9	+ .87	+617	0.9	− 377	+ 23	0.9	− 424	+ 32

Plate 2459 has two exposures only.

FAINTER COMPONENT.

$+15.90\,c - 8.37\,\mu - 0.08\,\pi = +0.1098$ mm. $\quad c = +0.0030$ mm.

$+213.03 \quad +4.04 \quad = -1.5838 \quad \mu = -.00739.$

$+9.25 \quad = +.0037 \quad \pi = +.00366.$

Probable error for unit weight, ± .0017 mm.=±″.026.
Annual proper motion in R. A., − ″.394±″.006.
Relative parallax, + ″.053±″.008.

BRIGHTER COMPONENT.

$+15.90\,c - 8.37\,\mu - 0.08\,\pi = +.1096$ mm. $\quad c = +0.0025$ mm.

$+213.03 \quad +4.04 \quad = -1.7857 \quad \mu = -.00839.$

$+9.25 \quad = +.0152 \quad \pi = +.00533.$

Probable error for unit weight, ± .0019 mm.=±″.028.
Annual proper motion in R. A., − ″.447±″.007.
Relative parallax, + ″.078±″.009.

The mean by weight is **+″.065±″.006.**

The spectroscopic determinations at Mount Wilson yield +0″.066 and +0″.072. Boss gives −0″.424 and −0″.384 for the proper motions. Most of the differences of these proper motions from each other and from the photographic results is due to orbital motion.

(490)

ψ Serpentis, $15^h\ 39^m$, $+2°\ 50'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
5936H	1916 July 6	+ 2	−0.73	−360	0.8	+0.0051	−0.009	
5963J	7	− 1	− .74	−359	1.0	+ 75	+ 26	
5994H	10	+10	− .77	−356	0.9	+ 44	− 16	Two exposures.
8964T	1917 Mar. 24	+ 5	+ .78	− 99	0.9	+ 100	+ 35	
9088J	Apr. 8	−15	+ .60	− 84	0.9	+ 56	− 20	
9659J	June 27	+ 7	− .62	− 4	0.7	− 21	− 67	
9699J	30	+ 6	− .66	− 1	1.0	+ 29	+ 9	
9725h	July 1	+15	− .67	0	0.8	+ 28	+ 9	
12112T	1918 Feb. 17	0	+ .96	+231	0.8	+ 85	+ 53	
12195J	Mar. 1	+ 2	+ .94	+243	0.9	+ 40	− 9	
12209K	2	+11	+ .93	+244	0.8	+ 50	+ 6	
12346T	15	+12	+ .85	+257	0.9	+ 11	− 45	
13402C	June 28	+ 2	− .63	+362	0.9	0	+ 20	
13423K	July 1	+21	− .67	+365	0.7	0	+ 20	
16028h	Mar. 2	+ 6	+ .93	+609	0.7	− 13	− 32	
16102T	7	− 7	+ .91	+614	0.9	+ 15	+ 10	

$+13.60\,c + 12.55\,\mu + 1.16\,\pi = +\ .0491$ mm. $c = +0.0043$ mm.

$+137.49 \quad +18.93 \quad = -\ .0290$ $\mu = -\ .00101.$

$+8.34 \quad = +\ .0107$ $\pi = +\ .00298.$

Probable error for unit weight, ± .0014 mm.=±″.020.
Annual proper motion in R. A., − ″.054 ±″.008.
Relative parallax, + **″.043±″.008.**

No other determination of this parallax has been published. Boss gives −0″.082 for the proper motion.

(491)

Σ 2052, $16^h\ 24^m$, $+18°\ 37'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
9935H	1917 July 27	− 2	−0.83	−366	0.8	+0.0310	−0.009	
12581J	1918 Mar. 28	+ 3	+ .85	−122	0.9	+ 206	− 34	
12606T	30	+19	+ .84	−120	0.9	+ 235	+ 9	
12634J	31	+ 2	+ .83	−119	0.9	+ 243	+ 25	
13573J	July 14	+11	− .69	− 14	0.5	+ 60	− 76	One exposure.
13657h	19	0	− .74	− 9	0.9	+ 142	+ 48	
13700T	26	+13	− .82	− 2	0.9	+ 97	− 6	
13730J	28	+18	− .84	0	0.9	+ 109	+ 15	
16226J	1919 Mar. 20	+ 7	+ .91	+235	0.9	0	− 32	
16270T	22	−10	+ .90	+237	0.8	+ 48	+ 42	
16337J	24	− 2	+ .88	+239	1.0	0	− 25	
16374T	28	0	+ .86	+243	0.9	+ 36	+ 31	
17418D	July 11	+14	− .66	+348	1.0	− 135	− 51	
17633D	29	+11	− .84	+366	0.9	− 86	+ 45	

$+12.20\,c + 9.02\,\mu + 0.87\,\pi = +\ 0.1065$ mm. $c = +0.0128$ mm.

$+59.31 \quad +2.38 \quad = -\ .2251$ $\mu = -\ .00589.$

$+8.35 \quad = +\ .0258$ $\pi = +\ .00343.$

Probable error for unit weight, ± .0017 mm.=±″.025.
Annual proper motion in R. A., − ″.314 ±″.013.
Relative parallax, + **″.050±″.008.**

Other determinations of this parallax are: At Mount Wilson (spectroscopic), +0″.058; Yale (heliometer), +0″.082±0″.030. Porter gives −0″.327 for the proper motion.

This is a binary with slow but unmistakable orbital motion. The components are of the same magnitude and are now close. The measures refer to their combined image.

(492) and (493)

μ **Draconis**, $17^h\ 3^m$, $+54°\ 36'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Brighter component.			Fainter component.		
					Wt.	Solution.	Resid.	Wt.	Solution.	Resid.
		min.				*mm.*	″		*mm.*	″
9864h	1917 July 20	0	−0.66	−365	0.9	+0.0026	−0.063	0.9	+0.0021	−0.072
9882H	21	+12	− .67	−364	0.9	+ 108	+ 58	0.9	+ 109	+ 57
9958H	29	+ 2	− .76	−356	1.0	+ 29	− 53	1.0	+ 56	− 13
12608T	1918 Mar. 30	+ 5	+ .91	−112	0.9	+ 72	+ 38	0.9	+ 87	+ 26
12712C	Apr. 13	+ 7	+ .80	− 98	0.9	+ 59	+ 26	0.9	+ 55	− 12
13677T	July 20	+13	− .65	0	1.0	0	+ 13	1.0	− 28	− 31
13853J	Aug. 6	+15	− .84	+ 17	1.0	+ 13	+ 44	1.0	+ 31	+ 73
16510J	1919 Apr. 8	+ 4	+ .85	+262	1.0	− 52	− 25	1.0	0	+ 18
16594T	21	−13	+ .72	+275	0.9	− 64	− 34	0.9	− 37	− 25
17467D	July 17	+10	− .61	+362	1.0	− 96	− 16	1.0	− 99	− 22
17743D	Aug. 10	+10	− .86	+386	0.9	− 83	+ 18	0.9	− 96	+ 1

BRIGHTER COMPONENT.

$+10.40\,c + 0.35\,\mu - 1.78\,\pi = -\ 0.0001$ mm. $c = +0.0004$ mm.

$+78.77\ \ +4.14\ = -\ .1597$ $\mu = -\ .00213.$

$+6.05\ = +\ .0026$ $\pi = +\ .00201.$

Probable error for unit weight, ± .0020 mm. = ±″.030.

Annual proper motion in R. A., − ″.114 ± ″.012.

Relative parallax, + ″.029 ± ″.013.

FAINTER COMPONENT.

$+10.40\,c + 0.35\,\mu - 1.78\,\pi = +\ 0.0086$ mm. $c = +0.0015$ mm.

$+78.77\ \ +4.14\ = -\ .1537$ $\mu = -\ .00214.$

$+6.05\ = +\ .0091$ $\pi = +\ .00340.$

Probable error for unit weight, ± .0020 mm. = ±″.030.

Annual proper motion in R. A., − ″.114 ± ″.012.

Relative parallax, + ″.050 ± ″.013.

The mean is **+0″.039 ± 0″.009.**

Other determinations are: Yerkes +0″.039 ± 0″.008 and +0″.049 ± 0″.009; Mount Wilson (spectroscopic), +0″.026 and +0″.028. Boss gives −0″.068 for the proper motion of the midway point.

There is a thirteenth magnitude star distant 12″ which has no physical relation to the two others.

(494)

Lalande 34496, $18^h\ 31^m$, $+34°\ 20'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				mm.	″	
10176J	1917 Aug. 19	− 7	−0.77	−365	0.8	−0.0136	0.000	
10237J	25	0	− .82	−359	0.9	− 142	− 12	
12941J	1918 May 14	+ 7	+ .69	− 87	1.0	− 67	− 34	
13072T	26	−13	+ .54	− 85	1.0	− 47	− 6	
13978T	Aug. 19	+ 3	− .76	0	0.9	0	+ 12	
13995T	20	+ 5	− .77	+ 1	1.0	+ 23	+ 45	
16683T	1919 May 2	+ 8	+ .83	+256	0.8	+ 46	− 44	
16714J	12	+ 2	+ .72	+266	1.0	+ 100	+ 28	
16755J	15	−19	+ .69	+269	1.0	+ 109	+ 39	
16767T	17	−14	+ .66	+271	0.9	+ 90	+ 13	
17727D	Aug. 8	+25	− .62	+354	1.0	+ 118	+ 3	
17749D	10	+18	− .65	+356	0.9	+ 79	− 54	
17852D	26	+ 6	− .83	+372	0.8	+ 105	− 26	
17903h	29	− 5	− .85	+375	1.0	+ 132	+ 12	

$+13.00\,c+15.45\,\mu-1.63\,\pi=+\ 0.0404$ mm. $c=-0.0011$ mm.
$+98.99\quad +0.99\quad =+\ .3308\qquad \mu=+\ .00352.$
$+6.94\quad =+\ .0030\qquad \pi=-\ .00033.$
Probable error for unit weight, ± .0014 mm. = ±″.021.
Annual proper motion in R. A., + ″.188 ±″.009.
Relative parallax, **− ″.005 ± ″.008.**

No other determination of this parallax has been published. Porter gives +0″.191 for the proper motion.

(495)

Weisse 1339, $18^h\ 45^m$, $+34°\ 25'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				mm.	″	
10239J	1917 Aug. 25	+ 2	−0.79	−372	0.8	−0.0033	+0.079	
10279J	27	−18	− .81	−370	0.8	− 99	− 22	
10280T	Sept. 1	+ 9	− .86	−365	1.0	− 86	− 3	
12900J	1918 May 8	+ 3	+ .80	−116	0.4	− 41	+ 23	One exposure.
13076T	26	+ 6	+ .58	− 98	0.9	− 50	+ 6	
13106J	30	− 2	+ .53	− 94	0.9	− 75	− 31	
14061J	Sept. 1	+ 7	− .86	0	0.9	− 79	− 54	
14082J	3	−19	− .87	+ 2	1.0	− 60	− 26	
16795J	1919 May 18	+12	+ .69	+259	0.8	− 19	− 9	
16809J	24	+16	+ .62	+265	0.9	− 15	− 3	
16830h	25	−23	+ .60	+266	0.8	0	+ 18	
17762D	Aug. 14	−32	− .66	+347	0.7	− 6	− 4	
17906h	29	+ 6	− .82	+362	1.0	0	0	
17928h	31	− 4	− .84	+364	0.8	+ 32	+ 47	

$+11.70\,c+\ 3.78\,\mu-2.82\,\pi=-\ 0.0458$ mm. $c=-0.0043$ mm.
$+87.01\quad +3.72\quad =+\ .0834\qquad \mu=+\ .00115.$
$+6.55\quad =+\ .0159\qquad \pi=-\ .00007.$
Probable error for unit weight, ± .0015 mm. = ±″.022.
Annual proper motion in R. A., + ″.061 ±″.009.
Relative parallax, **− ″.001 ± ″.009.**

No other determination of this parallax has been published. Porter gives +0″ 062 for the proper motion.

(496)

11 Aquilae, $18^h\ 54^m$, $+13°\ 29'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
6939h	1916 Sept. 20	− 3	−0.96	−704	0.8	−0.0032	+0.006	
9415H	1917 May 25	+ 7	+ .62	−457	1.0	− 32	− 48	
10261T	Aug. 26	+ 7	− .78	−364	0.7	− 48	− 31	
10293T	Sept. 4	+ 7	− .86	−355	0.9	− 13	+ 22	
10298s	6	0	− .88	−353	0.9	− 13	+ 23	
13078T	1918 May 26	+12	+ .61	− 91	1.0	+ 43	+ 53	
13117K	31	+ 7	+ .55	− 86	0.7	− 7	− 19	
14165h	Sept. 14	+ 9	− .93	+ 20	0.6	− 17	+ 10	Two exposures.
16857T	1919 May 26	− 6	+ .61	+274	0.7	0	− 20	Two exposures.
16901h	28	−20	+ .59	+276	0.8	+ 53	+ 57	
16920T	29	−20	+ .58	+277	1.0	0	− 19	
17951J	Sept. 2	+ 2	− .84	+373	1.0	− 23	− 12	
17989D	4	0	− .86	+375	1.0	− 30	− 22	

$+11.10\,c - 6.14\,\mu - 2.05\,\pi = -0.0099$ mm. $c = -0.0004$ mm.
$+140.76 \quad +6.84 \quad = + .0419$ $\mu = + .00018$.
$+6.34 \quad = + .0155$ $\pi = + .00213$.
Probable error for unit weight, ± .0015 mm. = ±″.022.
Annual proper motion in R. A., + ″.009 ±″.007.
Relative parallax, + **″.031±″.009.**

No other determination of this parallax has been published. Boss gives +0″.005 for the proper motion.

There is a ninth magnitude companion, distant 16″, with which this star forms Σ 2424. The proper motions show that there is no physical connection between the two.

(497) and **(498)**

Σ 2481, $19^h\ 8^m$, $+38°\ 37'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Preceding compouent.			Following component.		
					Wt.	Solution.	Resid.	Wt.	Solution.	Resid.
		min.				*mm.*	″		*mm.*	″
3389T	1915 Sept. 29	+ 7	−0.98	−978	1.0	+0.0339	−0.010	1.0	+0.0354	+0.038
6589H	Aug. 24	+ 2	− .73	−648	0.8	+ 224	+ 44	0.8	+ 198	+ 23
6639J	29	+ 5	− .77	−643	1.0	+ 187	− 7	1.0	+ 174	− 6
6728J	Sept. 5	−17	− .84	−636	0.8	+ 188	+ 1	0.8	+ 183	+ 10
9361H	1917 May 14	− 3	+ .78	−385	0.8	+ 104	+ 39	0.8	+ 39	− 23
9371H	18	+ 2	+ .75	−381	0.9	+ 56	− 28	0.9	+ 43	− 15
9416H	25	0	+ .66	−374	0.9	+ 104	+ 50	0.9	+ 70	+ 28
10282T	Sept. 1	+21	− .80	−275	1.0	+ 23	+ 1	1.0	0	− 23
10310s	9	+14	− .88	−267	0.9	− 16	− 48	0.9	− 19	− 48
10315J	10	− 8	− .88	−266	0.8	0	− 26	0.8	− 5	− 26
13034J	1918 May 21	0	+ .71	− 13	1.0	− 110	− 20	1.0	− 100	+ 12
13149J	June 3	− 5	+ .54	0	0.8	− 101	+ 3	0.8	− 140	− 38
16775T	1919 May 17	+17	+ .76	+348	0.8	− 292	− 44	0.8	− 327	− 86
16861T	26	+12	+ .66	+357	1.0	− 276	− 12	1.0	− 242	+ 44
16903h	28	0	+ .63	+359	0.9	− 262	+ 9	0.9	− 232	+ 57
17991D	Sept. 4	+ 7	− .83	+458	0.9	− 311	+ 6	0.9	− 306	0
18050D	6	+11	− .84	+460	1.0	− 314	+ 6	1.0	− 303	+ 6
18078D	8	+ 7	− .87	+462	0.8	− 282	+ 53	0.8	− 288	+ 29

PRECEDING COMPONENT.

$$\begin{array}{rrrll}
+16.10\,c- & 21.77\,\mu- & 2.71\,\pi= & -\ 0.0666\text{ mm.} & c=-0.0103\text{ mm.}\\
 & +351.32 & +17.56\ \ = & -\ 1.3921 & \mu=-\ .00461.\\
 & & +\ 9.80\ \ = & -\ \ .0512 & \pi=+\ .00021.
\end{array}$$

Probable error for unit weight, ± .0014 mm. = ±″.020.
Annual proper motion in R. A., − ″.246 ± ″.004.
Relative parallax, + ″.003 ± ″.006.

FOLLOWING COMPONENT.

$$\begin{array}{rrrll}
+16.10\,c- & 21.77\,\mu- & 2.71\,\pi= & -\ 0.0789\text{ mm.} & c=-0.0110\text{ mm.}\\
 & +351.32 & +17.56\ \ = & -\ 1.3212 & \mu=-\ .00441.\\
 & & +\ 9.80\ \ = & -\ \ .0544 & \pi=-\ .00069.
\end{array}$$

Probable error for unit weight, ± .0017 mm. = ±″.024.
Annual proper motion in R. A., − ″.235 ± ″.005.
Relative parallax, − ″.010 ± ″.008.

The mean by weight is − **0″.002 ± 0″.005.**

Other determinations: Mount Wilson (spectroscopic), + 0″.026 and + 0″.029; Swarthmore, − 0″.011 ± 0″.009 and + 0″.016 ± 0″.009; McCormick, + 0″.018 ± 0″.012 and + 0″.046 ± 0″.011; Yerkes, + 0″.018 ± 0″.008 and + 0″.009 ± 0″.009. Porter gives − 0″.246 for the proper motion of the midway point.

These two stars, now 4″ apart, show very slow orbital motion. The preceding star is itself a close binary system, Secchi 2, always very close and with a comparatively short period.

(499)

Piazzi 233, 19^h 35^m, + 49° 3′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
3469T	1915 Oct. 6	+10	−0.97	−346	1.0	−0.0036	−0.018	
3534D	10	+ 1	− .98	−342	0.9	− 15	+ 12	
3564J	11	−10	− .98	−341	0.9	− 39	− 23	
5535J	1916 June 3	− 4	+ .63	−105	0.8	0	+ 9	
5586H	8	0	+ .56	−100	0.8	+ 5	+ 15	
6674J	Aug. 31	+ 4	− .72	− 16	1.0	− 21	− 26	
6705h	Sept. 3	0	− .75	− 13	1.0	0	+ 4	
6887J	16	+ 2	− .87	0	0.9	+ 29	+ 44	
9420H	1917 May 25	+ 6	+ .74	+251	0.8	+ 23	+ 7	
9522J	June 12	+ 2	+ .51	+269	0.9	+ 21	+ 4	
13191K	1918 June 8	+ 6	+ .57	+630	0.7	0	− 58	
13242T	14	− 2	+ .49	+636	0.8	+ 54	+ 19	
14201J	Sept. 23	+ 6	− .92	+737	1.0	+ 53	+ 13	
14271T	Oct. 1	+15	− .96	+745	1.0	+ 43	− 1	
14278J	3	−13	− .96	+747	0.8	+ 41	− 6	

$$\begin{array}{rrrll}
+13.30\,c+ & 23.19\,\mu- & 4.84\,\pi= & +\ 0.0133\text{ mm.} & c=-0.0000\text{ mm.}\\
 & +260.90 & -3.32\ \ = & +\ \ .1618 & \mu=+\ .00062.\\
 & & +8.59\ \ = & -\ \ .0001 & \pi=+\ .00022.
\end{array}$$

Probable error for unit weight, ± .0011 mm. = ±″.016.
Annual proper motion in R. A., + ″.033 ± ″.004.
Relative parallax, + **″.003 ± ″.006.**

No other determination of this parallax has been published. Porter gives + 0″.026 for the proper motion.

(500)

OAquilae, 19

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
3439D	1915 Oct. 3	+17	−0.95	−621	0.8	−0.0302	+0.060	
3536H	10	+ 8	− .97	−614	1.0	− 343	− 3	
3567J	11	0	− .97	−613	1.0	− 338	+ 3	
5478H	1916 May 30	+ 5	+ .71	−381	0.6	− 240	− 85	
5564H	June 5	+13	+ .63	−375	0.7	− 163	+ 26	
6690J	Sept. 2	+ 4	− .71	−286	0.8	− 193	− 15	
6738J	5	+ 5	− .74	−283	1.0	− 198	− 23	
6833J	11	+ 4	− .81	−277	0.7	− 214	− 45	
6889J	16	+ 6	− .84	−272	1.0	− 165	+ 23	
9550J	1917 June 15	−24	+ .51	0	0.8	− 24	− 15	
13123J	1918 June 1	+ 4	+ .69	+351	0.9	+ 195	+ 66	
14272T	Oct. 1	+12	− .94	+473	0.9	+ 158	+ 6	
16908h	1919 May 28	+17	+ .74	+712	1.0	+ 342	+ 39	
16977h	31	+ 4	+ .71	+715	0.8	+ 333	+ 25	
16996T	June 1	+ 6	+ .69	+716	0.9	+ 262	− 79	
18135h	Sept. 13	− 9	− .81	+820	0.9	+ 314	− 1	
18147D	15	0	− .83	+822	0.9	+ 307	− 13	

$+14.70\,c + 9.55\,\mu - 3.92\,\pi = -0.0146$ mm. $c = -0.0031$ mm.
$+442.30 \quad +20.75 \quad = +2.0430$ $\mu = +.00454$.
$+9.34 \quad = +.1359$ $\pi = +.00316$.

Probable error for unit weight, ± .0018 mm. = ±″.027.
Annual proper motion in R. A., + ″.242 ±″.005.
Relative parallax, + **″.046 ±″.010.**

No other determination of this parallax has been published. Boss gives +0″.236 for the proper motion.

(501)

Piazzi 306, $19^{h}\,47^{m}$, $+11°\,23'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
3600H	1915 Oct. 12	−14	−0.97	− 336	0.9	+0.0446	−0.012	
3618H	15	+ 2	− .98	− 332	0.9	+ 470	+ 28	
3632T	16	0	− .98	− 331	0.9	+ 419	− 47	
5479H	1916 May 30	+11	+ .71	− 104	0.8	+ 327	− 1	
5511J	June 1	+11	+ .69	− 102	0.9	+ 308	− 28	
6676J	Aug. 31	+ 5	− .68	− 11	0.9	+ 209	− 58	
6707h	Sept. 3	+ 4	− .71	− 8	1.0	+ 299	+ 77	
6719T	4	+ 9	− .72	− 7	0.9	+ 246	0	
6834J	11	+ 9	− .81	0	0.7	+ 259	+ 28	
9553J	1917 June 15	0	+ .51	+ 277	0.8	+ 88	+ 13	
9568h	16	+ 4	+ .50	+ 278	1.0	+ 79	0	
10823T	Oct. 16	+10	− .98	+ 400	0.8	0	+ 29	
13273J	1918 June 15	+ 6	+ .51	+ 642	1.0	− 163	− 10	
16978h	1919 May 31	+13	+ .71	+ 992	0.9	− 357	+ 32	
18136h	Sept. 13	− 2	− .81	+1097	0.9	− 499	− 45	

$+13.30\,c + 22.44\,\mu - 3.43\,\pi = +0.1845$ mm. $c = +0.0251$ mm.
$+296.52 \quad +8.73 \quad = -1.3356$ $\mu = -.00645$.
$+7.75 \quad = -.1313$ $\pi = +.00145$.

Probable error for unit weight, ± .0017 mm. = ±″.025.
Annual proper motion in R. A., − ″.344 ±″.006.
Relative parallax, + **″.021 ±″.010.**

No other determination of this parallax has been published. Porter gives 0″.345 for the proper motion.

(502)

OΣ 389, $19^h\ 48^m$, +30° 53′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
7194H	1916 Oct. 4	−23	−0.96	−347	0.8	0.0000	+0.028	
7219J	5	−11	− .96	−346	1.0	− 30	− 18	
7279h	10	0	− .97	−341	0.8	− 14	+ 6	
9551J	1917 June 15	−18	+ .51	− 93	0.8	− 11	− 44	
9565h	16	−23	+ .50	− 92	0.9	+ 15	− 4	
10378T	Sept. 13	+13	− .82	− 3	0.9	− 23	− 35	
10409J	14	+ 6	− .82	− 2	1.0	+ 30	+ 41	
10434T	16	+11	− .84	0	1.0	0	0	
13193K	1918 June 8	+14	+ .61	+265	1.0	+ 59	+ 31	
16866T	1919 May 26	+ 8	+ .76	+617	1.0	+ 65	+ 13	
16995T	June 1	− 7	+ .70	+623	0.9	+ 70	+ 22	
17019J	3	+ 6	+ .67	+625	1.0	+ 39	− 25	
18024J	Sept. 5	+ 6	− .73	+719	1.0	+ 40	+ 4	
18082D	8	+11	− .76	+722	0.8	+ 17	− 25	

$+12.90\,c + 23.06\,\mu - 2.72\,\pi = +0.0253$ mm. $c = +0.0014$ mm.

$+244.91\quad +12.67 = +.1719$ $\mu = +.00048.$

$+7.67 = +.0149$ $\pi = +.00163.$

Probable error for unit weight, ± .0013 mm. = ±″.018.

Annual proper motion in R. A., +″.026 ±″.005.

Relative parallax, **+″.024 ±″.008.**

No other determination of this parallax has been published. The total proper motion that we give for this star in Table 1 was derived from an examination of the star catalogues.

The companion is two magnitudes fainter and distant 13″. The two are relatively fixed.

(503)

Weisse 1190, $19^h\ 49^m$, +1° 41′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
3601H	1915 Oct. 12	− 7	−0.97	− 348	1.0	−0.0020	−0.001	Two exposures.
3619H	15	+ 6	− .98	− 344	0.9	− 7	+ 18	
3651D	17	+ 4	− .98	− 342	0.9	− 61	− 61	
5565H	1916 June 5	+20	+ .65	− 110	0.9	+ 8	− 3	
5588H	8	+ 6	+ .60	− 107	0.5	− 37	− 61	Two exposures.
5611H	11	−22	+ .56	− 104	0.9	0	− 13	
5635T	12	+ 5	+ .55	− 103	1.0	0	− 13	
6739J	Sept. 5	+ 8	− .73	− 18	1.0	+ 47	+ 77	
6874T	13	+15	− .82	− 10	1.0	− 50	− 64	
6890J	16	+ 9	− .83	− 7	1.0	+ 42	+ 70	
6986J	23	0	− .89	0	1.0	+ 10	+ 25	
13297T	1918 June 17	− 6	+ .49	+ 632	0.9	+ 44	+ 18	
17067h	1919 June 6	+ 9	+ .64	+ 986	0.8	+ 83	+ 55	
17091h	9	+ 5	+ .60	+ 989	1.0	+ 41	− 6	Two exposures.
18117D	Sept. 12	+ 9	− .79	+1074	0.6	− 39	− 101	Two exposures.
18173J	16	+ 5	− .83	+1088	0.9	+ 29	− 1	

$+14.30\,c + 26.19\,\mu - 3.74\,\pi = +0.0107$ mm. $c = +0.0005$ mm.

$+424.31\quad +8.20 = +.1629$ $\mu = +.00033.$

$+8.38 = +.0119$ $\pi = +.00132.$

Probable error for unit weight, ± .0020 mm. = ±″.029.

Annual proper motion in R. A., +″.017 ±″.006.

Relative parallax, **+″.018 ±″.011.**

No other determination of this parallax has been published. Porter gives −0″.013 for the proper motion.

This star was first referred to four comparison stars of which Weisse 1196 was one. When attention was called to the large proper motion of the latter, it was omitted as a comparison star and from the same measures the parallax of Weisse 1190 was deduced. Weisse 1196 was also referred to the same three comparison stars with the results given on the next page. See Astronomical Journal, No. 776.

(504)

Weisse 1196, $19^h\ 49^m$, $+1°\ 41'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
3601H	1915 Oct. 12	− 7	−0.97	− 348	1.0	−0.0046	−0.042	Two exposures.
3619H	15	+ 6	− .98	− 344	0.9	− 31	− 20	
3651D	17	+ 4	− .98	− 342	0.9	− 42	− 36	
5565H	1916 June 5	+20	+ .65	− 110	0.9	− 19	− 80	
5588H	8	+ 6	+ .60	− 107	0.5	+ 9	− 91	Two exposures.
5611H	11	−22	+ .56	− 104	0.9	+ 26	− 10	
5635T	12	+ 5	+ .55	− 103	1.0	+ 51	+ 26	
6739J	Sept. 5	+ 8	− .73	− 18	1.0	+ 58	+ 102	
6874T	13	+15	− .82	− 10	1.0	− 25	− 15	
6890J	16	+ 9	− .83	− 7	1.0	+ 30	+ 64	
6986J	23	0	− .89	0	1.0	0	+ 25	
13297T	1918 June 17	− 6	+ .49	+ 632	0.9	+ 85	+ 89	
17067h	1919 June 6	+ 9	+ .64	+ 986	0.8	+ 48	+ 32	
17091h	9	+ 5	+ .60	+ 989	1.0	0	− 35	Two exposures.
18117D	Sept. 12	+ 9	− .79	+1074	0.6	− 15	+ 13	Two exposures.
18173J	16	+ 5	− .83	+1088	0.9	− 86	− 91	

$+14.30\,c + 26.19\,\mu - 3.74\,\pi = +\ 0.0040$ mm. $\quad c = +0.0013$ mm.
$+424.31\quad +8.20\quad = +\ .0234 \qquad \mu = -\ .00009.$
$+8.38\quad = +\ .0226 \qquad \pi = +\ .00338.$
Probable error for unit weight, ± .0027 mm. $= \pm''.039$.
Annual proper motion in R. A., $-\ ''.005 \pm ''.008$.
Relative parallax, **$+\ ''.049 \pm ''.015$.**

No other determination of this parallax has been published. Porter gives 0″.000 for the proper motion.

This star, as explained in connection with Weisse 1190, was referred to three comparison stars not originally intended for this purpose and not very well suited to it. This accounts for the unusually large probable errors. Weisse 1190 and Weisse 1196 have the same large proper motion. See Astronomical Journal No. 776. Adopting +0″.032 as the mean absolute parallax of the two, their linear separation must be at least 5,000 times that between the earth and the sun.

(505)

η Cygni, $19^h\ 53^m$, $+34°\ 49'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
7121h	1916 Oct. 1	+ 7	−0.93	−602	0.8	+0.0013	+0.013	
7143J	2	−11	− .94	−601	1.0	+ 9	+ 6	
7177h	3	− 7	− .95	−600	1.0	+ 3	− 1	
9448T	1917 May 29	+ 7	+ .74	−362	0.9	+ 18	+ 16	
9453J	30	+ 7	+ .73	−361	0.8	0	− 10	
10410J	Sept. 14	+ 7	− .81	−254	0.6	− 22	− 26	
10435T	16	+13	− .83	−252	0.8	− 16	− 19	
13086T	1918 May 26	+13	+ .78	0	0.6	0	+ 4	
13299T	June 17	+ 4	+ .50	+ 22	0.8	− 16	− 16	
14303T	Oct. 4	+10	− .95	+131	0.8	− 28	− 19	
14400J	15	− 9	− .98	+142	1.0	0	+ 22	
16867T	1919 May 26	+ 9	+ .78	+365	1.0	+ 11	+ 35	
16889J	27	+ 7	+ .77	+366	0.6	− 5	+ 12	
16930T	29	+ 8	+ .74	+368	1.0	− 40	− 39	
18084D	Sept. 8	+24	− .75	+470	0.8	− 30	− 9	
18118D	12	+16	− .79	+474	0.8	− 10	+ 20	

$+13.30\,c - 6.79\,\mu - 2.65\,\pi = -\ 0.0087$ mm. $\quad c = -0.0007$ mm.
$+202.54\quad +13.37\quad = -\ .0425 \qquad \mu = -\ .00027.$
$+\ 9.05\quad = +\ .0029 \qquad \pi = +\ .00051.$
Probable error for unit weight, ± $.0009 = \pm''.014$.
Annual proper motion in R. A., $-\ ''.014 \quad \pm ''.004$.
Relative parallax, **$+\ ''.007 \quad \pm ''.005$.**

The spectroscopic determination of this parallax at Mount Wilson yields +0″.036. Boss gives −0″.031 for the proper motion.

This star forms β980 with a thirteenth magnitude star distant 7″. The two have the same proper motion.

(506)

27 Cygni, 20h 3m, +35° 42′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
3536H	1915 Oct. 10	+ 1	−0.95	−615	1.0	+0.0298	+0.020	
3569J	11	0	− .96	−614	1.0	+ 316	+ 48	
3634T	16	+11	− .97	−609	1.0	+ 278	− 6	
3678T	20	+ 2	− .98	−605	0.9	+ 258	− 29	
5589H	1916 June 8	+ 3	+ .65	−373	0.8	+ 209	0	
5615H	11	− 9	+ .61	−370	0.8	+ 222	+ 23	
5638T	12	+14	+ .59	−369	0.8	+ 190	− 23	
6892J	Sept. 16	+ 8	− .81	−273	0.9	+ 148	+ 4	
6980T	22	+10	− .86	−267	0.9	+ 134	− 12	
7007h	24	− 9	− .87	−265	0.9	+ 112	− 42	
9570h	1917 June 16	+ 4	+ .54	0	1.2	+ 68	+ 20	Four exposures.
9602J	18	−21	+ .52	+ 2	1.0	+ 48	− 6	
10436T	Sept. 16	+11	− .81	+ 92	0.9	− 27	− 34	
10613T	25	+ 4	− .88	+101	0.9	− 17	− 12	
10684T	Oct. 1	+13	− .92	+107	0.9	0	+ 18	
13087T	1918 May 26	+ 8	+ .80	+344	0.5	− 77	+ 10	Two exposures.
16931T	1919 May 29	+ 4	+ .77	+712	1.0	− 249	− 20	
18176J	Sept. 16	+11	− .80	+922	0.9	− 322	+ 34	

$+16.30\,c - 20.09\,\mu - 5.29\,\pi = +0.1490$ mm. $c = +0.0046$ mm.

$+333.77 \quad +21.48 \quad = -1.4281$ $\mu = -.00410.$

$+10.63 \quad = -.0964$ $\pi = +.00149.$

Probable error for unit weight, ± .0012 mm.=±″.017.

Annual proper motion in R. A., −″.219 ±″.004.

Relative parallax, **+″.022±″.006.**

Other determinations of this parallax are: Mount Wilson (spectroscopic), +0″.052; Yerkes, +0″.045±0″.007. Boss gives −0″.229 for the proper motion.

(507)

Lalande 38613, 20h 5m, +16° 30′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
3708J	1915 Oct. 21	+ 2	−0.97	−606	1.0	0.0000	−0.026	
3734H	22	+ 2	− .97	−605	1.0	+ 38	+ 29	
3767D	24	+ 7	− .97	−603	1.0	+ 41	+ 34	
5617H	1916 June 11	0	+ .62	−372	0.8	+ 12	− 25	
5661J	17	− 8	+ .53	−366	0.8	+ 36	+ 9	
6919T	Sept. 19	+ 8	− .82	−272	0.9	0	− 19	
7050J	26	−11	− .88	−265	0.9	+ 9	− 6	
7099T	30	− 6	− .91	−261	0.9	+ 5	− 10	
9604J	1917 June 18	−11	+ .53	0	0.8	+ 20	− 4	
13276J	1918 June 15	+ 5	+ .57	+362	0.9	+ 19	+ 1	
13339C	19	0	+ .51	+366	0.4	− 32	− 72	Two exposures.
14305T	Oct. 4	+15	− .93	+473	0.6	+ 27	+ 39	Two exposures.
16958J	1919 May 30	0	+ .76	+711	0.9	+ 31	+ 26	
17021J	June 3	+ 4	+ .72	+715	0.9	+ 31	+ 26	
18253J	Sept. 24	−10	− .87	+828	0.9	− 33	− 42	
18280J	26	− 8	− .88	+830	0.9	+ 2	+ 9	

$+13.60\,c + 4.09\,\mu - 4.01\,\pi = +0.0194$ mm. $c = +0.0018$ mm.

$+396.40 \quad +16.85 \quad = -.0393$ $\mu = -.00016.$

$+8.91 \quad = -.0006$ $\pi = +.00104.$

Probable error for unit weight, ± .0013 mm. = ±″.018.

Annual proper motion in R. A., −″.009 ±″.003.

Relative parallax, **+″.015 ±″.007.**

No other determination of this parallax has been published. Porter gives $-0''.010$ for the proper motion.

This star forms Σ2634 with a 9.5 magitude star distant $6''$. They have the same large proper motion except for a little difference probably due to slow orbital motion.

(508)

Groombridge 3150, $20^h\ 17^m$, $+66°\ 32'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
2267H	1915 June 12	− 5	+0.65	−475	0.7	−0.0300	+0.069	Two exposures.
3538H	Oct. 10	+ 8	− .94	−355	1.0	− 319	− 32	
3571J	11	+ 9	− .95	−354	1.0	− 315	− 28	
3623H	15	+ 9	− .95	−350	0.9	− 280	+ 20	
3636T	16	+14	− .95	−349	0.9	− 300	− 12	
5541J	1916 June 3	+ 3	+ .74	−118	0.7	− 39	− 7	
5620H	11	+ 8	+ .65	−110	1.0	− 48	− 26	
5663J	17	− 3	+ .57	−104	0.6	0	+ 42	
6951h	Sept. 20	+17	− .81	− 9	0.9	0	− 12	
6991J	23	+13	− .83	− 6	1.0	+ 35	+ 36	
7053J	26	− 2	− .86	− 3	0.9	+ 27	+ 23	
7082J	29	−10	− .88	0	0.9	− 17	− 42	
9609J	1917 June 18	+15	+ .56	+262	1.0	+ 284	− 7	
10763C	Oct. 9	+ 3	− .93	+375	0.8	+ 325	− 18	
10790J	11	+11	− .94	+377	0.8	+ 361	+ 35	Clouds.
13340C	1918 June 19	+11	+ .55	+628	0.8	+ 581	− 38	
13362T	23	−24	+ .50	+632	0.8	+ 601	− 12	
14339h	Oct. 8	+19	− .93	+739	0.9	+ 677	+ 36	

$$
\begin{array}{rrrlr}
+15.60\,c + & 5.95\,\mu - & 5.69\,\pi = + & 0.0991 \text{ mm.} & c = +0.0043 \text{ mm.} \\
 & +207.87 & +\ 3.92 = + & 1.8421 & \mu = +\ .00868. \\
 & & +10.27 = + & .0445 & \pi = +\ .00340.
\end{array}
$$

Probable error for unit weight, ± .0014 mm. = ±″.021.
Annual proper motion in R. A., + ″.462 ±″.005.
Relative parallax, + **″.050±″.007.**

Other determinations of this parallax: Yale (heliometer), $+0''.105 \pm 0''.021$; Mount Wilson (spectroscopic), $+0''.066$. Boss gives $+0''.478$ for the proper motion.

(509)

1 Delphini, $20^h\ 26^m$, $+10°\ 34'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
7180h	1916 Oct. 3	− 4	−0.89	−382	0.9	−0.0034	−0.039	
7199H	4	−13	− .89	−381	0.9	− 22	− 22	
7223J	5	−14	− .90	−380	1.0	− 23	− 23	
9558J	1917 June 15	+ 5	+ .63	−127	0.8	+ 37	+ 53	
9573h	16	+ 6	+ .62	−126	0.9	0	− 3	
10828T	Oct. 16	+11	− .94	− 4	0.9	+ 77	+ 92	
10853C	17	+ 4	− .95	− 3	0.8	+ 20	+ 9	
10866J	20	+ 5	− .96	0	1.0	0	− 19	
13196K	1918 June 8	+ 3	+ .72	+231	0.9	+ 68	+ 67	
13365T	23	−10	+ .53	+246	0.9	+ 12	− 15	
13382T	26	−25	+ .49	+249	0.8	+ 15	− 12	
14419T	Oct. 16	0	− .94	+361	1.0	+ 58	+ 35	
14444J	18	−20	− .95	+363	0.8	− 13	− 69	
17093h	1919 June 9	−12	+ .71	+597	0.9	0	− 58	
17109J	11	−15	+ .69	+599	1.0	+ 23	− 28	
18316D	Sept. 27	+ 6	− .84	+707	0.9	+ 75	+ 32	

$$
\begin{array}{rrrlr}
+14.40\,c + & 17.63\,\mu - & 3.62\,\pi = + & 0.0264 \text{ mm.} & c = +0.0011 \text{ mm.} \\
 & +195.04 & +8.31 = + & .1230 & \mu = +\ .00055. \\
 & & +9.42 = - & .0024 & \pi = -\ .00033.
\end{array}
$$

Probable error for unit weight, ± .0021 mm. = ±″.031.
Annual proper motion in R. A., + ″.029 ±″.009.
Relative parallax, − **″.005±″.011.**

No other determination of this parallax has been published. Boss gives $+0''.019$ for the proper motion.

This star forms β 63 with a star two magnitudes fainter at a distance of $1''$. Slow orbital motion is present.

(510)

κ Delphini, $20^{h}\ 34^{m}$, $+9°\ 44'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				mm.	″	
2246T	1915 June 9	−14	+0.73	−481	0.5	−0.0281	+0.028	Two exposures.
2280H	15	− 8	+ .67	−475	0.8	− 273	+ 35	
2291T	16	0	+ .65	−474	0.9	− 300	− 6	
3364J	Sept. 24	− 1	− .80	−374	0.9	− 227	+ 29	
3398T	29	0	− .84	−369	0.9	− 276	− 45	
3442D	Oct. 3	+ 5	− .87	−365	0.9	− 270	− 42	
3515T	9	+ 3	− .91	−359	0.9	− 232	+ 10	
5753J	1916 June 25	0	+ .52	− 99	0.8	− 79	− 23	Two exposures.
7056J	Sept. 26	+ 5	− .82	− 6	0.7	0	+ 25	Wind.
7148J	Oct. 2	− 4	− .86	0	0.9	− 7	+ 10	
9575h	1917 June 16	+13	+ .64	+257	0.9	+ 129	− 47	
10618T	Sept. 25	−19	− .81	+258	1.0	+ 191	+ 60	
10642J	26	− 4	− .81	+359	1.0	+ 180	− 47	
13180C	1918 June 7	− 5	+ .75	+613	0.7	+ 390	+ 7	
13368T	23	+ 4	+ .56	+629	1.0	+ 404	+ 15	

$+12.80\,c - 5.44\,\mu - 2.48\,\pi = -\ 0.0437$ mm. $\quad c = -0.0006$ mm.

$+190.38\ \ +7.04 = +\ 1.2017 \qquad \mu = +\ .00626.$

$+7.39 = +\ .0524 \qquad \pi = +\ .00092.$

Probable error for unit weight, $\pm$ .0016 mm.$=\pm''.024$.

Annual proper motion in R. A., $+''.334 \pm''.006$.

Relative parallax, **$+''.013 \pm ''.009$.**

The spectroscopic determination of this parallax at Mount Wilson yields $+0''.044$. Boss gives $+0''.319$ for the proper motion.

There is an eleventh magnitude companion, now distant $20''$, with which this star forms OΣ 533. The proper motions show that the two are not physically related.

(511) and (512)

γ Delphini, $20^{h}\ 42^{m}$, $+15°\ 46'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Fainter component.			Brighter component.		
					Wt.	Solution.	Resid.	Wt.	Solution.	Resid.
		min.				mm.	″		mm.	″
3605H	1915 Oct. 12	−11	−0.91	−360	0.9	+0.0011	+0.007	0.9	+0.0005	+0.013
3625H	15	+ 7	− .92	−356	0.8	− 29	− 51	0.8	+ 18	+ 31
3638T	16	+ 8	− .93	−355	0.9	+ 30	+ 36	0.9	0	+ 6
3655D	17	+ 5	− .93	−354	1.0	+ 6	0	1.0	+ 5	+ 12
5703J	1916 June 21	+14	+ .60	−106	0.8	+ 18	− 3	0.8	0	− 4
5724T	22	+ 3	+ .59	−105	0.9	+ 33	+ 19	0.9	0	− 6
5755J	25	+ 4	+ .55	−102	0.8	+ 14	− 9	0.8	− 19	− 31
7086J	Sept. 29	− 7	− .82	− 6	0.7	− 34	− 48	0.7	− 41	− 25
7150J	Oct. 2	0	− .85	− 3	0.9	+ 23	+ 35	0.9	− 38	− 22
7201H	4	−13	− .86	− 1	0.9	0	0	0.9	− 26	− 3
7224J	5	−22	− .87	0	1.0	− 4	− 3	1.0	− 31	− 9
9685H	1917 June 29	−11	+ .50	+267	0.8	+ 10	− 3	0.8	− 28	− 12
13371T	1918 June 23	+16	+ .58	+626	0.9	0	− 7	0.9	− 37	+ 4
13407K	28	+20	+ .52	+631	0.8	+ 3	− 3	0.8	− 34	+ 9
13427C	July 1	+12	+ .48	+634	0.6	+ 10	+ 10	0.6	− 5	+ 54
14408J	Oct. 15	+ 5	− .92	+740	0.9	− 15	+ 1	0.9	− 64	+ 4
14449J	18	+ 6	− .94	+743	0.8	− 16	+ 4	0.8	− 83	− 20

Plate 13427 has two exposures only.

FAINTER COMPONENT.

$$\begin{array}{rrrl}
+14.40\,c+ & 13.69\,\mu-4.80\,\pi=+ & 0.0057\text{ mm.} & c=+0.0010\text{ mm.}\\
 & +238.76\quad +7.47\quad =- & .0258 & \mu=-\ .00021.\\
 & +8.77\quad =+ & .0051 & \pi=+\ .00133.
\end{array}$$

Probable error for unit weight, ± .0010 mm.=±″.015.
Annual proper motion in R. A., − ″.011±″.004.
Relative parallax, + ″.019±″.006.

BRIGHTER COMPONENT.

$$\begin{array}{rrrl}
+14.40\,c+ & 13.69\,\mu-4.80\,\pi=- & 0.0318\text{ mm.} & c=-0.0012\text{ mm.}\\
 & +238.76\quad +7.47\quad =- & .1438 & \mu=-\ .00058.\\
 & +8.77\quad =+ & .0140 & \pi=+\ .00145.
\end{array}$$

Probable error for unit weight, ± .0009 mm.=±″.013.
Annual proper motion in R. A., − ″.031±″.003.
Relative parallax, + ″.021±″.005.

The mean is **+0″.020±0″.004.**

Other determinations are: Mount Wilson (spectroscopic), +0″.032 and +0″.021; McCormick, +0″.046±0″.008 and +0″.038±0″.009; Swarthmore, −0″.008±0″.014 and +0″.007±0″.012. Boss gives −0″.016 and −0″.029 for the proper motions.

These two stars have the same large proper motion except for a small difference probably due to slow orbital motion.

(513) and **(514)**

OΣ 447, $21^h\ 36^m$, +41° 16′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Brighter component.			Fainter component.		
					Wt.	Solution.	Resid.	Wt.	Solution.	Resid.
		min.				mm.	″		mm.	″
7653T	1916 Nov. 2	+ 6	−0. 92	−348	0. 9	+0. 0004	+0. 009	0. 9	−0. 0015	−0. 022
7680H	3	+ 2	− . 92	−347	0. 9	− 16	− 20	0. 9	+ 13	+ 20
7697J	4	− 3	− . 92	−346	0. 8	0	+ 4	0. 8	+ 10	+ 15
9746H	1917 July 2	+11	+ . 63	−106	0. 7	+ 28	+ 47	0. 7	0	0
9777h	4	− 8	+ . 61	−104	1. 0	0	+ 6	1. 0	+ 7	+ 12
9818H	18	−11	+ . 42	− 90	0. 9	− 2	+ 4	0. 9	− 9	− 13
10798T	Oct. 13	+10	− . 80	− 3	1. 0	− 17	− 18	1. 0	+ 8	+ 9
10933T	28	+11	− . 90	+ 12	0. 8	− 18	− 19	0. 8	− 15	− 26
13379T	1918 June 23	+16	+ . 74	+250	0. 8	− 37	− 42			
13536T	July 8	+15	+ . 55	+265	0. 8	− 13	− 9	0. 8	+ 11	+ 12
13548J	9	+ 9	+ . 55	+266	0. 7	− 8	− 1	0. 7	− 8	− 16
14554T	Oct. 28	+10	− . 90	+377	0. 9	− 6	+ 4	0. 9	0	− 9
14568J	Nov. 2	+ 3	− . 92	+382	1. 0	− 31	− 32	1. 0	− 2	− 10
14604J	5	− 3	− . 93	+385	0. 9	+ 42	+ 73	0. 9	+ 27	+ 31

Plate 9746 and plate 13548 have two exposures only.
Plate 9777 has four exposures.

BRIGHTER COMPONENT.

$$\begin{array}{rrrl}
+12.10\,c+ & 5.11\,\mu-3.65\,\pi=- & 0.0067\text{ mm.} & c=-0.0005\text{ mm.}\\
 & +90.16\quad +0.68\quad =- & .0093 & \mu=-\ .00007.\\
 & +7.55\quad =+ & .0015 & \pi=-\ .00005.
\end{array}$$

Probable error for unit weight, ± .0014 mm.=±″.020.
Annual proper motion in R. A., − ″.004±″.008.
Relative parallax, ″.000±″.008.

FAINTER COMPONENT.

$$\begin{array}{rrrl}
+11.30\,c+ & 3.11\,\mu-4.24\,\pi=+ & 0.0026\text{ mm.} & c=+0.0002\text{ mm.}\\
 & +85.16\quad -0.80\quad =+ & .0070 & \mu=+\ .00007.\\
 & +7.11\quad =- & .0017 & \pi=-\ .00013.
\end{array}$$

Probable error for unit weight, ± .0008 mm.=±″.012.
Annual proper motion in R. A., + ″.004±″.005.
Relative parallax, − ″.002±″.005.

The mean is **$-0''.001 \pm 0''.004$.** The total proper motion quoted in Table 1 was derived from an examination of the star catalogues. No other determination of this parallax has been published.

It is probable that these two stars (29″ apart) are physically related.

(515) and (516) **OΣ (App.) 226, $21^h\ 51^m$, $+67°\ 38'$.**

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Fainter component.			Brighter component.		
					Wt.	Solution.	Resid.	Wt.	Solution.	Resid.
		min.				*mm.*	″		*mm.*	″
7774J	1916 Nov. 8	− 3	−0.92	−346	0.8	+0.0007	−0.015	0.8	+0.0011	−0.034
7815H	10	+11	− .93	−344	0.8	+ 53	+ 53	0.8	+ 59	+ 36
7901J	18	−11	− .93	−336	1.2	+ 29	+ 18	1.2	+ 39	+ 7
9717J	1917 June 30	− 4	+ .70	−112	0.9	− 18	− 38	0.9	− 5	− 19
9755J	July 3	0	+ .67	−109	0.8	+ 9	+ 1	0.8	+ 8	0
10875J	Oct. 20	− 3	− .82	0	0.8	0	− 16	0.8	+ 39	+ 20
10935T	28	+10	− .87	+ 8	0.9	+ 19	+ 12	0.9	+ 37	+ 18
13458J	1918 July 3	0	+ .67	+256	0.9	− 35	− 54	0.9	+ 4	+ 7
13510C	7	0	+ .62	+260	0.8	+ 22	+ 31	0.8	− 9	− 15
13538T	8	+12	+ .61	+261	0.9	− 5	− 7	0.9	− 18	− 26
14571J	Nov. 2	+ 7	− .90	+378	1.0	− 5	− 13	1.0	+ 30	+ 19
14760J	14	0	− .93	+390	0.9	− 26	− 44	0.9	− 21	− 55
14796h	25	−10	− .93	+401	0.8	+ 3	− 1	0.8	+ 8	− 13
17386D	1919 July 7	−17	+ .62	+625	0.9	0	+ 7	0.9	+ 7	+ 22
17406h	10	+20	+ .59	+628	0.9	+ 42	+ 69	0.9	+ 9	+ 25

Plate 7901 has four exposures.

FAINTER COMPONENT.

$+13.30\,c + 17.14\,\mu - 2.61\,\pi = +\ 0.0085$ mm. $c = +0.0008$ mm.
$+163.55 \quad +8.93 \quad = -\ .0179$ $\mu = -\ .00017$.
$+8.42 \quad = -\ .0066$ $\pi = -\ .00035$.
Probable error for unit weight, ± .0016 mm. = ±″.023.
Annual proper motion in R. A., − ″.009±″.008.
Relative parallax, − ″.005±″.009.

BRIGHTER COMPONENT.

$+13.30\,c + 17.14\,\mu - 2.61\,\pi = +\ .0181$ mm. $c = +0.0014$ mm.
$+163.55 \quad +8.93 \quad = -\ .0250$ $\mu = -\ .00023$.
$+8.42 \quad = -\ .0166$ $\pi = -\ .00129$.
Probable error for unit weight, ± .0012 mm. = ±″.017.
Annual proper motion in R. A., − ″.012±″.006.
Relative parallax, − ″.019±″.007.

The mean by weight is **$-0''.014 \pm 0''.005$.**

No other determination of this parallax has been published. These two stars have the same proper motion.

(517)

Lalande 43751, $22^h\ 19^m$, +38° 4′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
7906J	1916 Nov. 18	− 5	−0.92	−352	1.0	−0.0189	−0.023	
7963h	21	− 3	− .92	−349	0.9	− 176	− 6	
8021T	26	+12	− .92	−344	1.0	− 163	+ 10	
9850T	1917 July 19	+18	+ .56	−109	1.0	− 43	+ 36	
9875h	20	− 7	+ .54	−108	0.9	− 55	+ 18	
9887H	21	−20	+ .53	−107	0.9	− 90	− 34	
10957J	Nov. 1	+ 7	− .84	− 4	1.0	− 12	− 12	
11055s	5	+10	− .87	0	1.0	0	+ 1	
13640J	1918 July 17	+ 5	+ .58	+254	1.0	+ 126	+ 22	
13693T	24	− 3	+ .50	+261	0.6	+ 94	− 31	
14765J	Nov. 14	− 2	− .91	+374	1.0	+ 200	+ 26	
14847T	27	+16	− .92	+387	0.5	+ 187	− 3	Two exposures.
17372J	1919 July 4	0	+ .74	+606	1.0	+ 282	− 1	
17376D	5	+ 4	+ .72	+607	0.9	+ 265	− 26	

$+12.70\,c + 8.15\,\mu - 1.94\,\pi = +0.0301$ mm. $c = -0.0009$ mm.
$+140.36 \quad +13.16 \quad = +\ .6703$ $\mu = +\ .00491.$
$+\ 7.50 \quad = +\ .0599$ $\pi = -\ .00086.$
Probable error for unit weight, ± .0011 mm. = ±″.015.
Annual proper motion in R. A., + ″.261 ±″.005.
Relative parallax, **− ″.013±″.006.**

No other determination of this parallax has been published. Porter gives +0″.253 for the proper motion.

(518) and (519)

Fedorenko 4220 and 4222, $22^h\ 34^m$, +72° 2′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Brighter component.			Fainter component.		
					Wt.	Solution.	Resid.	Wt.	Solution.	Resid.
		min.				*mm.*	″		*mm.*	″
4070T	1915 Nov. 12	+ 8	−0.88	−723	0.6	−0.0061	+0.095	......	....	....
7781J	1916 Nov. 8	+ 4	− .86	−361	1.0	− 114	− 64	1.0	−0.0122	−0.057
8079J	Dec. 1	+ 3	− .92	−338	1.0	− 86	− 28	1.0	− 73	+ 10
9890H	1917 July 21	−10	+ .58	−106	1.0	0	− 4	1.0	− 9	− 1
9891H	21	− 3	+ .58	−106	0.9	0	− 4	0.9	0	+ 12
9903T	22	− 3	+ .57	−105	0.9	+ 11	+ 13	0.9	+ 5	+ 19
10945T	Oct. 31	+ 9	− .83	− 4	1.0	0	+ 20	1.0	0	+ 31
11016J	Nov. 4	− 5	− .83	0	0.9	− 26	− 19	0.9	− 35	− 20
13695T	1918 July 24	+14	+ .54	+262	0.7	+ 94	+ 53	......	....	....
13741J	28	−11	+ .49	+266	0.9	+ 27	− 42	0.9	+ 75	+ 32
14768J	Nov. 14	+ 4	− .88	+375	1.0	+ 49	+ 12	1.0	+ 41	− 1
14875J	30	−18	− .92	+391	0.9	+ 58	+ 22	0.9	+ 63	+ 29
17474D	1919 July 17	−12	+ .64	+620	0.8	+ 110	− 6	0.8	+ 106	− 15
17493J	18	−23	+ .64	+621	0.9	+ 115	+ 1	0.9	+ 87	− 44

Plate 4070 has two exposures only.

BRIGHTER COMPONENT.

$$\begin{array}{rrrrrl}
+12.50\,c+ & 7.72\,\mu- & 2.08\,\pi= & +\ 0.0133 \text{ mm.} & & c=+0.0005 \text{ mm.} \\
 & +163.38 & +10.73 = & +\ .2777 & & \mu=+\ .00152. \\
 & & +\ 6.96 = & +\ .0315 & & \pi=+\ .00233.
\end{array}$$

Probable error for unit weight, $\pm$ .0017 mm. $= \pm''.025$.
Annual proper motion in R. A., $+''.081 \pm ''.008$.
Relative parallax, $+''.034 \pm ''.010$.

FAINTER COMPONENT.

$$\begin{array}{rrrrrl}
+11.20\,c+ & 10.23\,\mu- & 1.93\,\pi= & +\ 0.0097 \text{ mm.} & & c=-0.0003 \text{ mm.} \\
 & +127.21 & +5.92 = & +\ .2262 & & \mu=+\ .00170. \\
 & & +6.28 = & +\ .0245 & & \pi=+\ .00220.
\end{array}$$

Probable error for unit weight, $\pm$ .0014 mm. $= \pm''.021$.
Annual proper motion in R. A., $+''.091 \pm ''.007$.
Relative parallax, $+''.032 \pm ''.009$.

The mean is **$+0''.033 \pm 0''.007$.** No other determination has been published.

An examination of all the catalogues in which the positions of these two stars are given yields $+0''.093$ and $+0''.074$ for the two components in right ascension, and $+0''.05$ and $+0''.05$ for those in declination. That the two proper motions are the same is shown by the micrometer measures. Therefore these two stars, 42″ apart, are physically related. Accepting $+0''.036$ as the absolute parallax of the pair, the projection of their linear separation on the celestial sphere exceeds more than a thousandfold the distance between the earth and the sun.

The preceding star is itself a very close double, β 1092, in rapid orbital motion.

(520) OΣ **478**, $22^h\ 40^m$, $+38°\ 56'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
11238J	1917 Nov. 10	− 2	−0.86	−260	0.9	−0.0028	−0.006	
11294T	12	+ 7	− .87	−258	0.8	− 17	+ 10	
13643J	1918 July 17	+ 6	+ .65	− 11	0.9	+ 8	+ 51	
13650T	18	+16	+ .64	− 10	0.9	− 20	+ 10	
13684T	20	+ 5	+ .62	− 8	0.9	− 55	− 42	
13743J	28	− 5	+ .51	0	0.9	− 25	+ 3	
14802h	Nov. 25	+20	− .91	+120	1.0	− 50	− 25	
14818J	26	+ 9	− .91	+121	1.0	− 34	− 1	
14849T	27	+14	− .92	+122	1.0	− 27	+ 9	
17476D	1919 July 17	+ 6	+ .65	+354	0.9	− 62	− 39	
17496J	18	0	+ .64	+355	0.9	− 10	+ 36	
17509J	21	−22	+ .61	+358	0.9	− 48	− 18	
18800D	Nov. 9	+14	− .85	+469	0.7	− 39	+ 3	
18820D	11	+ 4	− .86	+471	0.8	− 41	0	
18837J	12	+ 7	− .87	+472	0.8	− 26	+ 23	

$$\begin{array}{rrrrrl}
+13.30\,c+ & 19.41\,\mu- & 2.31\,\pi= & -\ 0.0422 \text{ mm.} & & c=-0.0028 \text{ mm.} \\
 & +100.97 & -2.91 = & -\ .0793 & & \mu=-\ .00025. \\
 & & +7.91 = & +\ .0087 & & \pi=+\ .00020.
\end{array}$$

Probable error for unit weight, $\pm$ .0012 mm. $= \pm''.018$.
Annual proper motion in R. A., $-''.013 \pm ''.008$.
Relative parallax, **$+''.003 \pm ''.006$.**

Other determinations are: Mount Wilson (spectroscopic), $+0''.005$; Mount Wilson (trigonometric), $+0''.002 \pm 0''.008$. Boss gives $-0''.004$ for the proper motion.

The companion is two magnitudes fainter and is distant 3″. The two have the same small proper motion. There is a third star of the twelfth magnitude distant 11″, which forms β450. It is not yet known whether this is physically related to the two others.

(521)

σ Pegasi, $22^h\ 47^m$, $+9°\ 18'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
7996J	1916 Nov. 25	+10	−0.91	−613	0.9	−0.0631	−0.015	
9829H	1917 July 18	+ 8	+ .67	−378	0.9	− 360	+ 4	
9853T	19	+13	+ .65	−377	1.0	− 392	− 44	
9926T	25	−10	+ .58	−371	0.9	− 342	+ 23	
10987T	Nov. 3	+12	− .80	−270	0.8	− 289	− 1	
11018J	4	+ 8	− .81	−269	1.0	− 281	+ 7	
11090J	6	0	− .82	−267	0.8	− 240	+ 64	
13772J	1918 July 31	−11	+ .51	0	0.9	0	0	
13799T	Aug. 1	0	+ .49	+ 1	0.9	− 32	− 48	
17455h	1919 July 16	+17	+ .69	+350	0.8	+ 376	+ 51	
17477D	17	+10	+ .68	+351	0.9	+ 350	+ 10	
18838J	Nov. 12	+ 5	− .85	+469	1.0	+ 417	− 16	
19058J	Dec. 3	+ 3	− .91	+490	0.6	+ 485	+ 57	
19070D	4	+ 6	− .91	+491	0.9	+ 427	− 29	Star 2 missing.
19104J	15	+12	− .89	+502	0.6	+ 427	− 19	

$+12.90c - 1.99\mu - 1.84\pi = -0.0361$ mm. $c = -0.0010$ mm.
$+186.18 \quad -5.28 = +1.7933$ $\mu = +.00968$.
$+7.24 = -.0352$ $\pi = +.00194$.
Probable error for unit weight, ± .0016 mm. = ±″.023.
Annual proper motion in R. A., + ″.516 ±″.006.
Relative parallax, **+ ″.028±″.009.**

Other determinations of this parallax are: Yale (heliometer), +0″.011±0″.040; Yerkes, +0″.043±0″.010; Mount Wilson (spectroscopic), +0″.038. Boss gives +0″.517 for the proper motion.

(522)

π Cephei, $23^h\ 5^m$, $+74°\ 51'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
8115T	1916 Dec. 2	− 3	−0.91	−342	1.0	−0.0025	−0.004	
8189T	6	+10	− .91	−338	1.0	− 11	+ 16	
9894H	1917 July 21	+ 7	+ .68	−111	1.0	− 27	− 1	
9907T	22	+11	+ .67	−110	1.0	− 70	− 64	
9927T	25	−14	+ .64	−107	0.6	0	+ 38	
9945H	27	0	+ .61	−105	0.9	0	+ 38	
11154C	Nov. 8	+10	− .80	− 1	0.9	− 43	− 16	
11182T	9	+ 8	− .81	0	1.0	− 19	+ 19	
11241J	10	− 6	− .81	+ 1	0.8	− 42	− 15	
13596J	1918 July 14	+ 4	+ .75	+247	0.6	0	+ 50	
13652T	18	+15	+ .71	+251	1.0	− 25	+ 35	
13748J	28	+ 2	+ .59	+261	1.0	− 61	− 35	
14881J	Nov. 30	− 2	− .90	+386	1.0	− 33	+ 15	
15080h	Dec. 18	+ 9	− .89	+404	1.0	− 86	− 61	
15134T	19	+ 9	− .89	+405	0.9	− 8	+ 53	

$+13.70c + 7.55\mu - 2.56\pi = -0.0437$ mm. $c = -0.0030$ mm.
$+90.01 \quad -2.18 = -.0494$ $\mu = -.00029$.
$+8.42 = +.0101$ $\pi = +.00022$.
Probable error for unit weight, ± .0017 mm. = ±″.025.
Annual proper motion in R. A., − ″.016 ±″.010.
Relative parallax, **+ ″.003±″.008.**

Other determinations of this parallax are: Mount Wilson (spectroscopic), +0″.011; Swarthmore, −0″.020±0″.012. Boss gives +0″.013 for the proper motion.

There are at least three stars in this system. The image on the plates is the combined image of a close double (OΣ489), the components differing by two magnitudes. Comparatively rapid orbital motion is present. The brighter star is a spectroscopic binary.

(523)

70 Pegasi, $23^h\ 24^m$, $+12°\ 13'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
563H	1914 Nov. 4	+19	−0.72	−758	0.8	−0.0086	+0.022	
593b	6	−24	− .73	−756	1.0	− 85	+ 22	
4310H	1915 Dec. 15	+ 8	− .90	−352	0.9	− 67	− 4	
6116H	1916 July 20	− 7	+ .74	−134	0.6	− 105	− 67	Two exposures.
6156h	23	− 4	+ .71	−131	0.7	− 63	+ 9	Two exposures.
8085J	Dec. 1	0	− .89	0	0.9	− 71	− 54	
8118T	2	− 2	− .89	+ 1	1.0	− 38	− 6	
9832H	1917 July 18	− 5	+ .76	+229	0.9	0	+ 39	
9856T	19	+ 3	+ .75	+230	1.0	− 63	− 53	
9930T	25	0	+ .70	+236	0.9	+ 22	+ 72	
11465C	Dec. 2	+ 5	− .89	+366	0.9	+ 11	+ 20	
11481C	12	−10	− .91	+376	0.9	− 16	− 20	
13648J	1918 July 17	0	+ .77	+593	0.8	0	− 6	
14958J	Dec. 8	+ 4	− .91	+737	1.0	+ 14	− 22	
15030T	17	+21	− .90	+746	1.0	+ 58	+ 41	

$$\begin{array}{rrrrl}
+13.30\,c+ & 14.22\,\mu- & 3.62\,\pi= & -\ 0.0398\ \text{mm.} & c=-0.0041\ \text{mm.}\\
 & +294.36 & +0.47 = & +\ .1941 & \mu=+\ .00086.\\
 & & +8.97 = & +\ .0085 & \pi=-\ .00076.
\end{array}$$

Probable error for unit weight, ± .0018 mm. = ±″.026.
Annual proper motion in R. A., + ″.046 ±″.006.
Relative parallax, **− ″.011±″.009.**

The spectroscopic determination of this parallax at Mount Wilson yields +0″.014. Boss gives +0″.059 for the proper motion.

(524)

72 Pegasi, $23^h\ 29^m$, $+30°\ 46'$.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
9991h	1917 July 30	+ 4	+0.65	−367	0.8	−0.0060	−0.015	
10003T	31	+17	+ .65	−366	1.0	− 45	+ 7	
11466C	Dec. 2	+ 8	− .89	−242	0.9	− 27	+ 18	
11556C	17	−20	− .90	−227	1.0	− 55	− 25	
11629J	22	+ 5	− .89	−222	0.8	+ 6	+ 63	
13649J	1918 July 17	+ 2	+ .78	− 15	0.9	0	+ 15	
13654T	18	+10	+ .77	− 14	0.8	0	+ 16	Two exposures.
13805T	Aug. 1	+16	+ .64	0	0.9	− 58	− 70	
14823J	Nov. 26	0	− .86	+117	1.0	+ 21	+ 29	
14856T	27	+14	− .87	+118	0.9	− 33	− 48	
14893h	Dec. 1	+10	− .89	+122	0.8	− 16	− 23	
17481D	1919 July 17	+ 6	+ .78	+350	0.5	+ 96	+ 96	
17520D	22	+14	+ .74	+355	0.9	+ 20	− 15	

$$\begin{array}{rrrrl}
+11.20\,c- & 4.92\,\mu- & 0.63\,\pi= & -\ 0.0175\ \text{mm.} & c=-0.0011\ \text{mm.}\\
 & +59.91 & +2.01 = & +\ .0719 & \mu=+\ .00110.\\
 & & +7.16 = & +\ .0044 & \pi=+\ .00021.
\end{array}$$

Probable error for unit weight, ± .0019 mm. = ±″.028.
Annual proper motion in R. A., + ″.059 ±″.013.
Relative parallax, **+ ″.003±″.011.**

The spectroscopic determination of this parallax at Mount Wilson yields +0″.009. Boss gives +0″.055 for the proper motion.

This is a close binary (β 720) whose components are equally bright. The orbital motion is comparatively rapid.

(525)

λ Piscium, 23h 37m, +1° 14′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
186J	1914 Sept. 30	−19	−0. 21	−448	0. 7	+0. 0064	+0. 038	
203H	Oct. 1	−37	− . 23	−447	0. 6	− 2	− 57	
2756T	1915 Aug. 4	+11	+ . 64	−140	0. 8	− 32	− 16	
2772J	6	0	+ . 60	−138	0. 6	0	+ 32	
2775T	7	+ 6	+ . 59	−137	0. 9	0	+ 32	
4338T	Dec. 22	+ 2	− . 90	0	0. 8	− 102	− 26	
6207h	1916 July 27	−12	+ . 71	+218	0. 8	− 56	+ 72	
6229H	28	−22	+ . 70	+219	0. 9	− 142	− 53	
6252J	29	− 6	+ . 68	+220	0. 9	− 138	− 45	
8192T	Dec. 6	0	− . 89	+350	0. 9	− 203	− 53	
8244H	10	+ 6	− . 91	+354	0. 6	− 129	+ 57	
8279J	22	+17	− . 89	+366	0. 8	− 169	+ 4	
8309T	23	+ 9	− . 89	+367	0. 6	− 131	+ 58	
9970H	1917 July 29	+15	+ . 68	+585	0. 8	− 192	+ 1	

$$\begin{array}{rrrl@{\qquad}l} +10.70\,c+ & 11.77\,\mu+ & 0.15\,\pi= & -\ 0.0989 \text{ mm.} & c=-0.0066 \text{ mm.} \\ & +107.61 & -2.82\ = & -\ .3411 & \mu=-\ .00240. \\ & & +5.50\ = & +\ .0160 & \pi=+\ .00187. \end{array}$$

Probable error for unit weight, ± .0020 mm. = ±″.029.
Annual proper motion in R. A., − ″.128 ±″.011.
Relative parallax, + **″.027 ±″.012.**

No other determination of this parallax has been published. Boss gives −0″.135 for the proper motion.

This star was first referred to a set of three comparison stars which yielded −0″.205 for the proper motion. This differs so much from Boss and Porter that we examined the comparison stars for proper motion and found that one of them moves 0″.2 a year. This star being rejected, a new set of comparison stars gave the results quoted above.

(526)

Anonymous, 23h 37m, +1° 7′.

Plate number and observer.	Date.	Hour angle.	Parallax factor.	Time in days.	Wt.	Solution.	Resid.	Remarks.
		min.				*mm.*	″	
186J	1914 Sept. 30	−19	−0. 21	−448	0. 7	−0. 0264	+0. 057	
203H	Oct. 1	−37	− . 23	−447	0. 6	− 319	− 25	
2651J	1915 July 18	− 2	+ . 80	−157	0. 5	− 172	+ 18	
2756T	Aug. 4	+11	+ . 64	−140	0. 8	− 157	+ 34	
2772J	6	0	+ . 60	−138	0. 6	− 182	− 3	
2775T	7	+ 6	+ . 59	−137	0. 9	− 214	− 50	
4338T	Dec. 22	+ 2	− . 90	0	0. 8	− 196	− 70	
6207h	1916 July 27	−12	+ . 71	+218	0. 8	− 24	+ 36	
6229H	28	−22	+ . 70	+219	0. 9	− 67	− 26	
6252J	29	− 6	+ . 68	+220	0. 9	− 43	+ 9	
8192T	Dec. 6	0	− . 89	+350	0. 9	0	+ 31	
8244H	10	+ 6	− . 91	+354	0. 6	0	+ 28	
8279J	22	+17	− . 89	+366	0. 8	− 20	− 7	
8309T	23	+ 9	− . 89	+367	0. 6	− 11	+ 6	
9970H	1917 July 29	+15	+ . 68	+585	0. 8	+ 73	− 15	

$$\begin{array}{rrrl@{\qquad}l} +11.20\,c+ & 10.99\,\mu+ & 0.55\,\pi= & -\ 0.1130 \text{ mm.} & c=-0.0137 \text{ mm.} \\ & +108.83 & -3.44\ = & +\ .2404 & \mu=+\ .00363. \\ & & +5.82\ = & -\ .0128 & \pi=+\ .00124. \end{array}$$

Probable error for unit weight, ± .0015 mm. = ±″.022.
Annual proper motion in R. A., +″.194 ±″.008.
Relative parallax, **+″.018 ±″.009.**

No other determination of this parallax has been published. This tenth magnitude star is the one referred to in connection with λ Piscium, the preceding star in this list. After rejecting it for comparison purposes, it was referred to the same three stars that were used for λ Piscium. One early and one late plate were measured in declination, and these showed that the proper motion in this direction is nearly zero. The total proper motion therefore is 0.″194 in 90°. The position of this star for 1900 is $23^{h}\ 37^{m}\ 7^{s}$, $+1°\ 6'\ 50''$.

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THE VEGETATION OF THE ALPINE REGION OF THE ROCKY MOUNTAINS IN COLORADO

BY

THEODORE HOLM

CONTENTS.

THE VEGETATION OF THE ALPINE REGION OF THE ROCKY MOUNTAINS IN COLORADO.

By Theodore Holm.

(With plates 1-7.)

INTRODUCTION.

With the object in view to present a sketch of the Alpine flora in Colorado, I have naturally felt induced to compare this with the Arctic, since no small number of species are common to both regions. The material upon which my observations are based was collected by myself in Colorado during the summers of 1896 and 1899, from the beginning of July to the middle of September. The mountains as follows were explored: The mountain range along Clear Creek Canyon from Golden City to the headwaters, including Torreys Peak, Grays Peak, and Mount Kelso; James Peak near Central City; Longs Peak near Estes Park; Mount Massive and Mount Elbert near Leadville; Pikes Peak; furthermore Thompsons Canyon on Longs Peak, which is located so as to contain a purely Alpine vegetation. The altitude of the Alpine region lies between 3,350 and 4,300 meters.

Moreover, I have had the opportunity to visit the polar regions as the naturalist of the Danish Dijmphna Expedition to the Kara Sea in the years 1882–1883, and as the naturalist of two Danish expeditions to Greenland in 1884–1886 under the auspices of the Danish Government.

Having thus had the opportunity to study the Arctic as well as the Alpine flora, I thought a comparison of both might prove useful to solve the question relative to the origin of these floras, and especially with reference to the singular, geographical distribution of certain species, which, so far, has been explained in different manners. Beside discussing the geographical distribution, I have also given much attention to the vegetative structures of these plants, and the drawings, which I have inserted, may give the reader some idea of the aspect of some of these high-Alpine types.

Dr. E. L. Greene identified most of the Compositae; Dr. W. J. Beal some of the Gramineae, and Dr. P. A. Rydberg has kindly named the Salices and Potentilla. My Arctic herbarium was augmented very considerably by the liberal gifts of the Swedish Riks-Museum through Dr. C. A. M. Lindman, and of the Canadian Geological Survey through my friend, the late Mr. James M. Macoun.

Chapter 1.

ENUMERATION OF THE ALPINE SPECIES OF VASCULAR PLANTS OBSERVED IN THE ROCKY MOUNTAINS OF COLORADO.

SELAGINELLACEAE.

Selaginella rupestris L. Very common among rocks, on bowlder fields, etc., on all the higher mountains from 12,000 to 14,000 feet.

CONIFERAE.

Juniperus communis L. var. *alpina* Gaud. Rare: Mount Massive, 12,000 feet.

GRAMINEAE.

Phleum alpinum L. Infrequent: Damp places among rocks, Mount Elbert and Mount Massive, 12,000 feet.

Agrostis varians Trin. Rare: James Peak, 13,000 feet; bowlder field on Longs Peak, 12,000 feet.

A. canina L. var. Rare on dry slopes of Mount Massive, 12,000 feet.

Calamagrostis Canadensis Beauv. var. **acuminata** Vasey. Very rare in the Alpine region: Steven's mine near Monnt Kelso, 11,500 feet.

C. purpurascens R. Br. Not common: Bowlder field on Longs Peak, 12,000 feet; Grays Peak, 12,500 feet; Mount Massive, 12,000 feet.

Deschampsia caespitosa Beauv. Frequent in wet, mossy ground along brooks and near the snow banks, very variable: James Peak, 13,000 feet; Mount Kelso; Grays Peak; Mount Massive, 12,000 feet; Thompsons Canyon on Longs Peak, 10,500 feet.

Trisetum subspicatum Beauv. Frequent in dry, stony ground, quite variable: James Peak, 13,000 feet; Mount Elbert; Mount Kelso; Mount Massive, 12,000 feet.

Avena Mortoniana Scrib. Very rare in mossy ground on James Peak, 13,000 feet.

Poa rupicola (Vas.) Nash. Frequent on dry rocks: James Peak, 13,000 feet; Grays Peak, 12,500 feet; Mount Elbert; Mount Massive, 12,000 feet.

P. flexuosa Wahlenb. Frequent among rocks, in dry ground: Grays Peak; Mount Elbert, 12,500 feet; Mount Kelso; Longs Peak, 12,000 feet; Steven's mine, 11,500 feet.

P. gracillima Vas. Abundant in thickets of *Salix glaucops* along brooks on Mount Kelso, 11,500 feet.

Poa Fendleriana Steud. (**P. Californica** Vasey). Very rare near snow banks: James Peak, 13,000 feet; Grays Peak; Mount Elbert, 12,500 feet.

P. alpina L. Rare: Bowlder field on Longs Peak, 12,500 feet; along brooks in thickets of *Salix glaucops* Mount Kelso, 11,500 feet; Mount Massive; Mount Elbert, 12,000 feet.

P. Lettermannii Vas. (pl. 7, figs. 67–70). Very rare: In wet moss, summit of Pikes Peak, 14,147 feet.

Festuca ovina L. Common in dry ground: James Peak, 13,000 feet; Longs Peak; Mount Massive; Mount Kelso; Mount Elbert, 12,000 feet.

F. ovina L. var. **supina** Hack. (pl. 7, figs. 71–74). Less frequent, in crevices of rocks: Pikes Peak, 14,147 feet; Mount Elbert; Grays Peak; Longs Peak, 12,500 feet.

Agropyrum violaceum (Horn.) Lge. Very rare on dry slopes of Mount Kelso, 12,000 feet.

A. Scribneri Vas. Very rare, among *Dryas*, James Peak, 13,000 feet; bowlder field on Longs Peak, 12,000 feet; Grays Peak, 12,500 feet; Mount Elbert, 12,000 feet.

CYPERACEAE.

Elyna Bellardi (All.). Frequent on most of the peaks.

Carex nardina Fr. Very rare: Mount Elbert, 12,000 feet.

C. festiva Dew. Seldom Alpine: Grays Peak, 13,000 feet.

C. festiva Dew. var. **Haydeniana** (Oln.). W. Boott. Frequent on grassy slopes: Mount Kelso; Mount Massive, 12,000 feet; Thompsons Canyon on Longs Peak, 10,500 feet.

C. festiva Dew. var. **decumbens** Holm. Abundant on grassy slopes of Mount Kelso, 12,000 feet.

C. petasata Dew. Rare in dry, stony ground: James Peak, 13,000 feet; Mount Massive; Mount Kelso, 12,000 feet.

C. siccata Dew. In dry, stony ground: Mount Kelso, 12,000 feet.

C. Bonplandii Kunth var. **minor** Olney. Very rare: Near the snow banks, headwaters of Clear Creek, 12,000 feet.

C. alpina Sw. var. **Stevenii** Holm. Seldom Alpine: Damp places on Grays Peak, 12,000 feet.

C. melanocephala Turcz. In thickets of *Salix glaucops* on Mount Kelso, 11,500 feet.

C. atrata L. (pl. 7, figs. 63–65). Rare in bowlder fields on Longs and Grays Peaks, 12,500 feet.

C. chalciolepis Holm (pl. 7, figs. 60–62). Frequent in dry ground: James Peak, 13,000 feet; Mount Kelso; Mount Massive; Mount Elbert; Grays and Longs Peaks, 12,000 feet; Thompsons Canyon on Longs Peak, 10,500 feet.

C. rigida Good. Very rare: Near the snow banks, headwaters of Clear Creek, 11,500 feet.

C. scopulorum Holm. Seldom Alpine: In swamps from Steven's mine to Mount Kelso and Grays Peak, 12,000 feet.

C. chimaphila Holm. Along brooks: Longs Peak, 12,000 feet.

C. elynoides Holm. Not infrequent on dry slopes: Mount Massive; Mount Kelso, 12,000 feet.

C. rupestris All. Very scarce: Dry slopes of James Peak, 13,000 feet; Mount Elbert; Longs Peak, 12,000 feet; Grays Peak, 12,500 feet.

C. nigricans C. A. Mey. Thompsons Canyon on Longs Peak, 10,500 feet.

C. pyrenaica Walenb. Bowlder fields: Grays Peak, 13,000 feet; Longs Peak, 12,000 feet.

C. misandra R. Br. Very rare: Along brooks on Grays Peak, 12,000 feet.

C. capillaris L. (pl. 7, fig. 66). Abundant, but very small, at Bear Lake in Thompsons Canyon on Longs Peak, 10,700 feet.

JUNCACEAE.

Luzula spicata D C. Frequent in dry ground: Grays Peak; James Peak, 13,000 feet; Longs Peak, 12,500 feet; Mount Massive; Mount Elbert, 12,000 feet; headwaters of Clear Creek, 11,500 feet.

Juncus Parryi Engelm. (pl. 7, fig. 59). Abundant near snow banks; headwaters of Clear Creek, 11,500 feet; Thompson's Canyon on Longs Peak, 10,500 feet.

J. Drummondii E. Mey. Common on grassy slopes: Mount Massive; Mount Kelso, 12,000 feet.

J. biglumis L. Very rare, along brooks on Longs Peak, 12,000 feet.

J. triglumis L. With the preceding; also on Grays Peak, 12,000 feet.

J. castaneus Sm. Along brooks, in thickets of *Salix glaucops:* Grays Peak; Mount Kelso, 12,000 feet.

J. Mertensianus E. Mey. Along brooks: Mount Kelso, 12,000 feet.

LILIACEAE.

Lloydia serotina Reich. Abundant on grassy slopes: James Peak, 13,000 feet; Mount Massive, 12,000; Thompsons Canyon, 10,500 feet.

Zygadenus glaucus Nutt. Very seldom Alpine: Thompsons Canyon, 10,500 feet; in swamps.

SALICACEAE.

Salix petrophila Rydb. James Peak, 13,000 feet; near snow banks, headwaters of Clear Creek, 11,500 feet; Thompsons Canyon, 10,500 feet.

S. reticulata L. (pl. 6, figs. 42–53). Infrequent: Grassy slopes on Mount Massive, 12,000 feet; Mount Elbert; Mount Kelso, 11,500 feet.

S. chlorophylla Ands. Near Steven's mine, Mount Kelso, 11,000 feet.

S. glaucops Ands. Common along brooks: Mount Massive; Mount Elbert, between 11,000 and 12,000 feet; Mount Kelso, 11,000 feet.

BETULACEAE.

Betula glandulosa Michx. Seldom Alpine: At Bear Lake in Thompsons Canyon on Longs Peak, 10,500 feet.

POLYGONACEAE.

Eriogonum flavum Nutt. Seldom Alpine: Among rocks on Torreys Peak, 12,000 feet; on grassy slopes of Mount Massive, 11,500 feet.

Polygonum viviparum L. Frequent: James Peak, 13,000 feet; bowlder fields on Longs Peak; Mount Massive; Mount Kelso; Mount Elbert; Grays Peak, 12,000 feet.

P. bistortoides Pursh. Abundant on grassy slopes: James Peak, 13,000 feet; Mount Massive, 12,000 feet.

Oxyria digyna Campd. Frequent among rocks: Longs Peak, 12,500 feet; Mount Kelso; Mount Elbert, 12,000 feet.

PORTULACACEAE.

Claytonia megarrhiza Torrey. Frequent, but only at the highest elevations among bowlders: Grays Peak; Pikes Peak, from 13,000 feet upward.

Calandrinia pygmaea Gr. (pl. 1, figs. 8–9). Near the snow banks on Mount Kelso; Mount Massive, 12,000 feet; headwaters of Clear Creek, same elevation.

ILLECEBRACEAE.

Paronychia pulvinata Gr. (pl. 5, fig. 41). Very rare, but evidently overlooked: On dry, stony slopes of Grays Peak, 13,000 feet.

CARYOPHYLLACEAE.

Silene acaulis L. Frequent in the Alpine region: James Peak, 13,000 feet; Grays Peak; bowlder fields on Longs Peak, 12,500 feet; Mount Massive; Mount Kelso; Mount Elbert, 12,000 feet.

Lychnis montana Wats. (pl. 1, figs. 2–4). Rare: Grays Peak, 12,000 feet; bowlder fields on Longs Peak, 12,000 feet; Pikes Peak, 14,000 feet.

Cerastium alpinum L. Rare on dry, stony slopes: James Peak, 13,000 feet; Grays Peak; bowlder field on Longs Peak, 12,500 feet.

C. arvense L. var. **occidentale** (Grne.). Abundant in thickets of *Salix glaucops:* from Stevens's mine to Grays Peak, 11,500 to 12,000 feet.

Stellaria umbellata Turcz. (pl. 1, figs. 5-7). Infrequent: Bowlder field on Pikes Peak, 14,000 feet; Grays Peak; Longs Peak, 12,500 feet.

S. longipes Goldie. Infrequent: Along brooks, Grays Peak, 12,000 feet.

S. longipes Goldie var. **laeta** Wats. Not uncommon among dry rocks: Grays Peak, 12,500 feet; Mount Elbert, 12,000 feet.

Arenaria Fendleri Gr. Very seldom Alpine: James Peak, 13,000 feet; bowlder field on Longs Peak, 12,500 feet.

A. congesta Nutt. Very rare in the Alpine region: On dry slopes of Mount Massive, 12,000 feet.

Alsine propinqua (Richards). Rare on exposed rocks: Grays Peak, 12,500 feet.

A. verna Bartl. With the preceding.

A. biflora (L.) Wahl. Frequent on dry rocks: James Peak, 13,000 feet; Grays Peak; Longs Peak; Mount Massive; Mount Elbert, 12,000 feet.

Sagina Linnaei Presl. Rare in wet soil in thickets of *Salix glaucops:* Mount Kelso, 11,500 feet.

RANUNCULACEAE.

Anemone narcissiflora L. In crevices of rocks near snow banks: Mount Massive, 12,000 feet; swamp in Thompsons Canyon on Longs Peak, 10,500 feet.

Thalictrum alpinum L. Very rare: In damp ground on Grays Peak, 13,000 feet.

Ranunculus adoneus Gr. Abundant near snow banks: Headwaters of Clear Creek, 11,500 feet.

Caltha leptosepala D C. Abundant near snow banks on Mount Elbert, 11,500 feet; Mount Kelso and Grays Peak, 11,500 feet.

Trollius laxus Salisb. With the preceding.

PAPAVERACEAE.

Papaver nudicaule L. Grays Peak, 13,000 feet.

CRUCIFERAE.

Draba crassifolia Grah. Very rare: James Peak, 13,000 feet.

D. streptocarpa Gr. Seldom Alpine: Thompsons Canyon on Longs Peak, 10,500 feet; James Peak, 13,000 feet.

Thlaspi Coloradense Rydb. Abundant in bowlder fields on Pikes Peak, 14,147 feet.

Th. glaucum A. Nels. Rare: In dry soil, Mount Elbert, 11,500 feet.

Smelowskia calycina C. A. Mey. Very rare: Dry rocks, Mount Elbert, 12,000 feet.

Erysimum nivale Grne. Very rare: James Peak, 13,000 feet.

Cardamine cordifolia Gr. Rare above timber line; in thickets of *Salix glaucops:* along brooks, Grays Peak, 12,000 feet.

CRASSULACEAE.

Rhodiola rosea L. Very rare: Bowlder field on Longs Peak, 12,500 feet.

SAXIFRAGACEAE.

Saxifraga flagellaris Willd. Infrequent: Bowlder field on Longs Peak; Grays Peak, 12,500 feet; on dry rocks, Mount Massive; Mount Elbert, 12,000 feet; in damp, mossy ground with *Carex misandra* on Grays Peak, 12,000 feet; Pikes Peak, 14,000 feet; James Peak, 13,000 feet.

S. chrysantha (pl. 2, fig. 17). Infrequent: On moist slopes, Pikes Peak, 13,700 feet; Grays Peak, 12,000 feet; Longs Peak, 12,000 feet.

S. cernua L. (pl. 2, figs. 13-16).Rare: On grassy slopes of Pikes Peak, 13,700 feet; James Peak, 13,000 feet.

S. nivalis L. Not uncommon on grassy slopes, Pikes Peak, 13,700 feet; James Peak, 13,000 feet; bowlder field, Longs Peak, 12,500 feet; Mount Massive; Mount Elbert, 12,000 feet.

S. bronchialis L. (pl. 2, figs. 11-12). Rare; on dry rocks, Grays Peak, 12,000 feet.

S. punctata L. Very seldom Alpine: In sheltered, damp places under rocks in Thompsons Canyon on Longs Peak, 10,500 feet.

Heuchera bracteata Ser. Rare: Among rocks on James Peak, 13,000 feet; Mount Kelso, 11,500 feet.

ROSACEAE.

Sieversia Rossii R. Br. (pl. 2, fig. 10). Abundant: Grays Peak; James Peak, 13,000 feet; bowlder fields on Longs Peak; Mount Massive; Mount Kelso; Mount Elbert, 12,000 feet; at Bear Lake in Thompsons Canyon on Longs Peak, 10,700 feet.

Dryas octopetala L. Abundant on dry rocks, bowlder fields, etc.: James Peak, 13,000 feet; Mount Elbert; Mount Massive, 12,000 feet.

Fragaria vesca L. A few sterile specimens were found on a grassy slope of Mount Massive, 11,500 feet.

Potentilla glaucophylla Lehm. On grassy slopes: James Peak, 13,000 feet; Mount Massive; Grays Peak, 12,000 feet.

P. dissecta Pursh. On dry rocks: Longs Peak; Mount Massive, 12,000 feet.

P. fruticosa L. Very seldom Alpine: Near Stevens's mine and Grays Peak, 11,000 feet.

Sibbaldia procumbens L. Frequent, especially near the snow banks: Grays Peak; Mount Massive, 12,000 feet; Thompsons Canyon, 10,500 feet.

LEGUMINOSAE.

Trifolium nanum Torr. (pl. 2, figs. 18–19). On dry rocks: Pikes Peak, 14,000 feet; Grays Peak, 12,500 feet.

T. Parryi Gr. On grassy slopes, quite frequent: James Peak, 13,000 feet; Grays Peak; Mount Elbert; Mount Massive, 12,000 feet; Thompsons Canyon on Longs Peak, 10,500 feet.

T. dasyphyllum T. et Gr. In bowlder fields: Longs Peak, 12,000 feet; grassy slopes of James Peak, 13,000 feet; Mount Massive; Mount Elbert, 12,000 feet.

VIOLACEAE.

Viola bellidifolia Grne. (pl. 1, fig. 1). In damp moss at Black Lake in Thompsons Canyon on Longs Peak, 10,300 feet.

ONAGRACEAE.

Epilobium Hornemannii Reich. Very rare on grassy slopes of Grays Peak, 12,000 feet.

Chamaenerium latifolium (L.) Spach. Very rare: Grassy slopes of Mount Kelso, 12,000 feet.

UMBELLIFERAE.

Angelica Grayi C. et R. Frequent in thickets of willows along brooks: Mount Massive, 12,000 feet; Mount Kelso, 11,590 feet.

Pseudocymopterus montanus C. et R. Abundant on grassy slopes of Mount Massive, 11,500 feet.

Oreoxys humilis Raf. (pl. 3, fig. 20). Rare: On dry slopes, Pikes Peak, 13,740 feet.

O. alpina C. et R. Rare: Among rocks on Grays Peak, 13,000 feet; James Peak, 13,000 feet.

ERICACEAE.

Vaccinium caespitosum Michx. (pl. 7, figs. 54–55). Not uncommon on Mount Massive, 12,000 feet.

V. Myrtillus L. Infrequent in swamps: Thompsons Canyon on Longs Peak, 10,500 feet.

V. Myrtillus L. var. **microphyllum** Hook. (pl. 7, figs. 56–58). With the preceding.

Arctostaphylos Uva ursi L. Seldom Alpine: Dry, stony slopes of Mount Massive, 12,000 feet.

Kalmia glauca Ait var. **microphylla** Hook. (pl. 3, fig. 22). Rare: Swamp in Thompsons Canyon on Longs Peak, 10,500 feet.

PRIMULACEAE.

Primula angustifolia Torr. (pl. 3, fig. 24). On dry slopes, infrequent: At Bear Lake in Thompsons Canyon on Longs Peak, 10,700 feet; Mount Elbert; Mount Massive; Grays Peak, 12,000 feet; James Peak, 13,000 feet.

P. Parryi Gr. Abundant along Alpine brooks and in damp crevices of rocks: Thompsons Canyon on Longs Peak, 10,500 feet; Mount Massive; Grays Peak, 12,000 feet; near the snow banks, headwaters of Clear Creek, 11,500 feet.

Androsace Chamaejasme Koch. In damp ground at Bear Lake in Thompsons Canyon on Longs Peak, 10,700 feet.

A. subumbellata Small. (pl. 3, fig. 23). Very scarce in dry ground: Mount Massive, 12,000 feet; Grays Peak; Longs Peak, 12,500 feet.

GENTIANEAE.

Gentiana frigida Hnke. Frequent: On dry rocks, Mount Elbert; Longs Peak, 12,000 feet; in damp, gravelly soil, Grays Peak, 12,000 feet; near the snow banks, headwaters of Clear Creek, 11,500 feet; in thickets of *Salix glaucops* And., from Stevens's mine to Grays Peak, 11,500 feet.

G. plebeja Cham. var. **Holmii** Wettst. (pl. 4, fig. 29). Rare: Swamp in Thompsons Canyon on Longs Peak, 10,500 feet; grassy slope, Mount Elbert; Mount Massive, 12,000 feet.

Swertia perennis L. Very rare along brooks: Grays Peak, 12,000 feet.

POLEMONIACEAE.

Phlox caspitosa Nutt. var. **condensata** Gr. Abundant on bowlder fields: Longs Peak, 12,000 feet.

Polemonium viscosum Nutt. (pl. 3, fig. 25). Infrequent: Bowlder field on Longs Peak, 13,000 feet; Pikes Peak, 13,700 feet.

P. confertum Gr. Not uncommon on grassy slopes, Mount Kelso, 12,000 feet; Mount Massive; near the snow banks on Mount Elbert, 12,000 feet.

P. ingratum Grne. Very rare in bowlder fields on Longs Peak, 12,500 feet.

HYDROPHYLLACEAE.

Phacelia sericea Gr. Very rare on grassy slopes of Mount Kelso, 12,000 feet.

BORAGINACEAE.

Eritrichium argenteum White. (pl. 4, fig. 30). Not infrequent in dry ground, bowlder fields, etc.: Pikes Peak, 13,000 feet; Longs Peak; Grays Peak, 12,500 feet; Mount Elbert, 12,000 feet.

Mertensia ciliata Don. Rare on grassy slopes of Mount Massive, 12,000 feet.

M. lonchophylla Grne. In dense mats, James Peak, 13,000 feet; Grays Peak; bowlder field on Longs Peak, 12,000 feet.

M. alpina Don (pl. 5, figs. 39–40). Abundant in wet, mossy ground on Pikes Peak, 13,000 feet.

SCROPHULARIACEAE.

Pentstemon confertus Dougl. var. **coeruleo-purpureus** Gr. On grassy slopes of Mount Massive, 11,500 feet.

P. glaucus Grah. var. **stenosepalus** Gr. Seldom Alpine: Grays Peak, 12,000 feet; Mount Kelso, 11,500 feet.

Chionophila Jamesii Benth. (pl. 5, figs. 32–35). Abundant in bowlder fields on Longs Peak, 12,000 to 12,500 feet; at Bear Lake in Thompsons Canyon, 10,700 feet.

Synthyris alpina Gr. (pl. 5, figs. 36–38). Not uncommon in bowlder fields on Longs Peak, 12,000 to 12,500 feet; dry mountain slopes of Grays Peak, 13,000 feet.

Veronica alpina L. Frequent on grassy slopes: Grays Peak; Mount Massive, 12,000 feet; at Black Lake in Thompsons Canyon on Longs Peak, 10,300 feet.

Castilleja breviflora Gr. On grassy slopes: James Peak, 13,000 feet.

C. septentrionalis Lindl. Abundant on grassy slopes: James Peak, 13,000 feet; bowlder fields on Longs Peak, 12,500 feet; Mount Massive, 12,000 feet; Thompsons Canyon on Longs Peak, 10,500 feet.

Pedicularis Groenlandica Retz. Rare above timber line: Grassy slopes, Mount Massive, 12,000 feet; headwaters of Clear Creek, near the snow banks, 11,500 feet; Thompsons Canyon, 10,500 feet.

P. scopulorum Gr. Very rare: In grassy places along brooks, Grays Peak, 12,000 feet.

P. Parryi Gr. Seldom Alpine: In thickets of *Salix glaucops*, Mount Kelso 11,500 feet; Thompsons Canyon on Longs Peak, 10,500 feet.

CAMPANULACEAE.

Campanula rotundifolia L. Frequent among rocks on Mount Massive, 12,000 feet; in thickets of *Salix glaucops*, Grays Peak, 11,500 feet.

C. uniflora L. Rare on grassy slopes: James Peak, 13,000 feet; Grays Peak, 12,500 feet.

VALERIANACEAE.

Valeriana acutiloba Rydbg. Rare: Forming dense mats on grassy slopes of Mount Kelso, 12,000 feet.

COMPOSITAE.

Chrysopsis villosa Nutt. Very seldom Alpine: Dry slopes of Mount Massive, 11,500 feet.

Machaeranthera Pattersonii Grne. Rare on grassy slopes of Mount Kelso, 12,000 feet.

Stenotus pygmaeus T. et Gr. James Peak, 13,000 feet; on grassy slopes of Mount Massive, 12,000 feet.

Erigeron salsuginosus Gr. Very rare; in dense clumps near the snow banks on Mount Massive, 12,000 feet.

E. pinnatisectus (Gr.) A. Nels. (pl. 5, fig. 31). Infrequent: James Peak, 13,000 feet; on grassy slopes, Mount Massive, 12,000 feet.

E. uniflorus L. Not uncommon: James Peak, 13,000 feet; grassy slopes on Grays Peak, 12,500 feet; Mount Kelso, 12,000 feet; Mount Massive, 12,000 feet; near the snow banks, headwaters of Clear Creek, 11,500 feet; Thompsons Canyon on Longs Peak, 10,500 feet.

Antennaria alpina Gärtn. Frequent: James Peak, 13,000 feet; on dry slopes, Mount Massive; Mount Kelso, 12,000 feet; on rocks above the snow banks, headwaters of Clear Creek, 11,500 feet; near Black Lake in Thompsons Canyon on Longs Peak, 10,300 feet.

A. rosea (Nutt.) Grne. Very seldom Alpine: Mount Massive, 12,000 feet.

Actinella grandiflora T. et Gr. Frequent: James Peak, 13,000 feet; on grassy slopes near snow banks, Mount Elbert; Mount Massive; Mount Kelso; Grays Peak, 12,000 feet.

A. acaulis Nutt. Rare: James Peak, 13,000 feet.

Achillea Millefolium L. Seldom Alpine: On dry, stony slopes of Mount Elbert; Mount Kelso; Mount Massive, 12,000 feet.

Artemisia Norvegica Fr. Abundant on James Peak, 13,000 feet; on grassy slopes of Mount Kelso, 12,000 feet.

A. borealis Pall. Very rare: Dry slopes of Mount Massive, 12,000 feet.

A. scopulorum Gr. (pl. 3, figs. 21). Not uncommon; James Peak, 13,000 feet; on dry slopes, Mount Elbert; Mount Kelso, 12,000 feet; headwaters of Clear Creek, 11,500 feet; covering large areas, Thompsons Canyon on Longs Peak, 10,500 feet.

Arnica alpina L. var. Rare: In thickets of *Salix glaucops* near Steven's mine, 11,500 feet.

Senecio crassulus Gr. Very rare; grassy slopes of Mount Kelso, 12,000 feet.

S. dimorphophyllus Grne. (pl. 4, fig. 27). Abundant near the snow banks on Mount Massive, 12,000 feet.

S. Fremontii Gr. Rare: In dry soil on Grays Peak, 12,500 feet.

S. blitoides Grne. (pl. 4, fig. 26). Near the snow banks on Mount Elbert, 12,000 feet.

S. taraxacoides (Gr.) Grne. James Peak, 13,000 feet.

S. Holmii Grne. (pl. 4, fig. 28). Frequent near snow banks, Mount Elbert, 12,000 feet.

S. amplectens Gr. Rare: In crevices of rocks, Mount Massive, 12,000 feet.

Cnicus eriocephalus Gr. Not uncommon: James Peak, 13,000 feet; on grassy slopes, Mount Massive; Mount Kelso, 12,000 feet.

Traximon glaucum Nutt. Rare: Mount Massive, 12,000 feet.

According to the enumeration given above 170 species of vascular plants were observed on these mountains, in the Alpine region. Of these, 121 are dicotyledonous, 47 monocotyledonous, 1 belongs to the Gymnosperms and 1 to the Cryptogams. The largest family represented is the Compositae with 24 species, then follow the Cyperaceae with 21, the Gramineae with 18, the Caryophyllaceae with 13, the Scrophulariaceae with 10, the Rosaceae and Saxifragaceae each with 7 species, etc.

Some of these were also observed at lower elevations, and among those that appear to belong more properly to the Spruce zone the following may be mentioned: *Ranunculus adoneus, Draba streptocarpa, Cardamine cordifolia,* the 2 species of Arenaria, *Potentilla fruticosa, Saxifraga punctata, Antennaria rosea, Swertia perennis, Pedicularis Groenlandica* and *Parryi, Betula glandulosa, Zygadenus glaucus, Carex festiva,* and *Calamagrostis Canadensis.*

Chapter 2.

THE GEOGRAPHICAL DISTRIBUTION OF THE ALPINE SPECIES.

The accompanying table shows the geographical range of the Alpine species, especially with reference to the Arctic regions. However, to make the comparison more complete some other regions have been included, viz, the Alps and Pyrenees, Caucasus, Baikal, and Altai Mountains, besides the Himalayas. The table thus contains the species known also from Europe and Asia, while the remaining have only, so far, been recorded from North America.

	Arctic America.	Greenland.	Spitzbergen.	Scandinavia.	Arctic Russia.	Nova Zembla.	Alps and Pyrenees.	Caucasus.	Arctic Siberia.	Asiatic coast of Bering Strait.	Baikal and Altai Mountains.	Himalayas.
Anemone narcissiflora	....	....	....	....	....	....	+	+	....	+	+	+
Thalictrum alpinum	+	+	....	+	+	+	+	+	+	+	+	+
Papaver nudicaule	+	+	+	+	+	+	....	....	+	+	+	+
Draba crassifolia	....	+	....	+	....	....	....	....	....	....	....	....
Smelowskia calycina	+	....	....	....	....	....	....	....	....	....	+	....
Silene acaulis	+	+	+	+	+	+	+	....	....	+	....	....
Cerastium alpinum	+	+	+	+	+	+	+	....	+	+	....	....
Stellaria umbellata	....	....	....	....	....	....	....	....	....	....	+	....
S. longipes	+	+	+	+	....	+	....	....	+	+	+	....
Alsine verna	....	+	....	+	+	....	+	....	+	....	+	....
A. propinqua	+	+	....	....	+	....	....	....	+	....	+	....
A. biflora	+	+	+	+	+	+	+	....	....	+	....	....
Sagina Linnaei	+	+	....	+	+	....	+	+	+	+	+	....
Dryas octopetala	+	+	+	+	+	+	+	+	+	+	+	....
Potentilla fruticosa	+	....	....	+	....	....	....	+	....	....	+	+
Sibbaldia procumbens	....	+	....	+	+	....	+	+	....	....	+	+
Saxifraga flagellaris	+	+	+	....	+	+	....	+	+	....	+	+
S. cernua	+	+	+	+	+	+	+	....	+	+	+	+
S. nivalis	+	+	+	+	+	+	....	....	+	....	+	....
S. bronchialis	+	....	....	....	+	....	....	....	+	+	+	....
S. punctata	+	....	....	....	....	....	....	....	....	+	+	....
Rhodiola rosea	+	+	....	+	+	+	+	....	+	+	....	+
Epilobium Hornemanii	....	....	....	+	+	....	....	....	....	....	....	....
Chamaenerium latifolium	+	+	....	....	+	+	....	....	+	+	+	+
Erigeron uniflorus	+	+	+	+	+	+	+	+	+	+	+	....
Antennaria alpina	+	+	....	+	+	....	....	+	+	+	+	....
Achillea Millefolium	+	+	....	+	+	....	+	+	+	+	+	+
Artemisia Norvegica	....	....	....	+	....	....	....	....	+	....	....	....
A. borealis	+	+	....	....	+	+	....	....	+	+	+	....
Arnica alpina	+	+	+	+	....	+	....	....	+	+	....	....
Campanula rotundifolia	....	+	....	+	+	+	+	+	+	....	+	....
C. uniflora	+	+	+	+	....	+	....	....	....	+	....	....
Vaccinium Myrtillus	....	+	....	+	+	....	+	+	....	....	+	....
Arctostaphylos Uva ursi	+	+	....	+	+	....	+	+	+	....	+	....
Androsace Chamaejasme	+	....	....	....	+	+	+	+	+	+	+	+
Gentiana frigida	....	....	....	....	....	....	+	+	+	+	....	....
Swertia perennis	....	....	....	....	....	....	+	+	....	....	+	....
Veronica alpina	....	+	....	+	+	....	+	....	+	....	....	....
Pedicularis Groenlandica	....	?	....	....	....	....	....	....	....	....	....	....
Polygonum viviparum	+	+	+	+	+	+	+	+	+	+	+	+
Oxyria digyna	+	+	+	+	+	+	+	+	+	+	+	+
Betula glandulosa	+	+	....	....	....	....	....	....	....	....	+	....
Salix reticulata	+	+	+	+	+	+	+	....	+	+	+	....
Lloydia serotina	+	....	....	....	+	+	+	+	+	+	+	+
Luzula spicata	+	+	....	+	+	+	+	+	+	+	+	+
Juncus biglumis	+	+	+	+	+	+	....	....	+	+	....	....
J. triglumis	+	+	....	+	+	....	+	+	....	....	+	+

	Arctic America.	Greenland.	Spitzbergen.	Scandinavia.	Arctic Russia.	Nova Zembla.	Alps and Pyrenees.	Caucasus.	Arctic Siberia.	Asiatic coast of Bering Strait.	Baikal and Altai Mountains.	Himalayas.
J. castaneus	+	+	......	+	+	......	+	......	......	+	+	......
Elyna Bellardii	+	+	......	+	+	......	+	+	+	+	+	......
Carex nardina	+	+	+	+	+	......	......	......	......	......	......	......
C. festiva	+	+	......	+	......	......	......	......	......	......	......	......
C. siccata	......	......	......	......	......	......	......	......	?	......	+	......
C. melanocephala	......	......	......	......	......	......	......	+	......	......	+	......
C. atrata	......	+	......	+	......	......	+	+	......	......	+	+
C. rigida	+	+	......	+	+	+	......	+	+	+	+	+
C. rupestris	+	+	+	+	+	+	+	......	......	......	......	......
C. pyrenaica	......	......	......	......	......	......	+	......	......	......	......	......
C. misandra	+	+	+	+	+	+	+	+	+	+	+	......
C. capillaris	......	+	......	+	+	......	+	+	......	+	+	......
Phleum alpinum	+	+	......	+	+	......	+	+	......	+	+	+
Agrostis canina var	......	+	......	+	+	......	......	......	......	......	+	......
Calamagrostis purpurascens	+	+	......	......	......	......	......	......	......	......	......	......
Deschampsia caespitosa	......	......	......	+	+	......	+	+	+	......	+	+
Trisetum subspicatum	+	+	+	+	+	+	+	+	+	+	+	+
Poa flexuosa	+	+	+	+	+	+	......	......	+	+	+	+
P. alpina	+	+	+	+	+	+	+	+	......	......	+	+
Festuca ovina	+	+	+	+	+	+	+	+	+	+	+	+
F. ovina var. *supina*	+	+	+	+	+	+	......	......	+	+	......	......
Agropyrum violaceum	+	+	......	+	......	......	......	......	......	......	......	......
Juniperus communis var. *alpina*	......	+	......	+	+	......	+	......	......	......	+	......

It will be seen from this table that 63 of the Alpine species occur also in the Arctic regions and that 31 of these are even circumpolar, viz:

Thalictrum alpinum.
Papaver nudicaule.
Silene acaulis.
Cerastium alpinum.
Stellaria longipes.
Alsine propinqua.
A. biflora.
Sagina Linnaei.
Dryas octopetala.
Saxifraga flagellaris.
S. cernua.
S. nivalis.
Rhodiola rosea.
Chamaenerium latifolium.
Artemisia borealis.
Antennaria alpina.
Erigeron uniflorus.
Arnica alpina.
Campanula uniflora.
Androsace Chamaejasme.
Polygonum viviparum.
Oxyria digyna.
Salix reticulata.
Lloydia serotina.
Luzula spicata.
Juncus biglumis.
Carex rigida.
C. misandra.
Trisetum subspicatum.
Poa flexuosa.
Festuca ovina.

The Arctic element is distributed as follows: Fifty-three species are known from Greenland 49 from Arctic Russia, 49 from Arctic North America, 39 from Arctic Siberia, 32 from Nova Zembla, 24 from Spitzbergen, 51 are known also from Scandinavia, and by extending the comparison to the Alpine regions of the mountains in Europe and Asia 50 of these Arctic-Alpine species occur also in Baikal and Altai Mountains, 39 in the Alps and Pyrenees, 32 in Caucasus, and finally 24 in the Himalayas.

Absent from the polar regions but recorded from some mountains farther south in Europe or Asia we observe *Stellaria umbellata* from Baikal; *Swertia perennis* from the Alps and Pyrenees, beside Caucasus; *Carex pyrenaica* from the Alps and Pyrenees, Caucasus, Japan, and New Zealand; *Carex siccata* from Baikal, and finally *Carex melanocephala* from Caucasus, Baikal, and Turkestan. Of these the last species, *C. melanocephala,* was identified by the late C. B.

Clarke, who examined my specimens and furnished me with notes on the synonymy. According to this author *Carex nova* Bail is identical with this species (in litt. Mar. 27, 1902).

Anemone narcissiflora I have enumerated as occurring in the polar regions, but it is only in the northeastern corner of Asia that it extends so far north and only as the var. *monantha* D C. Farther south the species shows an enormous geographical distribution throughout the Northern Hemisphere in the mountains: The Alps of Switzerland, the Pyrenees, Jura, Caucasus, Cappadocia, Ural, Altai, Davuria, Kamtschatka, St. Lawrence, Unalaska, Alaska, and Colorado, where it occurs with several well-marked forms.

Gentiana frigida genuina is only known from two stations within the Arctic region, viz, St. Lawrence Bay and Arakamtschetschene Island (Siberia). It is also a native of the Carpathian Mountains.

Concerning *Pedicularis Groenlandica*, it is very doubtful whether this species was ever collected in Greenland, although it has been reported from Labrador and Hudson Bay. In the Rocky Mountains it extends as far south as to the borders of New Mexico. *Calamagrostis purpurascens* is rare in Greenland and is known only, so far, from Fort Yukon and Bernard Harbor in Arctic America.

Finally may be mentioned that some few of these species are also Alpine in the Atlantic States, viz, *Silene acaulis, Alsine verna, Sibbaldia procumbens, Rhodiola rosea, Artemisia borealis, Veronica alpina, Polygonum viviparum, Oxyria digyna, Betula glandulosa, Luzula spicata, Carex rigida, C. capillaris, Trisetum subspicatum, Phleum alpinum, Poa alpina,* and *Agropyrum violaceum.*

Chapter 3.

THE HISTORY OF THE ALPINE FLORA.

We have seen from the enumeration of the species and the subsequent tabulation of those which are common to both worlds that the Alpine vegetation is composed of members of the present Arctic flora, of members of the mountainous flora throughout the Northern Hemisphere, and finally of types peculiar to North America. In other words, some of these plants exhibit a geographical distribution of enormous range. It is altogether a commingling of types having originated from centers very remote and comprising not a few members of the circumpolar flora. Nevertheless when we consider the data given with reference to the corresponding vegetation, the Alpine, of the European Mountains, we obtain exactly the same result, the composition of types being principally the same: Alpine, endemic, Arctic, and circumpolar.

The Arctic, and especially the circumpolar element, naturally points toward the conclusion that these plants formerly belonged to the Arctic flora, but having been driven south during the glacial epoch they sought refuge on these mountains. In Europe the important discovery of fossil glacial plants proved the correctness of this supposition, and Nathorst [1] has offered an excellent explanation of this problem. This naturalist succeeded in detecting a number of leaves of Arctic plants in glacial deposits in southern Sweden and Germany, among which were *Salix polaris, S. herbacea, S. reticulata, Dryas octopetala, Betula nana,* etc. In the lowlands of Zürich, Switzerland, Nathorst made the same discovery, and it is a most important fact that *Salix polaris* should occur there in a fossil state, since it is a native of the most northern regions. Some of the other plants—for instance, *Dryas octopetala, Polygonum viviparum, Azalea procumbens,* etc.—are now inhabitants of the Alps as well as of the Arctic regions. Thus the lowlands of middle Europe did harbor an Arctic vegetation during the glacial epoch which afterwards returned to the north when the ice receded, and most probably accompanied by Alpine species, natives of the European Alps. Some Arctic species were, however, able to persist in these mountains, notably Dryas, Azalea, Polygonum, etc. Thus they are in recent time inhabitants of both the Arctic and Alpine regions, while *Salix polaris,* unable to endure even the Alpine climate, returned to the polar regions.

In the Carpathian Mountains several Siberian species are known to occur, some of which are common to the Alps, some others not. Even the Caucasus is, in spite of the southern latitude, remarkably rich in glacial species, and it seems natural to suppose that if they were able to reach these mountains the Alpine flora might, at least partly, have been able to migrate north, thus entering the Arctic regions. The recent Arctic flora may thus contain species contributed from the southern mountains intermingled with those that originated in the polar regions. With regard to Asia, Nathorst calls attention to the enormous distribution of the flora of Altai due to the absence of inland ice. Thus the species were not prevented from migration to the north or south in accordance with climatologic conditions. As a matter of fact, members of the Altai flora are now to be found not only in the Arctic regions, but also in the Himalayas, and several found their way to Arctic America and Greenland, where they are still in existence. With respect to North America, the Rocky Mountains have no doubt contributed to the Arctic flora, inasmuch as they are harboring a number of glacial species.

The power of certain Arctic species to adapt themselves so as to thrive and persist on the higher mountains farther south, as well as the Alpine species being capable of migrating north together with the Arctic and to locate there, are the factors that govern the remarkable distribution of Alpine, Arctic, and circumpolar species; and most remarkable is the fact that

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[1] Polarforskningens Bidrag till Forntidens Vaextgeografi (in: A. E. Nordenskiöld, Studier och Forskningar, Stockholm, 1883.)

only a few of these glacial plants now inhabiting the Alpine regions have changed their aspect and structure so as to exhibit a variation from their Arctic prototypes.

Thus in defining the Arctic element of the Alpine flora of Colorado it seems natural to suppose that all the circumpolar species originated in the polar regions, while some of those that are merely Arctic-Alpine may have developed in the south, but accompanied their Arctic brethren on their return to the north. The latter explanation is also applicable to such species as are not Alpine, but which, nevertheless, are known to occur in the northern regions. I think especially of *Chamaenerium angustifolium*, *Linnaea borealis*, *Draba aurea*, *Arabis Holboellii*, *Pyrola secunda*, *Carex vulgaris*, and *Luzula parviflora*, all of which are known from subarctic Greenland.

As regards the distribution of the Alpine species according to altitude, it is interesting to see that many of those observed at the highest elevations are mostly endemic, viz, Thlaspi, Lychnis, Claytonia, *Trifolium nanum*, *Saxifraga chrysantha*, *Oreoxys humilis*, *O. alpina*, *Polemonium viscosum*, Eritrichium, *Mertensia alpina*, Chionophila, Synthyris, and *Poa Lettermannii*, while the remaining *Saxifraga flagellaris*, *S. nivalis*, *S. cernua*, Lloydia, etc., extend to the Arctic regions and to the higher mountains in Europe and Asia. Chionophila is monotypic; of Synthyris and Oreoxys, only a very few species are known, and these three genera are confined to North America; the other genera are cosmopolitan. At lower elevations, but still in the Alpine region, we meet with a number of species that are endemic to North America, and of these several are confined to this region and may be looked upon as representing an old Alpine vegetation. On the other hand, several of the Alpine species have descended to the wooded belts, the spruce, as well as the aspen zone, where they are now frequently appearing in a more or less specific disguise. Finally, it deserves notice that a pronounced lowland element does exist at high elevations in these mountains, consisting of species which may have accompanied the Arctic on their way to the summits. Among these are: *Potentilla fruticosa*, Kalmia, Arctostaphylos, Vaccinium Myrtillus, *Campanula rotundifolia*, Troximon, Achillea, *Pentstemon confertus*, *P. glaucus*, *Pedicularis Groenlandica*, *Deschampsia caespitosa*, and *Calamagrostis Canadensis*.

The Alpine vegetation thus comprises four distinct elements, viz: Circumpolar, Arctic, Alpine, and lowland species.

Chapter 4.

NOTES ON THE PROBABLE LOCATION OF THE CENTERS OF DISTRIBUTION AND DEVELOPMENT OF THE ALPINE SPECIES.

In a previously published paper dealing with the genus Carex in Colorado [1] I have demonstrated the fact that certain species of this genus are represented in mountains very remote from each other—for instance, the Rocky Mountains, the European Alps, and the Himalayas—and associated with more or less closely allied types. *Carex alpina* Vahl, *C. atrata* L. and *C. stellulata* Good, for instance, show a remarkably wide geographical distribution and are accompanied by species of the corresponding "greges." In regard to *C. atrata* this species is very rare in the Arctic regions of Europe, but not infrequent in the mountains farther south. In the Rocky Mountains it is accompanied by *C. chalciolepis* nob. and *C. bella* Bail, while a near ally *C. ovata* Rudge abounds in the northeastern parts of this continent. In Europe *C. atrata* is, to some extent, accompanied by two allies, *C. nigra* Gaud and *C. aterrima* Hppe. Finally, in the Himalayas we not only meet with several species that may be looked upon as representing immediate allies of *C. atrata* but also with the species itself. If thus the association with allies in connection with frequent occurrence and tendency to vary may throw any light upon the question relative to the center of distribution or even of development of the respective species, it seems as if *C. atrata* may have had more than one center; very likely one in the Rocky Mountains, another in the European Alps, and a third one in the Himalayas. A like distribution and association with allied types may be readily recorded from several of the other Alpine plants, whether these be simply Alpine or Arctic-Alpine. Most of, if not all, the circumpolar species may be excluded, since these undoubtedly originated in the Arctic mountains, a view held by Heer,[2] Nathorst (l. c.), and several other authors. It seems natural to suppose that the same species by migrating to stations remote from each other became modified so as to produce varieties, and these becoming sufficiently constant and sometimes sufficiently distinct so as to deserve rank of species. In other words, the new surroundings might be the cause of developing new varieties or even species at several stations, more or less remote from each other, at the same time as new centers of geographical distribution might be established.

The hypothesis that the same species may have developed at several stations, hence from more than a single individual, was proposed by Schouw: [3] "Eadem momenta cosmica easdem plantas diversis in locis produxisse," and accepted by Agassiz,[4] Elias Fries,[5] and some other writers. Alphonse De Candolle formerly [6] adopted and strenuously maintained Schouw's hypothesis, but in his work, "Géographie botanique raisonnée," he has in effect discarded it. Linnaeus [7] did not believe in more than one single center of development. According to him each species had developed from a single individual or in dioecious species from a single couple of individuals. Joseph Hooker,[8] Asa Gray,[9] and a number of recent authors were in favor of the Linnean hypothesis as well as Alphonse De Candolle (l. c.). The last of these authors, De Candolle (Geogr. bot., p. 1116), explained the fact of certain species occurring at stations remote from each other by the possibility of these having been formerly much more widely distributed than at present, but separated from each other by change in climate or destruction of continents. This explanation of De Candolle carries great weight and is acceptable, of

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[1] Am. Journ. of Sc., Vol. XVI. 1903. p. 40.

[2] Ueber die nivale Flora der Schweiz. 1883.

[3] Dissertatio de sedibus plantarum originariis. Copenhagen, 1816. P. 64.

[4] Geographical distribution of animals. 1850.

[5] Botaniska utflygter, vol. 3. 1864. P. 114.

[6] Fragment d'un discours sur la géographie botanique (Bull, univ. 1834).

[7] De telluris incremento (Amoen. acad., vol. 2, Stockholm, 1743).

[8] Outlines of the distribution of Arctic plants (Transact. Linn, Soc. vol. 23, 1861, p. 251).

[9] On the Botany of Japan (Mem. Am. Acad. Sci., vol. 6, n. s., 1857, p. 444).

course, in many instances, but it is not absolutely necessary to accept it in all cases. As a matter of fact it seems very difficult to appreciate the occurrence of *Papaver pyrenaicum* in the Rocky Mountains and the Pyrenees in any other way than by accepting Schouw's hypothesis. and so with a number of others, and especially of such as are Alpine rather than Arctic-Alpine. As for the latter, the Arctic-Alpine, the question of these being, to some extent, remnants of a glacial vegetation must necessarily be considered.

By examining the geographical distribution of our Alpine species it will be seen that many points are in favor of the acceptance of Schouw's hypothesis. This may be demonstrated by outlining the actual limits of the present distribution, and especially of the larger genera, besides giving an account of association with allied species.

With respect to the variation of the species, it may be mentioned in this connection that several instances occur where variation according to northern latitude coincides with that of altitude, but less so with that of longitude farther south.

Anemone narcissiflora L.

By De Candolle[10] this species is a member of the section Omalocarpus together with *A. umbellata* Willd., and *A. Siberica* L.; two other species—*A. demissa* Hook. f. and *A. polyanthes* Don.—from the Himalayas are referred to the same section by Hooker.[11] Of these, *A. narcissiflora* is a very variable plant, and the following varieties are described by De Candolle: *fasciculata*, *monantha*, and *vilososissima*, besides *pedicellaris* and *frigida;* the two last mentioned may, however, according to this author, represent distinct species. The geographical distribution of the typical plant has been given above, and concerning the varieties *fasciculata* occurs in South Europe, in Cappadocia, and in Altai; *monantha* in dry, barren places in the European mountains, furthermore in Davuria, eastern Asia, Alaska, and west America; *vilososissima* has been reported from Altai, Kotzebue Sound, and Unalaska. In accordance with Turczaninow[12] *A. narcissiflora* is very frequent in the Baikal Mountains, and represented by several forms, among which are *fasciculata* and *monantha;* the latter of these is said to occur in the Alpine region, is of dwarfed habit, and with the flower only half as large as in the typical plant. C. A. Meyer[13] states that the species is frequent throughout the Caucasus Mountains; Kjellman[14] observed only the variety *monantha* in dry as well as damp soil at St. Lawrence Bay. In Colorado the typical plant is the most frequent, but one-flowered specimens are sometimes met with; in these, however, the flower is by no means smaller than the typical plant. On the other hand, there is a one-flowered form in Alaska which is very distinct from the others by the much larger size of the flower, especially when compared with the Siberian plant (Baikal); specimens of the Alaskan form were kindly presented to the writer by Mr. Thomas H. Kearney, who had collected it on Hall Island, Bering Sea, and near Orca, Prince Williams Sound.

The fact that the section, Omalocarpus, is represented by several species in the Himalaya Mountains, elsewhere by only one—*A. narcissiflora*—seems to indicate that the most important center of geographical distribution and of development of the section is located in these mountains; a characteristic of the Himalayan *Anemone narcissiflora* is that it is densely villous, as stated by Hooker, as is also the case with the plant from Baikal, thus representing the forma *villosissima* of Alpine regions. The European and North American forms are pilose rather than villous, and we have seen that the one-flowered variety differs as to the size of flower. The species evidently developed in the Altai Mountains, and spread from there to the Himalayas, westward to the Caucasus and the European Alps, where the plant is now widely dispersed, but of a somewhat different habit—*pilosa*, *fasciculata*, *monantha*. In the Rocky Mountains of Colorado the species has larger flowers than the European plant, as is also the case of the one-flowered form (*monantha*), while in Alaska the latter is very distinct from

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[10] Regni vegetabilis systema naturale. Vol. I, p. 212. Paris, 1818.

[11] Flora of British India. Vol. 1. London, 1875.

[12] Flora Baicalensi-Dahurica. Moscow, 1842. P. 43.

[13] Verzeichniss der Pflanzen Caucasus. St. Petersburg, 1831. P. 203.

[14] Asiatiska Beringssunds-Kustens Fanerogamflora (Vega-Expeditionens vetensk. arbet. P. 542).

monantha of all the other regions. For this reason one might suppose that the Rocky Mountains represent another geographical center of this species, a stouter plant with the flowers larger; but the fact that Omalocarpus is monotypic on this continent, and moreover confined to Colorado, California, northwestern Canada, and Alaska, seems to indicate that *A. narcissiflora* did not develop in these mountains as a species, but that it came from Asia, and evidently from Altai, by way of the northeastern corner, the only place where the distribution reaches the Arctic regions—St. Lawrence Bay.

Ranunculus adoneus Gray.

A native of the Rocky Mountains of Colorado, and of the Wasatch, Utah; it has an ally in Washington—*R. triternatus* Gray; furthermore, *R. Suksdorfii* Gray from Washington and Oregon, and *R. eximius* Grne. from Colorado to Idaho are, also, related to this species. Thus all are natives of these mountains, and represent a very characteristic section of the genus.

The Arctic *R. nivalis* L. does not extend to Colorado, but is represented by an analogue, *R. Macauleyi* Gray, which is a native of the higher mountains of southern Colorado and New Mexico.

Caltha leptosepala D C.

In North America the genus Caltha is represented by the circumpolar *C. palustris* L.; by *C. natans* Pall. which inhabits wet sphagnous bogs and flowing water, British America, Athabasca plains and northward, and is known also from Minnesota, at Tower and in Vermillion Lake; the main distribution of the species is, however, northern Asia and Kamchatka. As this is an aquatic plant the wide, geographical distribution is not surprising. Then there are two other species, *C. leptosepala* D C. and *C. biflora* D C., both of which have been recorded from Alaska south to California. With respect to *C. palustris*, although being circumpolar, the center of geographical distribution is evidently located south of the Arctic Circle, where the species reaches its highest development, and is accompanied by several more or less characteristic forms. But the Rocky Mountains seem to be the center of distribution as well as of development of the species *C. leptosepala*, and of *C. biflora*. Characteristic of these two species is the white or bluish-white colors of the sepals, and the stipitate follicles.

Trollius laxus Salisb.

This is the only species represented on this continent from New Hampshire to Michigan and south to Delaware. In the Rocky Mountains the variety *albiflorus* Gray is recorded from British America to Colorado and Utah and to the Cascades in British Columbia. The typical plant, as well as the variety *albiflorus*, thus have originated on this continent, and they are quite distinct from the European and Asiatic species.

Papaver nudicaule L.

"Everywhere upon the shore of the Arctic Sea throughout the whole breadth of the continent, and in the islands," and "upon the Rocky Mountains at a great elevation" is the distribution of this plant in Canada, according to Macoun.[15] Furthermore, the species is known from Alaska and from Grays Peak in Colorado. It is very frequent in Greenland and extends from there throughout Arctic Europe and on the mountains of Norway (Dovre). In Asia it extends from Ural to Kamtschatka, and it is abundant in the Altai and Baikal Mountains. Several varieties are described, and not less than seven are recorded from Altai and Baikal, according to Turczaninow (l. c., p. 96). In North America a near ally *P. Macounii* Grne. has been found on the Pribilof Islands, and, strange to say, another species *P. pyrenaicum* L. has been discovered in the Rocky Mountains—Alberta, Sheep Mountain, Waterton Lake,[16] and

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[15] Catalogue of Canadian Plants, pt. 1, p. 34. Montreal, 1883.

[16] The Canadian specimens of this Papaver were submitted to the writer by Mr. James M. Macoun, with the request to describe it as a new species. However I recognized it at once to be identical with the Pyrenean plant, and my determination was promptly verified by the botanists at Kew. In looking through the material of *P. nudicaule* in the United States National Museum I found some other specimens from Montana (l. c.) which also belong to this interesting species.

Montana near Stanton Lake at 7,500 feet (by R. S. Williams). *Papaver nudicaule* evidently developed in the Arctic regions, wandering from there to the mountains farther south, where it is now more or less frequent. An important geographical center is undoubtedly the Altai and Baikal Mountains, where it occurs in several characteristic forms, but I believe the species developed in the Arctic mountains. The occurrence of *P. pyrenaicum* L. in the northern Rocky Mountains, so very remote from the European stations, the Alps and Pyrenees, is difficult to account for unless we adopt the hypothesis of the species having developed both in Europe and on this continent, rather than having formerly been more widely distributed, but exterminated except at these two very remote stations.

Draba crassifolia Grah.

According to Macoun (l. c.) this plant is "abundant on the sides of ravines and grassy slopes above the limits of trees on Cathedral, Castle, and other mountains in the Rocky Mountains, latitude 51°." It is very rare farther south and is known only from a few stations in Colorado and in the Sierra Nevada. It is known also from Greenland between latitude 64° and 72° and from Finmark in the valley of Tromsoe. This geographical distribution may at a first glance seem very strange, especially considering the very distant station in Finmark. However, *Draba crassifolia* is not the only plant of unquestionable American origin which has found its way to Norway. There are a few others the geographical distribution of which is about the same: *Carex scirpoidea* Michx., *C. nardina* Fr., *C. festiva* Dew., *Platanthera obtusata* Lindl., and *Artemisia Norvegica* Fr. Of these the three Carices are not only recorded from Greenland but also from Iceland and Finmark. *Platanthera obtusata*, so very frequent in cool, mossy woods throughout the forest region of Canada, does not occur in Greenland or Iceland but in Finmark. The Artemisia, on the other hand, is not, so far, reported from any station intermediate between Norway and the Rocky Mountains and does not occur north of the Arctic Circle. These plants, including the Draba, have their widest distribution on this continent and south of the Arctic regions. They all are associated with allied types and I presume, therefore, that they developed in the Rocky Mountains. Their occurrence in Norway, partly also in Greenland and Iceland, seems to indicate that they belong to that category of plants which, although of southern origin, accompanied the Arctic northwards, gaining foothold on some of the mountains in Greenland, Iceland, and Norway. It may be mentioned also that in Finmark the very rare *Carex holostoma* Drej. has been discovered and this species has so far only been recorded from a few places on the west coast of Greenland.

Chrysodraba, of which *D. crassifolia* is a member, is altogether well exemplified in the mountains of this continent, and several are endemic: *D. Mogollonica* Grne., *D. montana* Wats., *D. Howellii* Wats., *D. Lemmonii* Wats., etc. Beside these the circumpolar *D. alpina* L., and the subarctic (Greenland) *D. aurea* Vahl are also known from these mountains. Very few yellow-flowered Draba are known from the European Alps, and none of these belong to the section Chrysodraba, but to Aizopsis: *D. aizoon* Walenb. and *D. aizoides* L. Three species, all Chrysodrabae, are recorded from the Caucasus: *D. repens* M. B., *D. incompta* Stev., and *D. mollissima* Stev. Of these *D. repens* is the only member of the section that has been found in Altai and Baikal Mountains, and this species is also Arctic.

It would thus appear as if especially the Rocky Mountains constitute a most important center of distribution and origin of Chrysodraba, of which *D. crassifolia* and *D. aurea* have reached the Arctic regions. On the other hand, one of the Old World species, *D. repens*, has from the Altai Mountains become distributed through northern Siberia, reaching the Arctic coast near Ural Mountains, and finally the east coast of Greenland, with no intermediate stations.

The genus Thlaspi is represented by a few species, of which one was found abundant on the very summit of Pikes Peak: *Thl. Coloradense* Rydbg. However, the American species are not well understood, and the statement that "*Thl. alpestre* L. is common throughout the West, especially in hilly and mountainous regions,"[17] is hardly correct. Moreover, *Thl. cochleariforme* D C. is by no means identical with real *Thl. alpestre* L. of the European Alps nor with *Thl. Suecicum* Jord. of Sweden. It is, on the other hand, more safe to consider, at least, the Rocky Mountain species of the genus as distinct from the European.

None of the perennial species of this genus have been recorded from the Arctic regions, but the annual *Thl. arvense* L. appears frequently as an introduced weed in Arctic Norway; however, only for a shorter period. The Alps of Switzerland and Germany are the home, and evidently the original, of several species: *Thl. perfoliatum* L., *Thl. alpestre* L., *Thl. montanum* L., *Thl. alpinum* Jacq., and *Thl. rotundifolium* Gaud. Of these, the annual *Thl. perfoliatum* L. has been reported as occurring in Canada (Ontario). A few species are known from the Caucasus: *Thl. arvense* L., *B. baicalense* D C., *Thl. perfoliatum* L., and *Thl. umbellatum* Gm. jun; from Altai Mountains, *Thl. perfoliatum* L. and *Thl. montanum* L. It would thus appear as if the Rocky Mountains and the European Alps are the two principal centers of the genus with regard to development and geographical distribution.

Smelowskia calycina C. A. Mey.

This plant inhabits the Alpine summits of the Rocky Mountains from Colorado to Alaska but is known also from Altai, where two other species occur, viz, *S. integrifolia* C. A. Mey. and *S. cinerea* C. A. Mey. Of these the latter, together with *S. asplenifolia* Turcz, are recorded from Baikal by Turczaninow (l. c., p. 285). No doubt the geographical center of these species lies within the mountain ranges of Baikal and Altai, from where *S. calycina* C. A. Mey. has become distributed across the Bering Strait to Alaska and south to Colorado.

Cardamine cordifolia Gr.

It is only seldom that this species occurs above timber line, and, as we know, only a few species, *C. bellidifolia* L., *C. pratensis* L., *C. digitata* Richards, and *C. purpurea* Cham. et Schl. are recorded from the Arctic regions. Of the species with the leaves undivided some are characteristic of the Allegheny Mountains, others of the Rocky Mountains, but *C. cordifolia* Gr. does not occur outside the mountains of Wyoming, New Mexico, Colorado, and Arizona.

Viola bellidifolia Grne.

Viola bellidifolia Grne is known only from a few stations in Wyoming and Colorado. It is a segregate of *V. Muehlenbergii* Torr., a native of Labrador and Greenland, reported also from the Allegheny Mountains south to North Carolina, and it is interesting to note that *V. canina* L., a near ally of these two species, also occurs in the Artic regions of Scandinavia and Russia, as well as in south Greenland. However, in consideration of the prevalence of these caulescent species with their numerous allies farther south, it would be most natural to suppose that the geographical center is located there rather than in the northern regions. *V. bellidifolia* Grne. has undoubtedly developed in the Rocky Mountains, similar to *V. retroscabra* Grne., *V. Sheltonii* Torr., and some of the more or less well-marked varieties of the eastern *V. Canadensis* L.

The **Caryophyllaceae** and especially the Alsineae, exhibit a remarkably wide geographical distribution throughout the northern hemisphere, being able to thrive in the most northerly points and at the highest elevations at which flowering plants are known to exist. Hart[18] reports *Lychnis apetala* from 81° 52′, *L. affinis* from 81° 50′, *Cerastium alpinum* from 82° 50′, *Stellaria longipes* and *Alsine verna* from 82° 27′, and *Alsine Groenlandica* from 81° 42′. According to Hemsley[19] *Arenaria Stracheyi* grows at an elevation of 19,200 feet in Tibet; *Cerastium trigynum*, *Stellaria subumbellata*, and *Sagina procumbens* are reported from the Himalayas at an elevation of 16,000 to 17,000 feet.

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[17] B. L. Robinson in Gray: Synopt. Flora of North America. Vol. 1, pt. 1, New York, 1895–1897. P. 123.

[18] Hart, H. C.: On the botany of the British Polar Expedition of 1875–1876 (Journ. of Bot., 1880).

[19] Hemsley, W. B., and Pearson, H. H. W.: On some collections of highland plants from Tibet and the Andes (Journ. of Bot., 1900, p. 238).

Lychnis montana Wats.

This is a member of the section Wahlbergella Fr., of which three species are recorded from the Arctic regions, *L. triflora* R. Br., *L. affinis* Vahl, and *L. apetala* L. *L. nesophila* Holm is a native of an island north of Hudson Bay, and a variety of *L. apetala* L., "*gracilis* Hook," is recorded from the Himalayas at an elevation of 15,000 to 17,000 feet. Wahlbergella is thus an Arctic-Alpine subgenus, and *L. apetala* L. is circumpolar, but known also from Altai and the Himalayas. Eulychnis Fenzl is represented in North America by only one species, *L. Drummondii* Wats., which is distributed from Canada to Arizona, especially in the mountains, but is not Alpine. Concerning the geographical center of the subgenus Wahlbergella, the circumpolar *L. apetala* L. undoubtedly originated in the polar mountains; *L. affinis* Vahl is a very rare plant in Arctic Europe, but not in Greenland, where it extends as far north as 81° 40′; *L. triflora* R. Br. is known only from Greenland and Grinnell Land, and I presume these two species, *L. affinis* Vahl and *L. triflora* R. Br., were originally developed in Greenland. *L. nesophila* Holm may be looked upon as a descendant of these, and much younger; finally, with regard to our Alpine *L. montana* Wats., this may represent a western remnant of the glacial vegetation, and is a close ally of *L. triflora* R. Br.

Cerastium arvense L.

Cerastium arvense L. is very variable in Europe, and according to Koch[20] "variat foliis angustioribus, anguste linearibus, et latioribus, rarius fere ovalibus, erectis, patentibus et reflexis, pilisque pedunculorum glandulosis eglandulosisve, horizontaliter patentibus et reflexis." This author mentions its range as being from the lowlands to the high Alpine regions of the European Alps. Ledebour[21] enumerates several characteristic varieties from Russia and Siberia, and in North America the species appears to be equally common and variable in accordance with environment; in recent years a number of these varieties have been raised to specific rank, although the distinction depends mainly upon such variations in structure of leaves and hairs as are already pointed out by Koch (l. c.), and hardly of sufficient importance to be considered as really specific. The very wide distribution of *C. arvense* L. naturally points toward the conclusion that certain modifications have taken place, thus the species does not always show the same habit or structure.

Stellaria umbellata Turcz.

The mountains of Colorado and Arizona, also the Sierras of California to Oregon, is the geographical range of this species on this continent, but it was in the mountains of Baikal that the plant was discovered and described by Turczaninow. In Colorado the species is one of those that inhabits the highest peaks, the very summits of these, but it descends also to the timbered belts at much lower altitudes; the Rocky Mountains constitute undoubtedly a most important geographical center of this plant, but its occurrence in the Baikal Mountains may indicate that the species developed there, and that it wandered from there to this continent associated with a number of other Siberian types, as, for instance, *Smelowskia calycina* C. A. Mey. and others.

Claytonia megarrhiza Parry inhabits the highest peaks, and follows the Rocky Mountains northward to British Columbia. Several other species of the genus occur in these mountains, but at lower altitudes, and it appears as if the Rocky Mountains are an important center of development of the genus. The fact, however, that such Alpine types as *C. arctica* Adams and *C. tuberosa* Pall. occur in the mountains of Siberia, Altai, for instance, may indicate another and perhaps much older center of distribution as well as of development; and it deserves attention that the species which illustrate the structure of Arctic-Alpine types are those of which the geographical range is the widest, Altai, Alaska, and Rocky Mountains.[22]

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[20] Synopsis Florae Germanicae et Helveticae Leipzig 1857. Vol. 1, p. 107.

[21] Flora Rossica, Vol. 1. Stuttgart, 1841. P. 413.

[22] Holm, Theo.: Claytonia Gronov. A morphological and anatomical study. (Nat. Acad. of Sci. Vol. X, Mem. 2. Washington, 1905.) Holm, Theo.: Types of Claytonia. Mindeskrift for Japetus Steenstrup. Köbenhavn, 1913.

Trifolium, section Lupinaster Moench.

In the Rocky Mountains this section is represented by the Alpine *T. nanum* Torr., *T. Parryi* Gray, and *T. dasyphyllum* T. et Gr.; in the European Alps by *T. alpinum* L.; in Siberia by *T. eximium* Steph., and *T. Lupinaster* L.; in the Caucasus by *T. polyphyllum* C. A. Mey. Thus in the mountains of these countries the section has developed, exemplified by very distinct species, none of which have become distributed beyond their natural boundaries, and none having ever been recorded from the high northern latitudes; in other words, we have before us the development of a very natural section at very remote stations, but all Alpine.

Dryas octopetala L.

We have seen from the table (p. 13) the enormous geographical range of this plant, being not only circumpolar but occurring in the vast mountain ranges farther south, but absent from the Himalayas, where *Sieversia elata* Royle is the nearest ally.

Three species are known of the genus, *D. octopetala* L., *D. integrifolia* Vahl, and *D. Drummondii* Hook. On this continent *D. octopetala* L. abounds in the Rocky Mountains, and has been reported from several stations in Alaska; it was said by Pursh to have been found on the White Mountains (New Hampshire) about a hundred years ago, but has never been found there since. In Greenland *D. octopetala* L. is very rare on the western coast, but is not infrequent on the eastern, between latitude 73° and 76° N.

D. integrifolia Vahl, on the other hand, is very frequent in west Greenland from latitude 60° to 76° 7′ N. On this continent the species is distributed from Labrador to Bering Straits, occurring in the Rocky Mountains of Canada, where Moose Mountain, Elbow River, is the most southern station of this plant. From Alaska the distribution extends to eastern Siberia "terra Tschuktschorum ad sinum St. Laurentii, inque insula St. Laurentii" (Ledebour, l. c.).

With regard to the third species, *D. Drummondii* Hook., this is also a native of the Rocky Mountains of Canada and extends as far north as the Arctic shores. It has been reported from the island of Anticosti, where *D. integrifolia* Vahl also grows. In eastern Siberia the species is reported from Aldan River.

While *Dryas octopetala* L. undoubtedly developed in the polar mountains, the center of the two other species is evidently to be sought in the Rocky Mountains and in the most northern part of these. Similar to *D. octopetala* L., *D. integrifolia* Vahl inhabits dry and rocky places, while *D. Drummondii* Hook. never grows on the mountain slopes, but prefers gravelly beaches and bars of rivers. Macoun (l. c., p. 515) states that this species is abundant in the gravel at the mouths of mountain streams from Morley through the Rocky Mountains to Donald, in the Columbia Valley.

Sieversia Rossii R. Br.

The species was founded upon specimens from Melville Island.[23] Since then the plant has been reported from northeastern Siberia and from Alaska. By a number of collectors the plant has been found in the Rocky Mountains from Wyoming to Arizona and described as a new species of Geum, of Sieversia, and of Acomastylis,[24] "*turbinata*." Being in possession of a copious material which I collected in Colorado, I have carefully compared these specimens with the Arctic, and I am unable to detect any character of specific importance. The plant in Colorado naturally varies somewhat in accordance with altitude, and the specimens from the high Alpine regions are in all respects identical with the Arctic. Some few other species are known from Alaska, viz, *S. dilatata* R. Br., and *S. glacialis* R. Br., while *S. triflora* R. Br. shows a far wider distribution from Labrador to British Columbia, south to New York and Mexico. Another North American species is *S. Peckii* R. Br., a native of the mountains of New Hampshire and North Carolina. In the Alps of Switzerland and Germany *S. reptans* Spreng. and *S. montana* Willd. inhabit the Alpine slopes, and, as already mentioned, there is also a species in the Himalayas, *S. elata* Royle. Of these *S. glacialis* R. Br. and *S. Rossii* R. Br. are the only

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[23] Brown, Robert: Chloris Melvilliana (Suppl. Appendix Parry's Voyage). London, 1823.

[24] Greene, E. L.: Leaflets, vol. 1, p. 174.

ones of which the geographical distribution extends to the Arctic regions of this continent and of Siberia, where the former, *S. glacialis* R. Br. is quite widely distributed and where it has evidently developed. With regard to *S. Rossii* R. Br. this species appears to be of North American origin, presumably within the Arctic Circle, from where it took part in the migration toward the south, leaving some remnants on the summits of the Rocky Mountains. *S. triflora* R. Br. and *S. Peckii* R. Br. are also of North American origin, but were evidently developed in regions farther south. Besides these geographical centers of the genus in northern Asia and America the European Alps constitute a third center, where *S. reptans* Spreng. and *S. montana* Willd. have had their origin, and finally the Himalayas are the home of *S. elata* Royle. Although the species are very much alike in their habit and principal structure, *S. Rossii* R. Br. is quite distinct "carpellorum cauda glabra," a character, however, of merely specific importance. We have thus in the genus Sieversia an example of a very characteristic genus having been developed at stations very remote and having given rise to species of a habit peculiar to each of these centers.

Potentilla fruticosa L.

In Sweden this plant is known only from the island Oeland, in the Baltic Sea. It occurs also in the Caucasus, in Baikal and Altai Mountains, and in the temperate and subalpine Himalayas at an elevation of 8,000 to 12,000 feet. On this continent the species has been reported from a number of stations in Canada, from Labrador to the Pacific, and northward to the Arctic Sea. Very interesting is the following statement by Macoun (l. c., p. 141): "Besides being frequent in eastern Canada at low altitudes it becomes truly Alpine in the Rocky Mountains and is found almost at the snow line." Southward the geographical distribution extends to Michigan, Pennsylvania, Arizona, and California. It seems strange that the species does not occur in Greenland, although it has such a wide distribution in the northern part of North America. Being Arctic, so far as concerns this continent, and exhibiting such wide geographical range between the two oceans, I presume the original center of the species was located within these regions but south of the Arctic. The scattered occurrence of the species in the Old World—Sweden, the Caucasus, Altai, and the Himalayas—seems to indicate a formerly much wider distribution, and a second geographical center may have been located there; for instance, in Altai.

Sibbaldia procumbens L.

This plant shows the same very wide distribution in the northern, but not Arctic, regions of North America as *Potentilla fruticosa* L. It occurs also in Greenland, as far north as latitude 70° 20′. In Europe the plant has been reported from Iceland, Faeroe Islands, Scandinavia, Arctic Russia, the Alps, Pyrenees, and Caucasus, while in Asia it is reported from Baikal Mountains and the Himalayas (above 17,000 feet). Sibbaldia is evidently not of Arctic origin. It may have developed in the mountains farther south, for instance, in North America.

THE GENUS SAXIFRAGA.

Most of the species are mountain plants, and quite a large number have been reported from the Alpine region of the Northern Hemisphere. Several species are Arctic, some are even circumpolar, and according to Feilden[25] the following species belong to the flora growing nearest the Pole: *S. oppositifolia*, *S. cernua*, *S. flagellaris*, *S. caespitosa*, *S. tricuspidata*, and *S. nivalis;* these have been gathered in Grinnell Land and islands to the north of Greenland between 82° and 24′ N. By Hart (l. c.) *S. rivularis* has been reported from 81° 40′, *S. aizoon* from 69° 55′, and *S. stellaris* from 68° 46′. The Alpine species of Colorado are by Engler[26] classified under the sections as follows: Trachyphyllum Gaud. (*S. chrysantha* Gr., *S. bronchialis* L., and *flagellaris* Willd.); *Nephrophyllum* Gaud. (*S. cernua* L.), Boraphila Engler (*S. punctata* L. and *S. nivalis* L.).

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[25] Feilden, H. W.: The flowering plants of Novaja Zemlya, etc. (Journ. of Bot., 1898).

[26] Engler, A.: Monographie der Gattung Saxifraga L. Breslau, 1872.

S. chrysantha Gr.

This is known only from Colorado. A near ally, *S. serpyllifolia* Pursh, occurs in Alaska, on the Asiatic coast of Bering Strait, and in the Altai Mountains. Besides that the variety *Palassiana* Sternb. is recorded from Arctic Siberia and Baikal.

S. bronchialis L.

Through Arctic Russia and Siberia this species extends to Altai and Baikal, to Kamchatka, Alaska, and follows the Rocky Mountains as far south as New Mexico. A near ally, *S. tricuspidata* Rottb., is a native of Arctic America and Greenland.

S. flagellaris Willd.

This polymorphous species is widely distributed in the Arctic regions, from whence it extends to the Caucasus, the Himalayas, Altai, and Baikal Mountains, as well as in Colorado. It is the typical plant that occurs in Colorado, but according to Engler (l. c.) the variety *setigera* Pursh has also been reported from this continent, Baffins Bay, Melville Island, Alaska, and the Rocky Mountains.

S. punctata L.

This species is not circumpolar, but has been reported from Arctic Siberia and North America, extending south to Ural, Baikal, Cascade Mountains, and the Rocky Mountains.

S. nivalis L.

Circumpolar and known also from Great Britain, Norway, Sweden, Germany, Baikal Mountains, Kamtschatka, Canada, Greenland, and south to Colorado.

Of these the circumpolar species are evidently of Arctic origin, but became widely distributed during and after the glacial epoch. *S. chrysantha*, is a native of Colorado, while its near ally, *S. serpyllifolia* Pursh, is distributed in regions much farther north, Alaska, and the Baikal Mountains. The geographical center of the latter may have been in these mountains. *S. bronchialis* shows quite a wide range in the Arctic regions, but the geographical center was evidently somewhat farther south, the mountains of Altai and Baikal. We remember that most of the other species of Trachyphyllum are endemic to the Himalayas. With regard to *S. punctata*, this may, similar to *S. bronchialis*, have originated in the Altai and Baikal Mountains.

Oreoxys humilis Raf. and O. alpina (Gr.) C. et R.

These species, together with *O. Bakeri* C. et R., are natives of the Rocky Mountains, Colorado, and are well represented in the high Alpine regions. It is interesting to note that the genus has two analogues in the Old World, namely, Gaya Gaud. and Pachypleurum Ledeb., of which *G. simplex* Gaud. is a native of the Alps of Switzerland; it has also been reported from Arctic Russia and Altai; *Pachypleurum alpinum* Ledeb. is, on the other hand, known from Arctic Russia and Arctic Siberia, and from the mountains of Altai and Baikal. We have thus among the Umbelliferae three allied genera, one of which is purely Alpine and of North American origin, the remaining two being Arctic-Alpine.

Among the **Compositae** we meet with several species of which the geographical distribution is of interest. Some of the Alpine types are also Arctic and even circumpolar, while others are confined to the Rocky Mountains.

The genus Erigeron is represented by *E. salsuginosus* Gr., *E. uniflorus* L., and *E. pinnatisectus* (Gr.) Nels. Of these the first species has been recorded from Kotzebue Sound and Unalaska, and it follows the higher mountains southward to California, Utah, and New Mexico, and the variety *glacialis* (Nutt.) Torr. et Gr. occurs in the Alpine region of the Rocky Mountains. *E. uniflorus* L., on the other hand, is circumpolar, and is also widely distributed in the boreal regions of this continent, from Labrador to the Arctic coast and Unalaska, south to Sierra Nevada, California, and Colorado. It occurs also in the Altai and Baikal Mountains and in the European Alps. *E. alpinus* L. shows about the same geographical distribution as *E. uniflorus* L. in the north as well as in the south, and both are evidently of Arctic origin. A genuine American type is, on the other hand, *E. pinnatisectus* (Gr.) Nels., which is confined to the Rocky Mountains. Its near ally, *E. compositus* Pursh, is not infrequent in the aspen zone of these mountains, and occurs also in Sierra Nevada, extending from there to the Arctic seacoast and Greenland.

Artemisia Norvegica Fr.

In North America this species occurs in the Rocky Mountains from latitude 62° to south Colorado and the Sierra Nevada, California. In Asia the distribution is given by Trautvetter as: "Siberia arctica et orientalis, Mandshuria"; furthermore, it is known from Europe: Mountains of Norway (Dovre) and Ural. The plant from Arctic Siberia, however, is not *A. Norvegica* Fr. but a near ally, if not a mere variety; it is *A. arctica* Lessg., by Gray described as var. *Pacifica* of *A. Norvegica*. Real *A. Norvegica* is thus a mountain plant which does not extend to the Arctic Circle, which is totally absent from the European Alps, and which is not a member of the Altai flora.

The main center of distribution seems to have been in the Rocky Mountains on this continent, but not in Norway so far as concerns Europe. I am uncertain about the plant reported from Ural.

None of the European species of the genus are near allies of this, and *A. Absinthium* L., *A. vulgaris* L., and *A. campestris* L. are the only ones known to occur in Norway. In North America, on the other hand, *Artemisia globularia* Cham. from Alaska and adjacent island, *A. Richardsoniana* Bess. from Arctic America, and *A. Parryi* Gr. from the mountains of Colorado, may be looked upon as near allies of this species. In addition to these several others are inhabiting the same Alpine regions, viz, *A. borealis* Pall., and *A. scopulorum* Gr. It seems, therefore, natural that the species *A. Norvegica* has had its center of development in the Rocky Mountains. The wide gap in distribution can not be explained satisfactorily, unless we suppose that the species did have a much wider range before, but became exterminated in the mountains between.

Artemisia borealis Pall.

Being circumpolar, and, furthermore, distributed from Colorado to Alaska and Labrador, and finally being a member of the Altai flora, this species did undoubtedly originate in the Arctic region. Migrating south during the glacial epoch, the species did not reach the European Alps nor Caucasus, but it evidently followed the Rocky Mountains, where it succeeded in getting foothold, and where it is still persisting.

Artemisia scopulorum Gr.

This species is only known from the Alpine region of the Rocky Mountains in Colorado, Utah, and Wyoming, where the center of distribution and of development naturally was located.

THE GENUS ANTENNARIA.

In recent years the genus has been studied very extensively on this continent, and Greene deserves credit for being the first author to demonstrate that *Antennaria plantaginifolia* (L.) Richards, as formerly understood, comprises several well-marked species. In the vicinity of Washington, D. C., Greene segregated not less than five species: *A. neglecta, fallax, decipiens, neodioica,* and *alsinoides*, and by extending his study of the genus farther north, and especially westward to the Rocky Mountains, this author discriminated a number of new species, the majority of which are undoubtedly valid. Since then several other authors have commenced to segregate species of the genus, with the result that Antennaria is now quite a large genus on this continent. This seems very natural, considering the fact that the genus is very abundantly represented in the lowlands as well as in the mountains, extending north to the Arctic region and to the highest altitudes in the Rocky Mountains. In Europe and Asia the genus is very poorly represented, only three species having been described, so far, viz, *A. dioica* (L.) Gärtn., *A. alpina* (L.), R. Br. and *A. Carpathica* (Wahlenb.) R. Br., besides a fourth one, but imperfectly known, from Australia. Of these Old World species *A. dioica* has been found only once on this continent "in woods at Providence, Rhode Island, by Geo. Thurber in 1844,"[27] while the two others have been reported from many stations in the north, from Labrador and westward to Bering Strait, and according to Gray,[28] southward on the high mountains to Colorado, California, and New Mexico. By John Macoun[29] *A. alpina* and *Carpathica* are recorded from a number of stations from Labrador to Alaska, and especially from the Rocky Mountains.

However, according to the recently published floras of the Rocky Mountains, by Aven Nelson[30] and P. A. Rydberg,[31] neither *A. alpina* nor *A. Carpathica* are credited to the United States, but only *A. pulcherrima* (Hook.) Greene, formerly considered a variety of *A. Carpathica;* nevertheless 43 species are recorded by Rydberg, and 21 by Nelson. *A. pulcherrima* inhabits prairies and marshy meadows in Canada, and occurs also in the Rocky Mountains, but only at lower elevations, being frequent in the aspen zone near Longs Peak. *A. Carpathica* and *A. alpina,* on the other hand, have been reported from the summits of the most elevated Rocky Mountains in Canada, and we should naturally expect that they had also found their way southward to Colorado. However, the former of these, *A. Carpathica,* is a plant of such characteristic aspect that it could hardly have been overlooked or confounded with any of the other species, while the latter does resemble some of the narrow-leaved species.

Antennaria alpina (L.) R. Br.[32] is quite a variable plant with respect to the outline of the leaves, their covering with tomentum, the development or absence of stolons above ground, and the composition of the inflorescence. The Colorado plant represents the variety *canescens* Lge.,[33] and it seems indeed as if this variety is the predominant in North America, but it has also been recorded from Greenland and Scandinavia. In some of the specimens from Colorado the leaves are somewhat broader than in the Old World representative, but the structure of the involucre is the same, and altogether my material can not be distinguished from this species. I observed no specimens of the staminate plant, which, as we know, is extremely rare, and has so far been recorded from only a very few stations in Scandinavia, France, and Alaska. The Alaskan staminate plants were of the variety *monocephala* D C. The species is widely distributed throughout the boreal regions of both worlds, but it is absent from Spitzbergen, and is replaced by *A. Carpathica* (Wahlenb.) R. Br. on Nova Zembla. The occurrence of *A. alpina* in Greenland, where it is very frequent, and in Alaska, is a fact that speaks in favor of its presence in the Rocky Mountains, like so many other Arctic, and especially circumpolar, species, although several authors are unwilling to accept it south of the American Arctic coast.

The genus **Senecio** is well represented in the Alpine region, and most of the species are confined to Colorado. It is a very striking assemblage of Alpine species, very distinct from those of the Old World at similar altitudes, and the Rocky Mountains altogether constitute a most important center of development and distribution of the genus. Although occurring at very high elevations in Colorado, the species are remarkably robust and tall, in this respect surpassed only by *Actinella grandiflora* Torr. and Gr.

Campanula rotundifolia L.

The typical species does not occur in Arctic America, but is replaced there by the variety *arctica* Lge., reported from "Canada and Labrador to the Arctic regions" (Gray). Another form is *Alaskana* Gray from the northern Aleutian Islands to Sitka and Kodiak. The typical species, on the other hand, is widely distributed on this continent, and Gray (l. c.)

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[27] Gray's new manual of botany, seventh edition, p. 820.

[28] Synoptical flora of North America. Gamopetalae. Washington, 1888. P. 232.

[29] Catalogue of Canadian plants. Montreal, 1884. P. 236.

[30] New Manual of Botany of the Rocky Mountains. 1909.

[31] Flora of the Rocky Mountains and adjacent plains. New York, 1917.

[32] Porsild, M. P.: On the genus Antennaria in Greenland. (Medd. om Groenland. II. Copenhagen, 1915. Holm, Theo.: *Antennaria alpina* and *A. Carpathica.* Rhodora, vol. 22. 1920.

[33] Flora Danica XLVII, Tab. 2786. Köbenhavn, 1868.

gives the range as follows: "Rocky banks through the subarctic regions and common northward, ranging south to the Allegheny Mountains, New Mexico, and the northern borders of California." In Greenland the typical plant is rare, while the var. *arctica* Lge. is frequent on both coasts. Two other varieties, *stricta* Schum. and *uniflora* Lge., are also reported from Greenland, but these are quite rare. Typical *C. rotundifolia* L. is, on the other hand, known from Arctic Europe and Asia, from the European Alps, and Pyrenees, Caucasus, Ural, Baikal, and Altai Mountains. It is evidently a plant of southern origin, but one of those that accompanied the Arctic vegetation on its return to the north when the ice receded. The very wide geographical distribution through both hemispheres does not exclude the possibility of the species having originated from one single station on this continent or in Europe. Being unquestionably a lowland plant and as such being much more abundant in Europe than in Asia and North America, I presume that middle Europe may have been the original center of development of the species. Furthermore, in Europe the species is associated with some others of which the general habit is much the same, but of which the capsule is dehiscent near the apex instead of at the base. These species are *C. patula* L., *C. Rapunculus* L., and *C. persicifolia* L.

Campanula uniflora L.

This species is almost circumpolar, and it seems natural to suppose that it developed in the Arctic regions. In Siberia it has only been reported from Nova Zembla, Konyam Bay, and Arakamtschetschene Island, but it is absent from Arctic Russia. In North America the species occurs "on the shores and islands of the Arctic Sea from the eastern to the western extremity" (Hooker), and has been recorded from a number of stations in the Alpine regions of the Rocky Mountains south to Colorado. However, the species is one of those of which the geographical range does not include the European Alps or the mountains of Asia, and, as present, it is not known to be abundant anywhere.

Vaccinium Myrtillus L. and the var. microphyllum Hook.

These I found growing together with Alpine plants in the deep, cold canyon known as Thompsons Canyon. Typical *V. Myrtillus* L. is known from Alaska and British Columbia, from there extending as far south as Colorado and Utah. A like distribution within the Rocky Mountains is given of the variety *microphyllum* Hook.; of these the former has also been collected in Greenland, but the exact station is not known. In Europe the range of the species extends to the northern borders of Scandinavia, 71° 10′ north latitude, and of Russia, but otherwise the plant is much more frequent farther south in the mountains as well as in the lowlands, where I presume it originated. Concerning the variety, this is known only from the Rocky Mountains and Sierra Nevada, California, and mostly occurring at high elevations.

Arctostaphylos Uva-ursi Spreng.

This plant reaches the Arctic region in both worlds, and farther south the geographical distribution is the same as that of *Vaccinium Myrtillus* L. Being more frequent at lower elevations and much more abundant in the cold temperate regions than in the Arctic, it seems safe to conclude that the plant is not of Arctic origin and that the main center of distribution was located in middle Europe.

Kalmia glauca Ait. var. microphylla Hook.

This depauperate, Alpine form has been collected at several stations in the Rocky Mountains as far south as Colorado and the Sierra Nevada, California, while the typical plant is common in peat bogs from the Atlantic to the Pacific, but scarcely extending north of the Arctic Circle. Neither the species nor the variety have been observed in Greenland, and the genus is altogether confined to this continent and Cuba.

Primula angustifolia Torr. and P. Parryi Gray.

Both are natives of the higher Rocky Mountains of Colorado. The geographical distribution of the former extends to New Mexico, while the latter is known also from Nevada and Arizona. Only a few other species are exclusively American, viz, *P. suffrutescens* Gray, *P. Cusickiana* Gray, and *P. Rusbyi* Grne. (Oregon and Arizona). The other species of the genus which inhabit North America are high northern, but they are more frequent in northeastern Asia and Europe. There is thus in the Rocky Mountains a center of development of a few species of Primula, but extremely poor in species when compared with the Alps of Europe and the mountains of Asia.

THE GENUS ANDROSACE.

In accordance with the table given above, *Androsace Chamaejasme* is almost circumpolar, being absent only from Finmark, Spitzbergen, and Greenland. It occurs also in Switzerland, and toward east the geographical range extends to the Caucasus, Baikal, Altai Mountains, and the Himalayas. On this continent the range extends from Colorado northward to the coast, from Bering Strait to the Archipelago.

The other species, *A. subumbellata,* is known from Montana to Arizona and is endemic to the Rocky Mountains. On this continent the genus is relatively poorly represented—by four species according to Gray—but recently some three or four more have been described and generally accepted. In the Alps of Switzerland the genus culminates with 13 species. Furthermore, 7 are known from the Caucasus, 8 from Altai and Baikal Mountains, 8 from eastern Siberia, 5 from Ural, etc. It would thus appear as if the geographical center of the genus were to be sought in the Alps or in the Altai Mountains. As a matter of fact, the three sections which have been established of the genus Aretia, Chamaejasme, and Haplorhiza are all represented in the Alps. The first of these, Aretia, is not known from Altai and Baikal but from eastern Siberia.

No doubt the European Alps may be considered a most important center owing to the large number of species, including several endemic. Nevertheless the Rocky Mountains must constitute another and of no smaller importance. For even if the genus in the Alps is accompanied by a close ally, the monotypic Aretia, an ally so close that several authors have united it with Androsace, there is on this continent another ally, Douglasia, with four species, which is also closely related to Androsace.

Concerning the distribution of Douglasia, *D. nivalis* Lindl., *D. montana* Gr., and *D. laevigata* Gr. are endemic to the Rocky Mountains and the Cascade Mountains, principally at higher elevations, while *D. arctica* Hook. is known only from the Arctic seashore. In other words, these two genera, being Arctic or Alpine, may well be considered as representing a high northern center of the Primulaceae. *Douglasia arctica* being a truly Arctic type and *Androsace Chamaejasme* being quite frequent on the Arctic shore, including the Archipelago, and sometimes accompanied by *A. septentrionalis* and *A. Gormani* Grne., this little alliance may indicate a former center located in the polar regions. Moreover, we remember that *A. Chamaejasme* is almost circumpolar.

The present more advanced development of both genera farther south in the Rocky Mountains may have had its origin from an Arctic center. The fact that both *A. Chamaejasme* and *A. septentrionalis* are known also from Altai and Baikal seems to indicate that they came from the north. In Europe these same species migrated as far south as to the Alps and to the Caucasus, where they still are in existence. The approximately circumpolar distribution of *A. Chamaejasme* in connection with the exclusively Arctic *Douglasia arctica* thus seems to illustrate an instance of a single center being located in the polar regions even if the genera in question are at present more amply represented farther south, the former in mountains so remote as the Alps, Caucasus, the Altai, the Himalayas, and the Rocky Mountains. And in these mountains the genus has developed into several endemic species, which in spite of the enormous distances offer an excellent illustration of "analogous endemism."

Gentiana frigida Hnke.

Originally described from specimens collected "in alpibus Styriae et in Carpathis," the species has also been reported from "terra Tschuktschorum ad sinum St. Laurentii," and, furthermore, from the Alpine region of the Rocky Mountains in Colorado, Utah, and Montana. By Ledebour[34] the (European) specific name *frigida* Hnke. is reserved for the European plant, while the other, from St. Lawrence Bay, is described as a new species, *G. Romanzowii* Ledeb. However, in Flora Rossica,[35] Ledebour himself enumerates the latter as a variety *Romanzowii* of *G. frigida* Hnke., a disposition already proposed by Grisebach.[36] As compared with these, the plant from the Rocky Mountains is somewhat variable in accordance with the altitude of the stations, but I find no distinction by which the American plant may be separated from the European. According to Kjellman (l. c., p. 507), typical *G. frigida* Hnke. does occur in Arctic Siberia—St. Lawrence Bay, Arakamschetschene Island—besides Nischne Kolymsk, northern Siberia. In other words, we have before us a species of which the geographical distribution is extremely local: The Carpathian Mountains in Europe, the northeastern part of Siberia, St. Paul and Shumagin Islands off the north coast of Alaska, and the Rocky Mountains. At present the species is very rare in Europe and Asia but quite frequent in the Alpine region of the Rocky Mountains, a fact that may indicate two distinct centers of development and geographical distribution unless we admit the possibility of a former, much wider range, but broken by the local extermination of the species. A similar wide and relatively scattered distribution is also noticeable in some of the other gentianaceous plants, which I collected in the Rocky Mountains, but mostly at lower elevations. Of these may be mentioned: *Gentiana tenella* Rottb., *G. humilis* Stev., *G. prostrata* Hnke., *Swertia perennis* L., and *Pleurogyne rotata* Griseb. all of which are known, also, from Eurasia. Of these the geographical range is as follows:

Gentiana tenella Rottb.: Scandinavia, including the Arctic region; Iceland; Alps of Switzerland and Tyrol; Arctic Russia; Arctic Siberia; Altai and Baikal Mountains; the Himalayas; Alaska.

G. humilis Stev.: Caucasus; Ural; Altai and Baikal Mountains; and the Himalayas.

G. prostrata Hnke.: Alps of Tyrol; Caucasus; Altai and Baikal Mountains; Asiatic coast of Bering Straits; Alaska.

Swertia perennis L.: Alps of Germany and Switzerland; middle and south Russia; Caucasus; Altai Mountains; Alaska.

Pleurogyne rotata Griseb.: Iceland; Arctic Russia; Altai and Baikal Mountains; Labrador and Hudson Bay to the high northwest coast and Kotzebue Sound; Greenland.

Similar to *Gentiana frigida* Hnke., these plants are mainly inhabitants of mountains. *G. tenella* Rottb. is almost circumpolar, and Pleurogyne is well represented in the northern and Arctic regions. The original geographical center of these two plants may thus have been located in the Arctic mountains. On the other hand, a more southern center may be attributed to *G. humilis* Stev. and *G. prostrata* Hnke.; for instance, the Baikal and Altai Mountains. With regard to *Swertis perennis* L., so widely distributed throughout middle and south Europe, I presume the species originated there, while the variety *obtusa* (Ledeb.) represents the plant as it occurs in South Russia, Siberia, and the Rocky Mountains. In Siberia, the Altai and Baikal Mountains constitute a most important geographical center of a number of plants, notably northern or even Arctic species, and it seems strange that *Gentiana frigida* Hnke. has not so far been discovered in these mountains. There is, however, a species called *G. algida* Pall. which is known from there as well as from eastern Siberia, and is a close ally of *G. frigida* Hnke., so close, indeed, that several authors have considered *G. algida* as merely a variety of *G. frigida*.

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[34] In A. de Bunge: Conspectus generis Gentianae imprimis specierum Rossicarum 1824. P. 215.

[35] Vol. 3. 1846–1851. P. 65.

[36] Genera et species Gentianearum. Stuttgart 1839. P. 279.

Polemonium viscosum Nutt.

This species is the southern Alpine analogue of the Arctic *P. pulchellum* Bunge. It is a native of the Rocky Mountains from Montana to Colorado, where several other species of the genus occur, nearly all being endemic. *P. pulchellum* Bunge is distributed throughout the Arctic regions of both worlds and is almost circumpolar, beside being a native of Altai.

Eritrichium argenteum White.

The genus Eritrichium shows several centers with regard to geographical distribution, but the species are relatively local; i. e., confined to certain mountain ranges and regions. *E. argenteum* White is a native of the Rocky Mountains, from Wyoming to Colorado, and *E. elongatum* (Rydb.) White, which is very rare in Colorado, occurs also in Montana and Oregon. *E. nanum* Schrad. is the only species that is known from the mountains of Austria and Switzerland, and is reported also from the Caucasus. *E. aretioides* (Cham. et Schlecht.) is a native of northeastern Asia, St. Lawrence Bay, etc., extending from there to Alaska, accompanied by *E. Chamissonis* A. D. C. *E. villosum* Bunge is widely distributed through Arctic Russia and Siberia, and has, furthermore, been reported from Baikal. At present *E. villosum* A. D C. shows the widest geographical range of the species and is a member of the Arctic flora. Similar to *Pleuropogon Sabinei* R. Br. and a number of other Arctic plants, it has reached the Baikal Mountains, but nevertheless the original center of its distribution and development must have been located in the Arctic mountains. Independently of this *E. villosum* A. D C., the European *E. nanum* Schrad., became developed in the Alps of Switzerland, while the other species mentioned above may have developed in West America, probably in the Rocky Mountains.

THE GENUS MERTENSIA.

With the exception of *Mertensia maritima* Don., the other species of the genus are relatively local, and confined to certain mountain ranges. *M. maritima* Don. is, as we know, widely distributed, in the north especially, from the Atlantic coast, Gulf of St. Lawrence, and Hudson Bay, and westward at various points on the Arctic coast to the Pacific and southward on sea beaches to latitude 49°. Furthermore, the species occurs in Greenland, Spitzbergen, Scandinavia, including Finmark, Arctic Russia, northeastern Siberia, Kamtschatka, and, finally, it is not infrequent in Iceland, Faroe Islands, Great Britain, and Denmark. The Alpine species of Colorado are, on the other hand, confined to these mountains, and several interesting forms have been described in recent years. *Mertensia Sibirica* Don. occurs at lower elevations in Colorado, and is known also from the higher parts of the Sierra Nevada, California, and far northward, the var. *Drummondii* Gray having been recorded from the Arctic seashore. Typical *M. Sibirica* Don. is known also from the mountains of Altai. In the Eastern States *M. Virginica* D C. is distributed from New York to South Carolina and Tennessee. *M. paniculata* Don., a very polymorphic species, shows a very wide distribution on this continent: Hudson Bay and Lake Superior, thence to the Rocky Mountains (south to Utah and Nevada), Alaska, Bering Straits, extending from there to northeastern Asia (fide Gray). No doubt the Rocky Mountains constitute an important center in respect to the genus Mertensia, while the Allegheny Mountains are not inhabited by more than one species, *M. Virginica* D C. According to Ledebour, the Baikal and Altai Mountains are the center of several species of the genus peculiar to Siberia or to these mountains alone.

Chionophila Jamesii Benth.

The monotypic genus Chionophila is confined to the Alpine regions of the Rocky Mountains of Wyoming and Colorado.

Synthyris alpina Gray.

This species is a native of the Alpine region of the Rocky Mountains of Wyoming and Colorado. Some few other species have been described, and these are mostly from northwest America, one, *S. rubra* Benth., extending as far north as British Columbia.

Veronica alpina L.

Widely distributed throughout the Arctic regions of Europe and Asia, the species, nevertheless, seems to be absent from Arctic North America, although it has been reported from Greenland, Labrador, the Hudson Bay region, Alaska, and from many stations in the Rocky Mountains. In Europe the species extends south to Iceland, Great Britain, and the Alps of Switzerland. It is no doubt of Arctic origin, having acquired the recent wide range during the glacial epoch.

THE GENUS CASTILLEJA.

C. breviflora Gray and *C. septentrionalis* Lindl. are the only species which I found in the Alpine region; of these the former is a native of Colorado and Wyoming, while the latter is known also from Labrador, White Mountains, Alaska, Aleutian Islands, etc. It is interesting to notice that *C. pallida* Kunth, a close ally of *C. septentrionalis* Lindl., is a native of the subarctic northwest coast and islands of North America, extending from there to Arctic Asia and Europe, to Greenland, and that it is known, also, from Altai and Baikal Mountains. But otherwise Castilleja is best represented in the Rocky Mountains, where the genus evidently developed, and from which locality *C. septentrionalis* Lindl., the most abundant species, became distributed toward northeast and northwest, while the subarctic *C. pallida* Kunth even reached the Altai and Baikal Mountains.

THE GENUS PEDICULARIS.

The species, about 120, are mainly inhabitants of mountains; several are Alpine, and not a few species are known from the Arctic regions. In North America about 30 species are recorded by Gray, and of these *P. scopulorum* Gray is a native of the Alpine regions of Colorado, sometimes accompanied by *P. Groenlandica* Retz. and *P. Parryi* Gray which, however, are much more characteristic of the spruce zone The genus is well represented in Alaska and adjacent islands, several extending from there to Asia, and even to Europe. Eight of the nine species known from Greenland occur also in Northeast America, Labrador, and the Hudson Bay region; 22 species are recorded from the mountains of middle Europe, several of which being natives of these mountains. Of the 60 species enumerated by Ledebour (Fl. Rossica), 37 are recorded from the Altai and Baikal Mountains. Four species of the genus are circumpolar, *P. lapponica* L., *P. sudetica* Willd., *P. hirsuta* L., and *P. lanata* (Willd.) Cham., and these may have originated in the Arctic mountains. The other species may have developed from several centers south of the boreal regions, and very remote from each other, viz, the mountains of middle Europe, Altai and Baikal Mountains, Rocky Mountains, and partly, also, the Caucasus.

POLYGONUM BISTORTOIDES Pursh.

By Meisner [37] this plant is considered to be identical with *P. Bistorta* L., a view held by several other authors, and Macoun (l. c.) enumerates *P. Bistorta* L. as the species of Arctic America, with *P. bistortoides* Pursh as a mere synonym. Whatever importance be attached to the difference in leaf outline, the plant of the Rocky Mountains does appear somewhat distinct from typical *P. Bistorta* L., and may deserve, at least, rank as variety. In considering the geographical distribution of both, we notice that *P. Bistorta* L. is widely distributed through the northern and Arctic regions of Russia and Siberia, extending south to the mountains of middle Europe, to the Caucasus, Baikal and Altai Mountains, while the so-called *P. bistortoides* Pursh is a native of the mountains of Montana, Washington, Colorado, New Mexico, and California. According to Ledebour (l. c.) *P. Bistorta* L. is, in Altai and Davuria, accompanied by two varieties: "*foliis latioribus*," and "*foliis angustioribus;*" of these the latter may be identical with the Rocky Mountain plant, but I have seen no specimens of the Asiatic, except from the Arctic regions.

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[37] Monographiae generis Polygoni prodromus. Geneva, 1826.

Polygonum viviparum L., and *Oxyria digyna* Campd. are circumpolar, and widely distributed throughout the Northern Hemisphere; in Colorado they are quite abundant and typically developed.

Betula glandulosa Michx.

This shrub has been found in south Greenland, and the geographical range extends from there to Labrador and Newfoundland westward to the barren grounds of Mackenzie River, through British Columbia to Alaska; it follows the Rocky Mountains as far south as Colorado; in Asia the species is known from eastern Siberia and the Altai Mountains. It does not occur within the Arctic region, and it is very seldom Alpine. Being so widely distributed on this continent, I presume that the boreal regions of Canada are the original home of this species.

Of the Alpine willows **Salix reticulata L.** is the only one of interest from a geographical point of view. It is circumpolar, and originated undoubtedly in the polar regions similar to *S. polaris* Wahlenb. and *S. glauca* L., which are also circumpolar.[38]

Lloydia serotina Reich. is an Arctic-Alpine type, but it is absent from Greenland, Spitzbergen, and Scandinavia, and has only been recorded from a few stations in the boreal regions of this continent, viz, northern Arctic coast (Dr. Richardson), St. Lawrence and Ounalashka Islands, Alaska;[39] thus it is hardly to be defined as a circumpolar species. *Lloydia* and *Allium Sibiricum* L. are about the only bulbous plants which so far have been found in the Arctic regions. By considering the geographical distribution, Lloydia has been recorded from several of the higher mountains in Europe and Asia, and its occurrence also in the Rocky Mountains may indicate that it is a mountain type rather than an Arctic. In other words, it is evidently of southern origin, but one of those which accompanied the Arctic plants on their return to the north, when the ice receded.

JUNCACEAE.

Among the Juncaceae, *Luzula spicata* D C., and *Juncus biglumis* L. are circumpolar. The latter does not occur in the Alps and Pyrenees, neither in Caucasus, Baikal, and Altai Mountains, nor in the Himalayas. In the Rocky Mountains it was known only from north of Smoking River (fide Macoun, l. c.) until I found it on Longs Peak, the most southern station, so far, of this species. It is undoubtedly of Arctic origin, and the same is evidently the case of *J. castaneus* Sm., *J. triglumis* L., and *J. arcticus* Willd., although these have been recorded from the higher mountains farther south. *Luzula spicata* may also be looked upon as representing an Arctic type inasmuch as it is associated in the Arctic regions with several close allies of much the same structure but quite distinct from those which abound in the mountains and lowlands farther south.

With regard to the **Cyperaceae,** *Elyna Bellardii* (All.) is an Arctic-Alpine type widely distributed in the Arctic regions of Europe, less so of Asia and North America; but it is frequent in the Rocky Mountains, also in the European Alps, while in Asia it has been recorded from Caucasus, Alatau, Altai, and Davuria. The genus, as well as Cobresia, has its largest distribution in the higher mountains of central or oriental Asia, and especially in the Himalayas, which may be regarded as the center of its development and distribution.

CAREX.

In a previously published paper [40] I have discussed the geographical distribution of all the species known from Colorado, and with respect to the Alpine types, collected by myself, the following table shows their distribution in general:

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[38] Holm, Theo.: Novaia Zemlia's Vegetation. (Dijmphna Togtet's Zoologisk-botaniske Udbytte. Kjöbenhavn, 1887. P. 28.)

[39] Macoun, John: Catalogue of Canadian plants. Part IV. Montreal, 1888. P. 42.

[40] Holm, Theo.: The genus Carex in Colorado (Am. Journ. of Sc., Vol. XVI, July, 1903, p. 17).

I. Northern Types.

CIRCUMPOLAR TYPES.

C. rigida and *C. misandra.*

ARCTIC, BUT NOT CIRCUMPOLAR.

C. nardina, *C. festiva*, *C. alpina*, *C. atrata*, and *C. capillaris.*

II. Northern, but Not Arctic Types.

C. siccata.

III. Northern Types, Endemic to North America.

C. petasata, *C. Bonplandii*, and *C. nigricans.*

IV. Southern Species.

SPECIES COMMON TO BOTH WORLDS.

C. pyrenaica, and *C. melanocephala.*

SPECIES ENDEMIC TO NORTH AMERICA.

C. chalciolepis, *C. scopulorum*, *C. chimaphila*, and *C. elynoides.*

Of these, the Arctic-Alpine species represent undoubtedly remnants of a glacial flora which were left on these mountains, while the others migrated back to their northern homes when the ice receded. Their center of development and distribution would thus be the Arctic region. This explanation might be plausible concerning the circumpolar species, but some of the merely Arctic-Alpine might have originated in the south and accompanied their Arctic brethren on their return to the north. The latter explanation might be applicable especially to such species as are not strictly Alpine but which nevertheless are known to occur in the Arctic region. When thus the geographical distribution fails to give us any exact information about the center of development of such Arctic species, which are not always Alpine, some other data may be taken into consideration. As touched upon in the introduction to this chapter, the association with allied species may give some clue to the solution of this problem.[41]

Carex atrata may thus have developed from one center in the Rocky Mountains, a second in the European Alps, and a third one in the Himalayas. A like distribution and association with allied types may be recorded from several of the other species, the Alpine as well as the Arctic-Alpine. Let us examine *Carex festiva*, for instance. This species is Arctic, but neither circumpolar nor strictly Alpine. Only the typical plant occurs in the Arctic region, where it is relatively rare; but much farther south, and especially in the subalpine zone of the Rocky Mountains, is a herd of this same species together with several aberrant forms associated with species that are closely related to *C. festiva: C. athrostachya*, *C. pratensis*, *C. petasata* cet. It seems, therefore, natural to suppose that *C. festiva* has its center of development and geographical distribution in the Rocky Mountains, where it is typically developed, accompanied by allies, and where it is most abundant. Its occurrence in the Arctic region may be explained in this manner, that individuals of this species were among those that migrated northward with the Arctic plants. But *C. rigida* and *C. misandra* may have originated within the Arctic region, where they have their widest distribution and where they show, especially the former, a much more pronounced tendency to develop varieties than they do farther south. A northern and Arctic center may be attributed also to *C. nardina*. But concerning the other members of the category, "Arctic, but not circumpolar types," these developed evidently in stations south of the Arctic region. The third and fourth category of northern types emphasize such species as are not Arctic. With the exception of *C. siccata*, these species are endemic to North America, where they evidently originated. Among the southern types *C. pyrenaica* shows a remarkably wide distribution—from Colorado to Canada, Alaska, the Pyrenees, Alps of Switzerland, Caucasus, Japan, and New Zealand—while its nearest ally, *C. nigricans*, is confined to the Rocky Mountains and Alaska. Thus it seems impossible to locate the geographical center of *C. pyrenaica*, especially on account of its occurrence in New Zealand. But the species endemic to this continent, naturally developed there and undoubtedly in the mountains. In other words, the presence of these various types of Carex indicate that the Rocky Mountains harbor a certain element of that flora, which we call the Arctic, which was reared in the polar regions but forced south during the glacial epoch. The genus Carex thus offers an excellent illustration of these data and in a much greater scale than most of the other genera which have been discussed in the preceding pages from this same point of view—geographical distribution and center of development.

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[41] Compare, R. V.: Wettstein: Grundzüge d. geogr.—morphol Methode d. Pflanzensystematik. 1898. P. 35, etc.

GRAMINEAE.[42]

The following species in Colorado are confined to the Alpine region: *Agrostis canina* L. var., *A. varians* Trin., *Avena Mortoniana* Scribn., *Poa flexuosa* Wahlenb., *P. gracillima* Vas., *P. Fendleriana* (Steud.), *P. Lettermannii* Vas., *P. alpina* L., *Festuca ovina* L., var. *supina* Hack., *Agropyrum Scribneri* Vas., and *A. violaceum* Lge. The remaining species, on the other hand, were also observed at lower elevations, from the aspen zone to the spruce zone. *Phleum alpinum* L., for instance, descends to the aspen zone on Longs Peak, where it is very frequent in swamps. *Calamagrostis purpurascens* R. Br. follows the creeks throughout the spruce zone on Longs Peak and the region of Clear Creek Canyon. *C. canadensis* var. *acuminata* Vas. is only exceptionally Alpine and thrives best in the swamps of the aspen zone. *Deschampsia caespitosa* Beauv. is most frequent and typically developed in swamps of the aspen zone, but is also very common near snow banks at high elevations. *Trisetum subspicatum* Beauv. does not descend much farther than just to the timber line. *Poa rupicola* (Vas.) Nash descends to the aspen zone on James Peak and near Central City, but only seldom. *Festuca ovina* L. was collected in the aspen zone near Central City, and in the spruce zone on Mount Massive and Longs Peak.

Four of these Alpine species are circumpolar: *Trisetum*, *Poa flexuosa*, *P. alpina*, *Festuca ovina*, and the var. *supina*. *Calamagrostis purpurascens* is the only one that is confined to this continent and Greenland. *Agropyrum violaceum* occurs in the Arctic regions of both hemispheres, and *Festuca ovina* var. *supina* is also an inhabitant of these high northern regions outside America. All the others extend to the mountains farther south, and five of these have even reached the Himalayas. The Alpine Gramineae in Colorado thus represent an assemblage of several very distinct geographical types—some that are endemic to this particular region; some that occur also on the Pacific and Atlantic coasts; some that have reached the polar regions in certain parts of both hemispheres; some that are circumpolar; and, finally, some that have become dispersed throughout the mountainous districts farther south in Europe and Asia.

The circumpolar species originated undoubtedly in the polar regions. But *Calamagrostis purpurascens* developed evidently in the Rocky Mountains and migrated with the Arctic flora to Greenland. *Agropyrum violaceum*, on the other hand, may have originated in the Arctic. *Phleum alpinum*, being much more frequent in the mountains of the temperate regions, did evidently develop there, but the occurrence of this plant in the Baikal Mountains and in the Himalayas and its absence from Arctic Siberia, beside its wide distribution in Europe and on this continent, seems to call for more than one center of geographical distribution. The species endemic to the Rocky Mountains naturally developed there.

The occurrence of **Juniperus communis** in the Arctic regions, as a depauperate form, however, may be considered as an indication of migration toward the north when the ice receded. The species, being so widely distributed farther south, naturally developed there, although it is not possible to locate the actual center.

By comparing the geographical distribution of these Alpine species, in order to locate the probable center of their distribution and development, it seems safe to conclude that the endemic species originated in the Rocky Mountains; that the circumpolar and a part of the Arctic element came from the Arctic regions; that several of the species, known also from various districts of the temperate zone, may have developed from more than a single center, at least in cases where the present distribution is extremely wide but at the same time interrupted by gaps of immense extent, the actual cause of which can not be satisfactorily explained.

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[42] Holm, Theo: The Gramineae of the Alpine region of the Rocky Mountains in Colorado. (Bot. Gazette, 46:422. Chicago, 1908.)

Chapter 5.

DESCRIPTIONS OF ALPINE TYPES.

Characteristic of the Alpine vegetation are the same features which we observe in the Arctic: Absence of trees; among the herbs are no saprophytes, no epiphytes, no climbers, and no parasites except some few Scrophulariaceae with green foliage. The woody plants are mostly in the shape of creeping shrubs; bulbous plants are absent, with the exception of *Lloydia*, *Zygadenus*, and *Saxifraga cernua;* fleshy rhizomes are very scarce, and tuberiferous stolons do not exist. Only a relatively small number of species are able to spread by means of stolons, subterranean (Carex), aerial (Antennaria, *Saxifraga flagellaris*, *Androsace Chamaejasme*, etc.). Similar to the Arctic plants,[1] the vegetative reproduction is secured by means of overwintering buds, which are not buried in the ground but situated close to the surface and protected by the withered foliage. Most of the herbs are caespitose, with the numerous leafy shoots forming cushions, or with the leaves more ample, frequently forming a rosette; a profuse branching is common to the herbaceous as well as to the woody species, as is exactly the case of the Arctic. The primary root often persists and increases in thickness sometimes to quite a considerable extent (Claytonia, Calandrinia, etc.).

We meet with the same floral structures as in the Arctic; some that are adapted to pollination by insects, others by the wind; among the former we observe the same brilliant colors and the profuse development of flowers. The similarity between the Alpine and Arctic vegetation is altogether striking, although the former enjoys a climate more favorable than the latter. On the other hand, the Arctic plants have the advantage of constant daylight for three months and are spared from the frequent, often violent, changes in temperature, which are a daily occurrence in the Alpine region, often accompanied by heavy rains, hailstorms, and snow.

From a morphological viewpoint, the Alpine plants offer several points of interest, and quite especially with reference to the method of hibernation and vegetative reproduction. The Alpine types may be represented by species of a genus which at lower altitudes exhibits a structure entirely distinct, as, for instance, in Arenaria, Claytonia, Saxifraga, Trifolium, etc., and the consequent difference in habit often becomes very striking. But in certain families, notably the Gramineae and Cyperaceae, there is no great difference in the external structure, whether the species be an Alpine or a lowland type; only in the development of stolons above ground, as for instance, in Glyceria, Cynodon, etc., such structures do not develop in the Alpine region; neither do we meet with the ramified culms, so very characteristic of the Gramineae of the plains, Munroa, Vilfa, Aristida, etc. The caespitose growth is the one characteristic of the Alpine Gramineae; *Poa Lettermannii* and *Festuca ovina* (pl. 7, figs. 67–74) illustrate this type, and these two specimens, dwarfed as they are, are nevertheless provided with perfectly normal spikelets; they represent the species of Gramineae, which in Colorado ascends to the highest altitudes. A corresponding caespitose habit is also characteristic of various Cyperaceae and Juncaceae (pl. 7, figs. 59, 60, and 66). These figures show, furthermore, the stunted growth of *Carex capillaris* and *C. atrata* when they occur in the Alpine region. Their proper home is at lower elevations, notably in the aspen zone, while *C. chalciolepis* (fig. 60) is a genuine Alpine type, which nevertheless is quite a tall plant with a very slender culm. *C. atrata* and *C. capillaris* thus offer a good example of reduction in height and structure of inflorescence acquired by Carices when they leave the wooded belts and migrate to the higher altitudes, above timber

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[1] Kjellman, F. R.: Ur Polarväxternas lif. (A. E. Nordenskiöld: Studier och Forskningar föranledda af mina resor i höga norden. Stockholm, 1884.)

line; a corresponding variation, caused by change of environment at different altitudes, is known from many other Carices, so excellently described by N. J. Andersson.[2]

The caespitose growth is also characteristic of many Alpine species of the Dicotyledones and is sometimes accompanied by another feature, the persisting primary root. But we meet here with several very distinct types. The vegetative organs above ground consist of numerous, often profusely branched, stems with the leaves imbricated or forming flat rosettes at the apex of the shoots; in both cases the specimen represents the structure known so well from Alpine and Arctic plants, resembling a cushion. The primary root may persist for several years as a slender deep taproot, or it may increase very considerably in thickness, and persist for many years; or finally the primary root may die off and become replaced by a fascicle of secondary roots proceeding from the lowermost stem parts. A very simple case of this structure may be seen in *Androsace subumbellata* (pl. 3, fig. 23). The primary root is very slender, and branches freely; the foliage consists of several small rosettes borne upon a corresponding number of axillary shoots, terminated by inflorescences. When the fruit has matured, the internodes of the inflorescence die off, and a new set of shoots become developed from the axils of the rosette leaves; in Androsace these shoots develop flowers in the first season; in most other plants showing this structure the shoot is a mere vegetative rosette during the first season, the inflorescence appearing in the second year.

A similar structure recurs in *Eritrichium argenteum* (pl. 4, fig. 30), but the leaves are imbricated, since the internodes are extremely short. The Arctic *E. villosum* Bunge. shows exactly the same structure. In *Silene acaulis*, *Arenaria Fendleri*, and *Phlox caespitosa* very large and compact cushions are formed by the numerous short branches with their opposite leaves; the primary root persists for several years, but increases only a little in thickness. Cushions are also to be observed in some of the Compositae, for instance, *Erigeron pinnatisectus* (pl. 5, fig. 31), and *Actinella acaulis;* in these the primary root is quite thick and bears a number of leafy shoots with terminal inflorescences. *Saxifraga bronchialis* (pl. 2, fig. 11) represents a type with relatively long branches of short internodes with the leaves imbricate, and terminated by an inflorescence.

In *Oreoxys humilis* (pl. 3, fig. 20), *Mertensia alpina* (pl. 5, fig. 39), and *Trifolium nanum* (pl. 2, fig. 18), all forming compact cushions, the primary root attains a considerable length and thickness, and may last for many years. The drawings represent only a small portion of the cushions; we notice the thick stem parts underground, densely covered with remnants of leaves, and terminated by rosettes of long-petioled leaves, and with a central inflorescence; in Oreoxys the flowering stem bends down to the ground, where the fruit matures, similar to Erigenia. These three plants are able to thrive at the highest elevations in the Rocky Mountains, and persist for many years. The other Alpine species of Trifolium do not show this structure, but simply a slender primary root and small cushions of leafy rosettes; the inflorescence is a head borne upon a long peduncle, instead of being almost sessile as in *T. nanum* (pl. 2, fig. 19), with only two flowers.

In some of the other Alpine types with a more or less caespitose growth the leaves are somewhat crowded, but without forming compact cushions; this structure is common, and is sometimes accompanied by a more or less developed rhizome, horizontal or ascending; in some of these the primary root persists, in others it becomes replaced by a system of secondary roots. *Lychnis montana* (pl. 1, figs. 2–4) shows a strong, primary root, crowned with an open rosette of leaves; at the time of flowering some vegetative shoots appear; these are, however, very short, bearing only one or two pairs of leaves, and become terminated by an inflorescence in the succeeding year.

Among the Ranunculacae, *Anemone narcissiflora*, *Caltha leptosepala*, and *Trollius laxus* have many basal leaves borne upon the very short vertical rhizome; a thick primary root of quite considerable length occurs in the Anemone, while in the others the root system consists of strong secondary roots when the first flowering state has been reached. In the Caltha the

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[2] Andersson, N. J.: Skandinaviens Cyperaceer. Stockholm, 1849. See also: Holm, Theo: Notes on *Carex spectabilis* Dew. (Am. Journ. Sci., Vol. XLIX, March, 1920, p. 200.)

inflorescence is generally two-flowered, but the basal internode seldom develops to any length, remaining inclosed within the leaf sheath, thus the flowers appear as being "scapose."

In *Gentiana frigida* the very short vertical rhizome is completely covered with the withered leaf sheaths, and the root system consists of many fleshy secondary roots of quite a considerable length, the primary root having died off evidently before the flowering state had been reached. There are many leaves forming an open rosette, and the fact that vegetative shoots appear in abundance, together with floral, makes it difficult to ascertain whether the growth of the shoot is monopodial or sympodial. In the subalpine *G. barbellata* Engelm. the ramification is very distinctly monopodial, and in this species the shoots are not so crowded as in *G. frigida*. While collecting *G. barbellata*, I noticed that the flowers exhale a strong odor like vanilla, the only species which, so far as I know, is fragrant.

In *Viola bellidifolia*, which is of the caulescent type, the basal internodes of the flowering stem are so short that the plant (pl. 1, fig. 1) might be mistaken for an acaulescent species. However, the basal internodes are present, and they winter over with buds in the leaf axils, which continue the growth of the plant above ground. It is this structure which Hjalmar Nilsson has defined as a "pseudo-rhizome," [3] being the only stem portion that persists. As may be seen from the figure, the primary root persists, but remains rather slender and ramifies but sparingly. *Viola bellidifolia* belongs to the group of which the ramification of the shoot is sympodial, similar to the European *V. canina* L.[4] In *Sieversia Rossii* (pl. 2, fig. 10) there is a deep primary root, and some secondary roots which have developed from the internodes of the short, creeping rhizome. The leaves are quite numerous, long petioled, and with the blade pinnately divided. The species forms dense mats at very high altitudes. In *Polemonium viscosum* (pl. 3, fig. 25) the slender rhizome is creeping, and capillary secondary roots develop freely from the nodi, while the primary root does not persist. Numerous glandular hairy leaves are borne on the apex of the rhizome, and the showy, deep-blue flowers are large in proportion to the size of the shoots. A similar creeping rhizome occurs also in *Artemisia scopulorum* (pl. 3, fig. 21), but it is thicker, and the secondary roots are quite strong. In the species of Primula (pl. 3, fig. 24) the subterranean stem is vertical but short, and the primary root is of short duration, becoming replaced by a number of fleshy secondary roots. *Synthyris alpina* (pl. 5, fig. 36) shows many long-petioled leaves borne upon a short rhizome with strong secondary roots. The long woolly inflorescence is borne upon a long scape. The Alpine species of Senecio (pl. 4, figs. 26–28) have short ascending rhizomes, terminated by a cluster of leaves and a tall inflorescence. *S. dimorphophyllus*, belongs to a group of which the foliage varies from entire or serrate to pinnatifid in the same species, especially well marked in *S. canus* Hook., *S. aureus* L., *S. Fendleri* Gr., and others.

A well-developed, horizontally creeping, and wooded rhizome, on the other hand, is present in *Saxifraga punctata*. This type of growth, with or without a persisting taproot, with or without a distinct rhizome, but with many leaves forming rosettes or cushions, is the one which we most frequently meet with in the Alpine region. Another type is represented by Claytonia and Calandrinia (pl. 1, figs. 8–9). In these the primary root persists for many years as a deep, fleshy, and very thick taproot, and the shoot above ground represents a monopodium, a rosette of many leaves with the inflorescences axillary. Characteristic of both is the seedling, with two cotyledons and the early development of the primary root as a fleshy taproot. We remember that in the tuberous rooted *Claytonia Virginica* [5] only one of the cotyledons develop, as is the case of several other plants with tuberous roots: Cyclamen, Ficaria, Erigenia, etc.

As mentioned in the preceding, stolons are seldom developed. They occur, however, in *Epilobium Hornemannii*, *Stellaria umbellata* (pl. 1, figs. 5–7), Oxyria, and a few others, where they are subterranean and bear only scalelike leaves. With reference to *Stellaria umbellata*,[6]

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[3] Nilsson, Hj.: Dikotyla jordstammar. (Acta Univ. Lundensis. Tom. XIX. Lund, 1882–83. P. 18, seq.)

[4] Holm, Theo.: Biological notes on Canadian species of Viola. (Ottawa Naturalist, Vol. XVII. Ottawa, 1903. P. 149.)

[5] Holm, Theo.: Claytonia (l. c.).

[6] Same: Method of hibernation and vegetative reproduction in North American species of Stellaria. (Am. Journ. Sci., Vol. XXV, April, 1908, p. 319.)

this species has a small rhizome in the shape of stolons with the internodes very short and mostly shorter than the small, fleshy, scalelike leaves. Beside these stolons the vegetative reproduction is secured by means of small buds located in the axils of the withered leaves. These buds develop into aerial shoots during the next season. In specimens from lower elevations the stolons are much longer with the internodes stretched. A corresponding structure recurs in *Stellaria longipes*, which is not infrequent (the var. *laeta*) in the Alpine region and which is very common on the Arctic shores as far north as 82° 27′ north latitude. This little herb shows a remarkable power to withstand the severity of the winter. The rhizome consists of long, subterranean stolons with small, scalelike leaves and stretched internodes. The aerial shoots are ascending, and the foliage is more or less crowded on account of the shortness of the internodes. When the winter commences, the leaves are still attached to the shoots, but in a withered condition. The stems, on the other hand, remain alive and persist throughout the winter. At the beginning of the spring small buds become visible in the axils of the withered leaves, soon developing into small leafy shoots. These shoots frequently remain purely vegetative for one or two years until they become terminated by an inflorescence. This type of vegetative reproduction is also characteristic of *Stellaria longifolia* Muehl., *S. humifusa* Rottb., *S. Holostea* L., and *S. crassifolia* Ehrh.

Swertia perennis has a creeping but relatively short rhizome, with slender, secondary roots; the development of horizontally creeping stolons, was observed only in the plant at much lower elevations. The leaves form an open cluster, surrounding the inflorescence, which appears to be terminal.

Stolons above ground, consisting of a single, stretched internode, and terminated by a rosette of leaves are characteristic of *Androsace Chamaejasme* and *Saxifraga flagellaris*, both of which have been described by the writer in Novaia Zemlia's Vegetation (l. c.); in Antennaria runners above ground are also a characteristic feature; they are exceedingly short, but numerous. In the subalpine species of Antennaria, *A. nardina* Greene, *A. Holmii* Greene, etc., the stolons are far better developed, not including the lowland species, *A. arnoglossa* Greene, etc. The Alpine species of this genus thus show a tendency to form cushions; with regard to *A. alpina* I found only the pistillate plant, while both sexes were equally common in *A. rosea*, especially at lower altitudes. Finally Chionophila[7] is also stoloniferous, and the ascending stolons are almost aerial; they are terminated by a rosette of opposite leaves, and do not separate from the mother plant until the next spring. The shoot above ground of Chionophila (pl. 5, figs. 32–35) represents a typical monopodium. In the specimen figured, the foliage consists of three pairs of opposite leaves, forming a rosette; in the axil of one of the leaves of the outermost pair (L^1) the inflorescence is developed, borne upon a short stem of three internodes. In the center of the rosette a small bud (B) is visible; this bud, the apical of the shoot, is vegetative, and will during the succeeding season develop a new set of leaves and an axillary inflorescence. Chionophila has no persisting primary root, and the short vertical rhizome bears only some secondary roots, which are quite long and fleshy. The foliage is very thick, and almost glabrous, only some few pluricellular hairs (in one row) being developed; in living specimens the calyx is distinctly folded (fig. 33), a structure that becomes lost when the specimen is pressed and dried. Similar to several of the other Scrophulariaceae, and especially the parastic, Chionophila turns black when dried; when fresh the foliage is glaucous.

These stoloniferous species are thus able to wander, and in *Saxifraga cernua* we have a type, the only one, however, in which the vegetative reproduction is secured by means of bulblets. These bulblets (pl. 2, figs. 13–16) are situated in pairs in the axils of the upper stem leaves, and they consist of thick leaves, or, to be more correct, of thickened leaf sheaths, the blade being merely represented by a minute lobe; some bulblets develop also at the base of the stem, close to the roots; when the bulblets fall off, they develop new individuals, and, as a matter of fact, they are necessary to the multiplication of the species, since they actually have taken the place of flowers. In the Arctic regions *S. cernua* is very frequent, often accompanied

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[7] Holm, Theo: *Chionophila* Benth. (Am. Journ. Sci., Vol. 1. 1921, p. 31)

by another species, of which the flowers are generally replaced by similar bulblets, of a more open structure, however, *S. stellaris* L. forma *comosa* Poir. In the Alps of Switzerland a third bulbiferous species occurs, *S. bulbifera* L., while common in North Europe is *S. granulata* L., with bulblets only upon the rhizome.

The genus Saxifraga is altogether a very polymorphic genus. We have in the Alpine region the densely caespitose *S. bronchialis*, the creeping *S. punctata* with a typical rhizome, the bulbiferous *S. cernua*, *S. nivalis* with simply a rosette of leaves, the creeping *S. flagellaris* with runners terminated by rosettes, and, moreover, we have in *S. chrysantha* (pl. 2, fig. 17) a type which makes an approach to the suffrutescent. In this species the branches are almost woody above ground, and terminated by rosettes of fleshy leaves; the infloresence, a single flower borne upon a leafy stem, terminates the shoot, and the rosette may persist for several years.

Suffrutescent in the stricter sense of the word, on the other hand, is *Pentstemon confertus*, with a woody, main stem buried in the ground, emitting herbaceous aerial shoots, which bear clusters of leaves and a terminal long-peduncled inflorescense. *Potentilla fruticosa* is a shrub, but it is rare above timber line. All the other shrubs are more or less creeping, for instance, Dryas, Arctostaphylos, *Vaccinium caespitosum* (pl. 7, figs. 54–55), *V. Myrtillus* var. *microphyllum* (pl. 7, figs. 56–58), and the singular *Paronychia pulvinata* (pl. 5, fig. 41), with the thick woody branches closely appressed to the ground.

Kalmia glauca var. *microphylla* (pl. 3, fig. 22) shows the low erect branches arising from the very stout trunk buried in the ground.

Now, with regard to the Betulaceae and Salicaceae, we have *Betula glandulosa* and a few Salices. Betula, however, is very seldom Alpine, but I did find it in Thompsons Canyon on Longs Peak, where it occurred as a low straggling shrub in a swamp near a frozen lake. Of the willows, *S. glaucops* and *S. chlorophylla* grow in the shape of small erect shrubs, especially along the mountain brooks; the two other species are merely creeping, with the branches appressed to the ground. *Salix reticulata* is of special interest since it represents an Arctic-Alpine type. I have figured a specimen from Mount Elbert on Plate 6, Figure 42, and on this same plate I have inserted some drawings of specimens from other localities outside the Rocky Mountains. The leaf varies a good deal in this species, but, as may be seen from the figures, this variation seems to be independent of the environment. The specimen from Copper Island (fig. 46) shows a remarkable round outline of the leaves, but in comparing the single leaves (figs. 43–44, 50–51, and 52–53) from specimens gathered on Mount Elbert, in Norway and Sweden, we notice the variation in outline to be analogous, and the minute specimens from Spitzbergen (fig. 47) and from Nova Zembla (fig. 48) agree in all respects with the larger specimens from stations much farther south. The shape of the leaves and the habit of the species remain the same wherever it grows.

Finally, *Juniperus communis* occurs sometimes above timber line as the variety *alpina*. It grows there as a low depressed shrub, a habit very different from that which may be observed at lower elevations in the wooded belts.

All the types which have been described in the preceding pages are perennial, and, as it would be natural to expect, the annual species are very scarce here as well as in the Arctic region. A dwarfed Gentiana, *G. plebeja* (pl. 4, fig. 29), was the only annual which I found, but there is also an annual Deschampsia, *D. calycina* Presl., which many years ago was collected on the summit of Grays Peak by B. H. Smith. In the Arctic region *Koenigia Islandica* L. and *Phippsia algida* R. Br. are about the only annual species which have been recorded so far. The latter, however, is not constantly an annual but, according to Blytt, may sometimes persist for two or three years.

While thus the vegetative reproduction is well expressed in these Alpine species, it deserves notice that so far as concerns the various kinds of fruit developed in these species the dry fruit is by far the commonest. Fleshy fruits are known only from Vaccinium and Arctostaphylos, but among the dry fruits are some which are especially adapted to be carried away by the wind, Dryas, Sieversia and the Compositae, or the seeds may be adapted for dissemination by the wind, as in Epilobium, Chamaenerium, and Salix. To these may be added several of the Gramineae, notably Calamagrostis, Deschampsia, and Festuca.

The structure of the flower is in the majority of the Dicotyledones actinomorphic, the proportion of the species exhibiting this type, actinomorphic, and those with the flowers zygomorphic being 2:1.

With regard to the color of the flowers, white is undoubtedly the predominant. Next to this comes, evidently, yellow, while blue is rare (Polemonium, Eritrichium, Pentstemon), and pink is less common than purplish (Pedicularis, Trifolium, Erigeron, Primula, etc.). The leaves are mostly entire, but lobed, laciniate, and decompound leaves are also quite well represented, for instance, in the Ranunculaceae, Rosaceae, Papilionaceae, Umbelliferae, many Compositae, Polemonium, etc. The glabrous leaf seems to be more frequent than the hairy. Succulent leaves are well exemplified by Claytonia, Calandrinia, *Saxifraga flagellaris*, Chionophila, and *Mertensia alpina*.

These structures represented by the organs of vegetative reproduction, by the fruits, the seeds, the flowers, and the leaves, are essentially identical with the corresponding possessed by the Arctic plants.

Chapter 6.

CONCLUDING REMARKS.

Of the 170 species of vascular plants which I found in the Alpine region of the Rocky Mountains in Colorado, 63 occur also in the Arctic region, and 31 of these are even circumpolar. Of the remaining species, very nearly 100 are endemic to North America, and many of these are endemic to these mountains. We have seen that the geographical distribution of a number of the Arctic-Alpine types is quite extensive, covering many of the higher mountain ranges throughout the Northern Hemisphere. Furthermore, we have seen that certain species inhabit stations very remote from each other, still having reached the Arctic regions.[1] Would it be natural to suppose that this enormous distribution south of the Arctic region was effected by means of migration of these plants? Or shall we accept the hypothesis of Schouw: "Eadem momenta cosmica easdem plantas diversis in locis produxisse"? The fact that the majority of these species are Alpine, wherever they occur outside the Arctic region, and that they are associated with more or less closely related species, seems to speak in favor of this hypothesis, proposed by Schouw. The difficulty in explaining the possibility of the very fact that several of these Arctic-Alpine species inhabit the Baikal Mountains, the south European Alps, and the Rocky Mountains, with no intermediate stations, would thus be removed; and there are other stations even much farther apart.

As a contribution toward solving this question, I have in detail summarized the geographical distribution of these Arctic-Alpine Rocky Mountain plants. And, furthermore, by describing these types I have endeavored to demonstrate the numerous analogies that exist in the Alpine, the Rocky Mountain Alpine flora, and the Arctic. We have seen that the association with related species is common to several of these, wherever they occur; we have seen also the uniformity in vegetative structures possessed by these species in the Alpine and Arctic regions. Moreover, I have attempted to show that the elements of the Alpine flora, endemic to these mountains, correspond almost exactly with the Arctic so far as concerns the vegetative structures, and above all the method of vegetative reproduction and hibernation, some of the most essential phases in the life of these plants. It is interesting to note that although the climatologic conditions in the Alpine region are very different from those prevailing in the Arctic, the plants which are able to thrive under both do not exhibit any marked deviation in structure, which might have been caused by the rather considerable difference as to temperature, precipitation, and light. Some modifications may be observed, however, but of diminutive importance; they may be classified as variations, and as such only.

Thus it seems safe to conclude that most, if not all, of the circumpolar species originated in the Arctic region. The other Arctic-Alpine species may have originated in the mountains farther south, some on this continent, some others in Europe or Asia, while some certain of these may have become developed and distributed from several centers, very remote.

---

[1] Holm, Theo: Contributions to the morphology, synonymy, and geographical distribution of arctic plants. (Report of the Canadian Arctic Exped. 1913–1918, Vol. V Ottawa, 1922.)

EXPLANATION OF PLATES.

PLATE 1.

FIG. 1. *Viola bellidifolia* Greene, from Thompsons Canyon on Longs Peak (10,500 feet altitude); natural size.

2. *Lychnis montana* Wats.

3. Same species, both from Pikes Peak (14,000 feet altitude); natural size.

4. Same species, from Longs Peak (12,000 feet altitude); natural size.

5. *Stellaria umbellata* Turcz., from Pikes Peak (14,000 feet altitude); natural size.

6. Same species; the inflorescence; enlarged.

7. Same species; a floral shoot with stolons; enlarged.

8. *Calandrinia pygmaea* Gr.; a seedling, showing the swollen primary root and the cotyledons from James Peak (13,000 feet altitude); enlarged.

9. Same species from the same locality; natural size.

PLATE 2.

FIG. 10. *Sieversia Rossii* R. Br., from Longs Peak (12,500 feet altitude); natural size.

11. *Saxifraga bronchialis* L., from Grays Peak (12,500 feet altitude); natural size.

12. Same species: a leaf; enlarged.

13. *Saxifraga cernua* L., from Pikes Peak (14,000 feet altitude); natural size.

14. Same species; base of the stem with the bulblets; enlarged.

15. Same species; a bulblet; enlarged.

16. Same species; inner leaves of the bulblets; enlarged.

17. *Saxifraga chrysantha* Gr., from Grays Peak (12,500 feet altitude); natural size.

18. *Trifolium nanum* Torr., from Grays Peak (12,500 feet altitude); natural size.

19. Same species; the inflorescence; natural size.

PLATE 3.

FIG. 20. *Oreoxys humilis* Raf., from Pikes Peak (14,000 feet altitude); natural size.

21. *Artemisia scopulorum* Gr., from James Peak (13,000 feet altitude); natural size.

22. *Kalmia glauca* Ait. var. *microphylla* Hook., from Thompsons Canyon on Longs Peak (10,700 feet altitude); natural size.

23. *Androsace subumbellata* Small, from Grays Peak (12,500 feet altitude); natural size.

24. *Primula angustifolia* Torr., from Thompsons Canyon on Longs Peak (10,700 feet altitude); natural size.

25. *Polemonium viscosum* Nutt., from Longs Peak (13,000 feet altitude); natural size.

PLATE 4.

FIG. 26. *Senecio blitoides* Greene, from Mount Elbert (12,000 feet altitude); natural size.

27. *Senecio dimorphophyllus* Greene, from Mount Massive (12,000 feet altitude); natural size.

28. *Senecio Holmii* Greene, from Mount Elbert (12,000 feet altitude); natural size.

29. *Gentiana plebeja* Cham. f. *Holmii* Wettst., from Mount Massive (12,000 feet altitude); natural size.

30. *Eritrichium argenteum* White, from Longs Peak (12,500 feet altitude); natural size.

PLATE 5.

FIG. 31. *Erigeron pinnatisectus* (Gr.) Nels., from James Peak (13,000 feet altitude); natural size.

32. *Chionophila Jamesii* Gr., from Longs Peak (12,500 feet altitude); natural size.

33. Same species: a flower; enlarged.

34. Same species; the calyx, laid open; enlarged.

35. Same species; diagram of the shoot L^1=the first pair of leaves, L^2=the second, and L^3=the third; in the axil of L^1 is the flowering stem (St.), and in the center is a bud (B), containing a corresponding foliage with an axillary inflorescence.

36. *Synthyris alpine* Gr., from Longs Peak (12,500 feet altitude); natural size.

37. Same species; the calyx; enlarged.

38. Same species; the fruit; enlarged.

39. *Mertensia alpina* Don., from Pikes Peak (14,000 feet altitude); natural size.

40. Same species: a flower; enlarged.

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PLATE 6.

Fig. 42. *Salix reticulata* L., from Mount Elbert (11,500 feet); natural size.

43., 44. Same specimen, two leaves; natural size.

45. Same species, from Churchill, Hudson Bay; natural size.

46. Same species, from Copper Island, Bering Sea; natural size.

47. Same species, from Spitzbergen, Belsund; natural size.

48. Same species, from Nova Zembla; natural size.

49. Same species, from Finmark; natural size.

50., 51. Leaves of same specimen from Finmark; natural size.

52., 53. Leaves of the pistillate plant from Sweden, Jämtland; natural size.

PLATE 7.

Fig. 54. *Vaccinium caespitosum* Michx., from Mount Massive (12,000 feet altitude); natural size.

55. Leaf of same species; natural size.

56. Leaf of *Vaccinium Myrtillus* L. var. *microphylla* Hook., from Thompsons Canyon on Longs Peak (10,500 feet altitude); natural size.

57. Leaf of same; natural size.

58. Leaf of same species, but the typical, from Silverplume (10,000 feet altitude); natural size.

59. *Juncus Parryi* Engelm., from headwaters of Clear Creek (12,000 feet altitude); natural size.

60. *Carex chalciolepis* nob., from James Peak (13,000 feet altitude); natural size.

61. Scale of pistillate flower of same; enlarged.

62. Utriculus of same; enlarged.

63. *Carex atrata* L., from Grays Peak (12,500 feet altitude); natural size.

64. Same species; scale of pistillate flower; enlarged.

65. Same species; Utriculus; enlarged.

66. *Carex capillaris* L., from Thompson Canyon on Longs Peak (10,500 feet altitude); natural size.

67. *Poa Lettermanni* Vas., from Pikes Peak (14,000 feet altitude); natural size.

68. Same specimen; a spikelet; enlarged.

69. Same specimen; the flowering glumes; enlarged.

70. Same specimen; palet, lodiculae and pistil; enlarged.

71. *Festuca ovina* L., var. *supina* Hack., from Pikes Peak (14,000 feet altitude); natural size.

72. Same specimen; a spikelet; enlarged.

73. Same specimen; the flowering glume; enlarged.

74. Same specimen; the palet; enlarged.

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9. Same species from the same locality; natural size.


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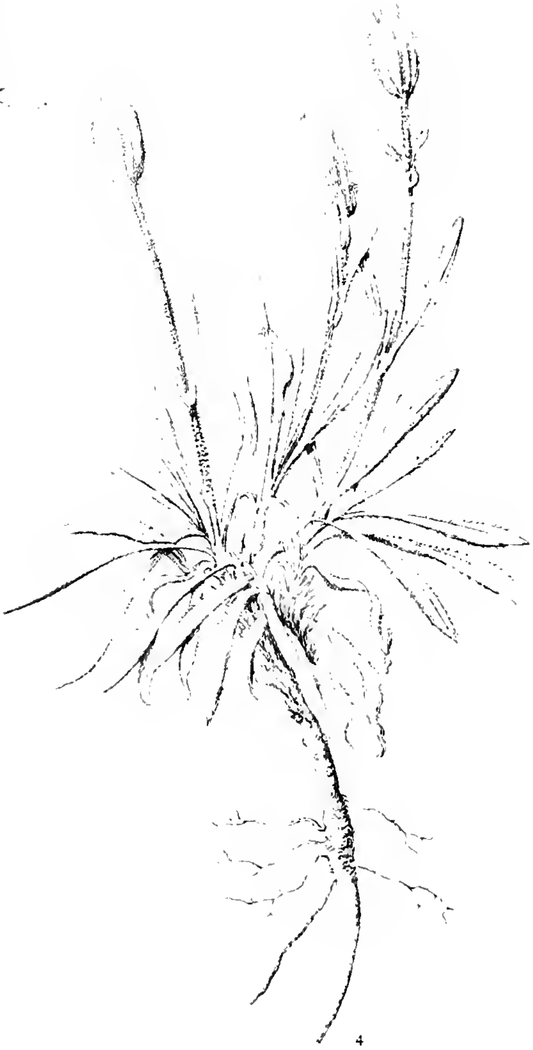
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PLATE TWO.

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19. Same species; the inflorescence; natural size.

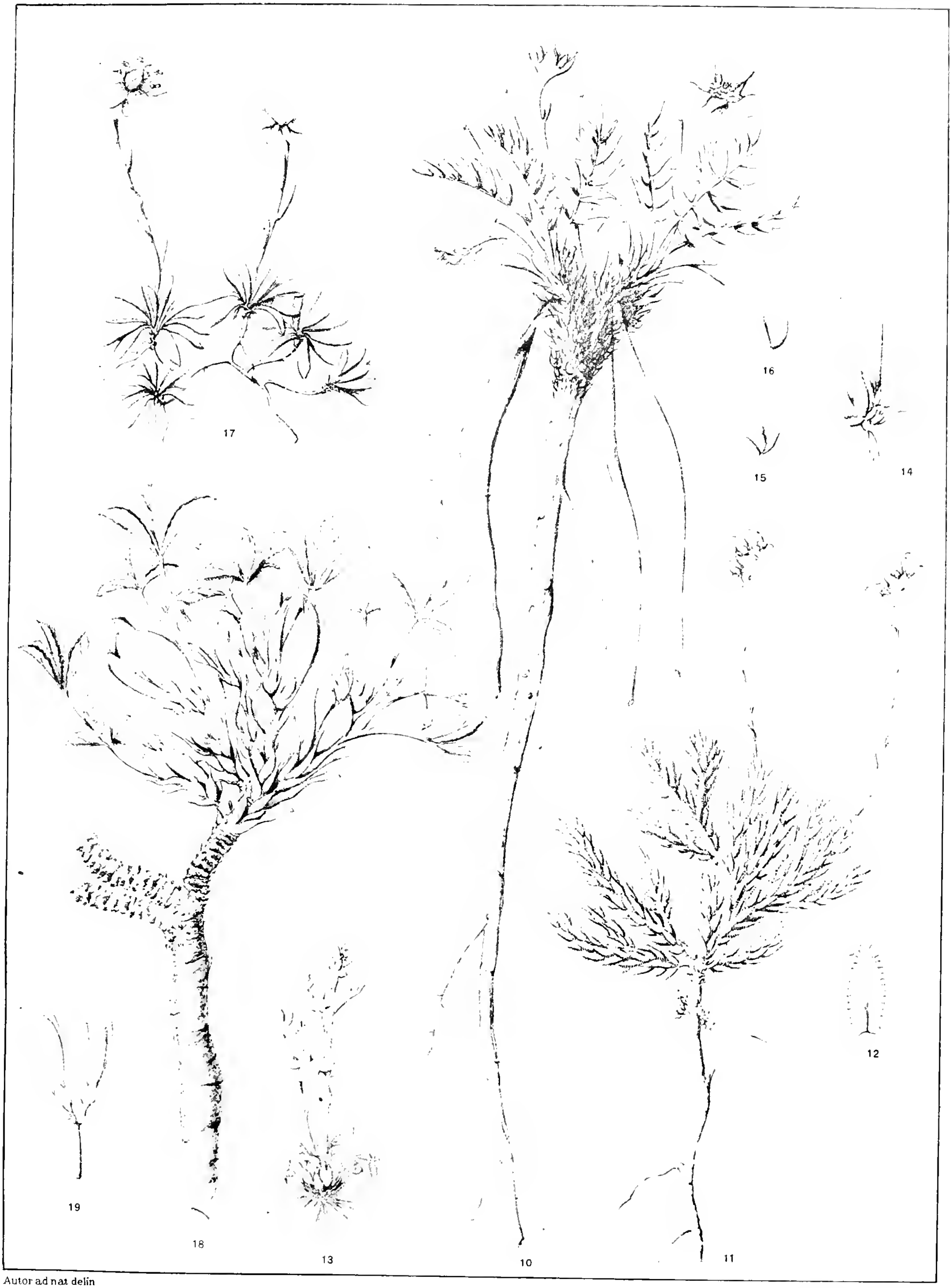

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PLATE FOUR.

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PLATE FIVE.

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40. Same species: a flower; enlarged.
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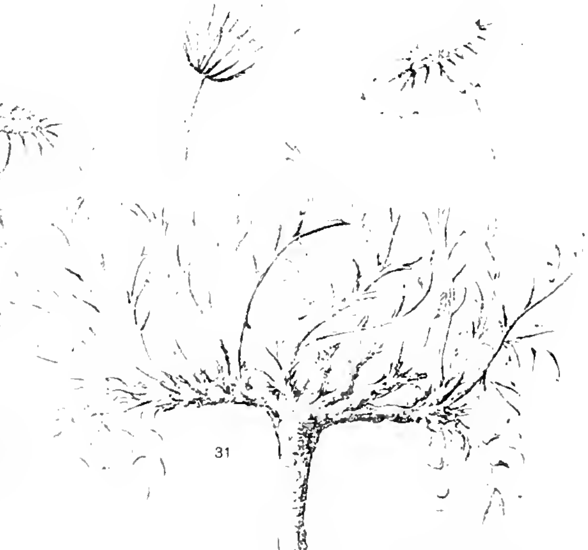

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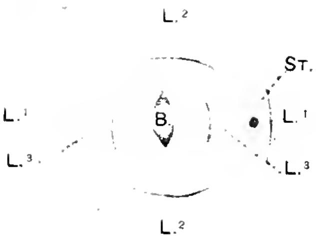

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PLATE SIX.

Fig. 42. *Salix reticulata* L., from Mount Elbert (11,500 feet); natural size.
43, 44. Same specimen, two leaves; natural size.
45. Same species from Churchill, Hudson Bay; natural size.
46. Same species from Copper Island, Bering Sea; natural size.
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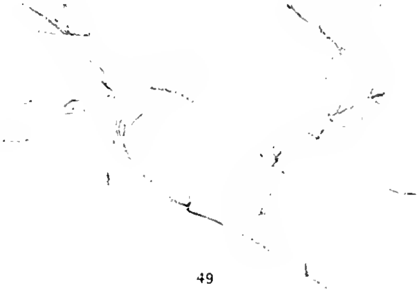

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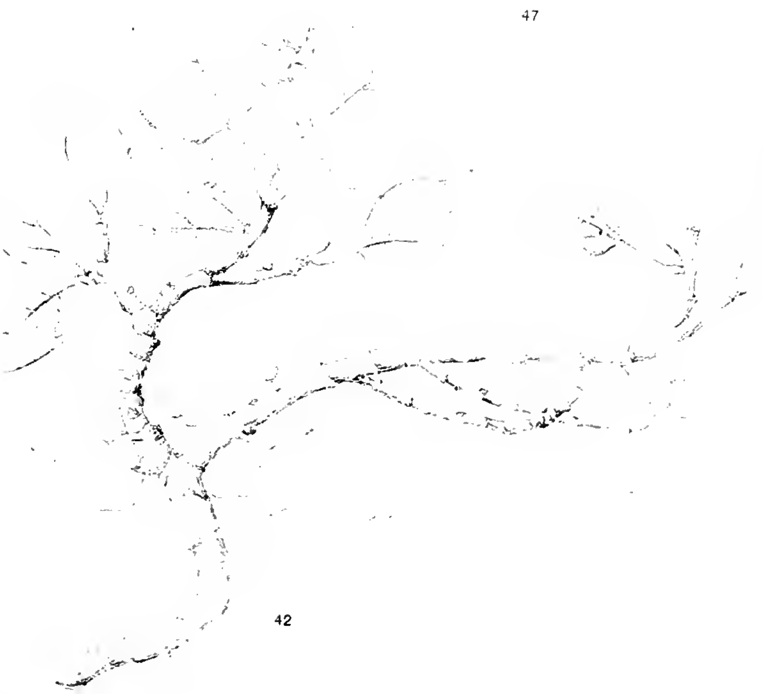

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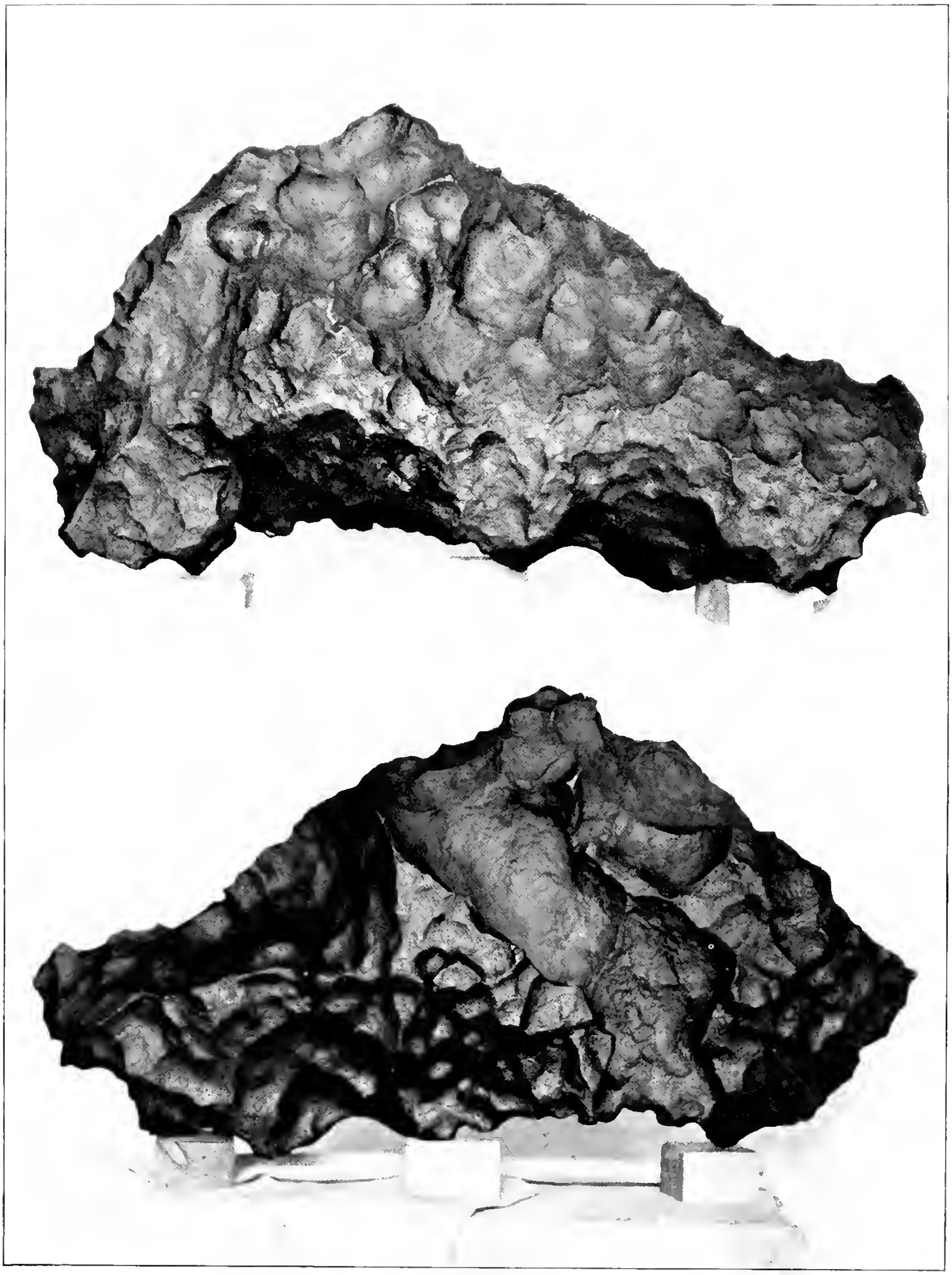
NATIONAL ACADEMY OF SCIENCES.

Volume XIX.
FOURTH MEMOIR.

A METEORIC IRON FROM OWENS VALLEY, CALIFORNIA.

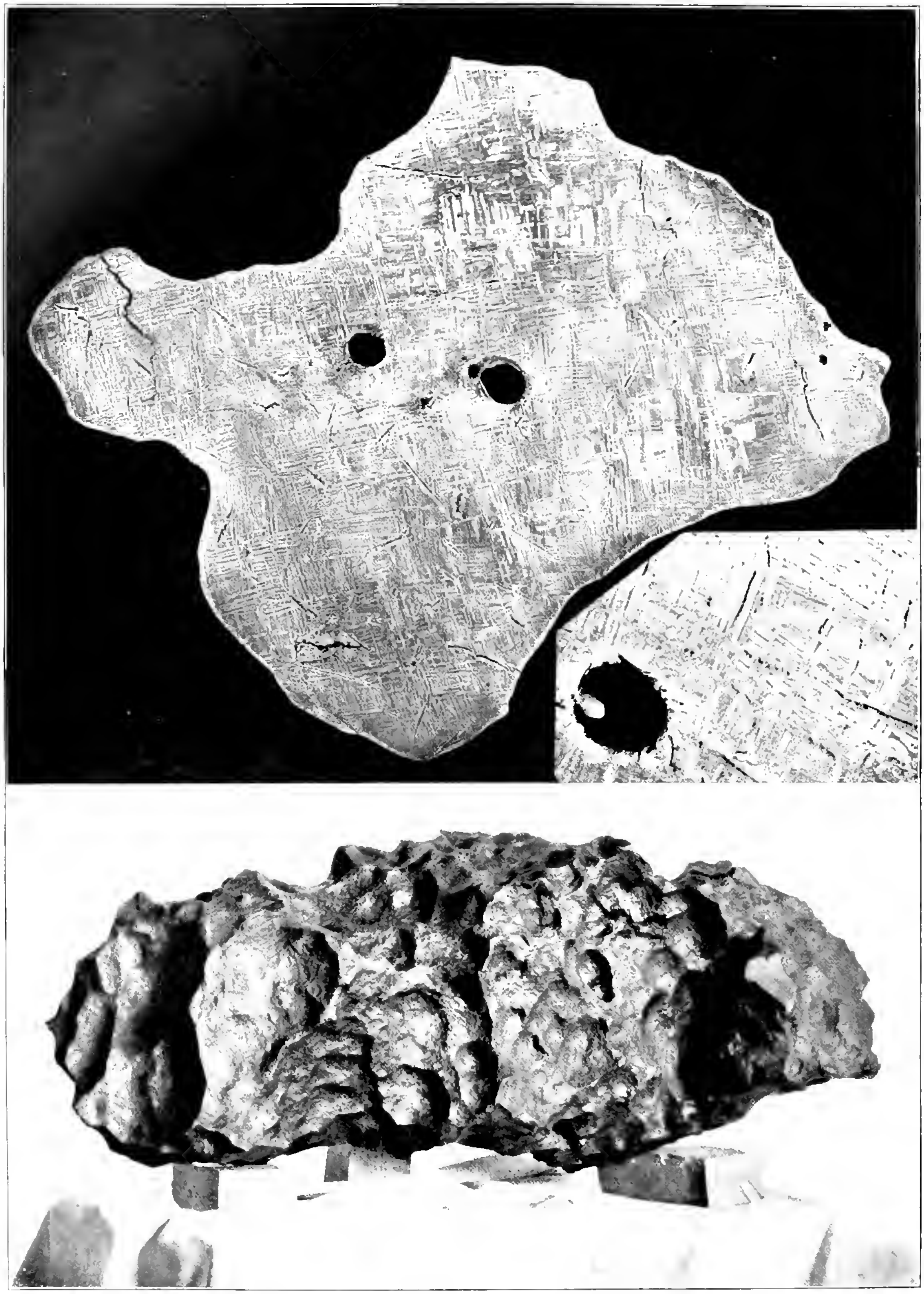
BY

GEORGE PERKINS MERRILL,
HEAD CURATOR OF GEOLOGY, UNITED STATES NATIONAL MUSEUM.



OWENS VALLEY METEORIC IRON.

Upper: Side view. Lower: Same in reversed position.



Owens Valley Meteoric Iron.

Upper left: Complete cross section about two-thirds natural size. Upper right: Portion of same natural size. At bottom: Lower surface of mass.

A METEORIC IRON FROM OWENS VALLEY, CALIFORNIA.

By George P. Merrill.

Head Curator of Geology, United States National Museum.

The iron meteorite here described and figured (Pls. I and II) was found by a sheep herder in 1913, some 22 miles northeast of Big Pine, Owens Valley, Inyo County, California. It passed immediately into the hands of Mr. Lincoln Ellsworth of New York City, in whose possession it has remained undescribed until the present. Except for a very uniform oxidation over the entire surface, the iron is in an excellent state of preservation, measuring 65 centimeters in length and weighing 193.17 kilograms (425 pounds). The outlines of the mass are well shown in the plates. The pittings, it will be observed, are quite uniformly distributed over the entire surface, and a striking feature is the absence of a nose or *brustseite* to indicate what may have been its orientation during flight. Whether this is due to weathering or a too frequent reversal of position to allow the formation of this feature, cannot be told definitely, though evidently the latter assumption is correct. Oxidation has obscured any flow lines that may possibly have existed.

Although taking great pride in the possession of the iron, Mr. Ellsworth has yielded to the interests of science and allowed the mass to be sawn so as to yield the surface shown in Figures 1 and 2, Plate II. The iron etches easily but not deeply, the surfaces soon becoming dull and the figures having little relief. The kamacite bands are sometimes slightly swollen and undulating with numerous enclosures of sulphide and phosphide which show up as black dots and dashes in the plate. Several of these are of a character to be classed as Reichenbach lamellae, but that they seemingly have no constant orientation. The taenite plates are very thin and inconspicuous, and, as shown by the analysis, there is but little schreibersite. Two rounded masses of troilite some 10 mm. in diameter, each partially bordered by the phosphide, are shown in the section. At the left, and in other parts of the section, are shown irregular fracture lines filled with a black unidentified material, probably carbon. The maximum width of the widmanstätten figures is 1 mm. and the iron therefore classed as a medium octahedrite. In comparison with other irons in the collection, it resembles closely that of Cleveland, East Tennessee, with which also it agrees quite closely in chemical composition, so far as the main constituents are concerned. It does not, however, etch so strongly and gives a dull, rather than a bright lustrous surface, as does the last named.

For the investigation of the chemical constitution of the iron I was fortunate in securing the services of Prof. Stuart R. Brinkley of the Kent Chemical Laboratory of Yale University, whose care and skill as an analyst need no commendation, as the results show for themselves. The following is from Professor Brinkley's report:

For the qualitative and preliminary work 50 grams of the sample submitted were digested with HCl of constant boiling strength until there was no further action. Tests were made on the acid soluble part and on the residue separately. In the HCl solution there were found to be present: Iron, nickel, cobalt, sulphur, phosphorus, and a trace of copper. Very careful tests were made for the following with negative results: The platinum metals, arsenic, antimony, tin, gold, silver, lead, mercury, cadmium, bismuth, selenium, tellurium, molybdenum, aluminum, zirconium, titanium, zinc, manganese, chromium, vanadium, uranium, tungsten, the alkali-earths, and the alkali metals.

For the HCl insoluble residue the remaining 25 grams of the material furnished were digested similarly with HCl and the residues combined, giving a sample amounting to the residue from 75 grams of the original material. Iron, nickel, cobalt, phosphorus, carbon, and silica were found. There was obtained a very slight precipitate of ammonium chloro-platinate showing a trace of platinum to be present. Moreover, this precipitate was somewhat brownish in color indicating a trace of iridium. Tests showed no palladium, osmium, ruthenium, nor rhodium in amounts sufficient for detection by wet method. Further negative results were obtained on making tests for all the other metals mentioned as being found absent in the HCl solution.

In the quantitative work 25 gram samples were used for the metals, 10 grams for each sulphur and total phosphorus, and 5 grams each for the combined and graphitic carbon. The following results were obtained:

	Per cent.		Per cent.
Iron	55. 15	Silica	0. 15
Nickel	30. 09	Platinum	Trace.
Cobalt	0. 67	Iridium	Trace.
Phosphorus	13. 06	Total	99. 12

It is evident that this is largely one of the variable compounds to which the name schreibersite is commonly applied.[1]

Carbon determinations run on the original sample showed:

	Per cent.
Combined carbon	0. 019
Graphitic carbon	0. 013

All the graphitic carbon would be in the acid insoluble part and probably most of the combined as cohenite.

The material soluble in HCl showed the following composition:

	Per cent.		Per cent.
Iron	91. 65	Sulphur	0. 13
Nickel	7. 80	Copper	[2] Trace.
Cobalt	0. 46		
Phosphorus	0. 007	Total	100. 047

From the accumulated residues from the HCl treatment a sample corresponding to 75 grams was obtained and this was found to contain 0.0008 gram platinum, the brown color of the ammonium chloro-platinate precipitate indicating iridium, though attempts to effect a separation were unsuccessful.

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[1] A study of the phosphide question as so admirably summed up by Cohen (Meteoritenkunde, B. 1, S 124), coupled with experience gained in my own work as mentioned in a previous paper (Mem. Nat. Acad. Sci., vol. 14, 1916, p. 10) has led me to the conclusion that the rhabdite alone has a definite crystallographic form and a chemical composition that can be expressed accurately by the formula $(FeNiCo)_3P$. The forms commonly described under the name schreibersite are but solid solutions of rhabdite in varying amounts of iron as in artificial iron and steel (see Sauveur, The Metallurgy and Heat Treatment of Iron and Steel, p. 144). In this way only, as it seems to me, can we account for the imperfect development of crystal faces and the continual variation in the proportional amounts of iron and phosphorus shown in the large series of analyses now available. I hope soon to be able to say more upon this subject. I can not wholly agree with Cohen in ascribing the discrepancies shown to impure material or poor analyses.

[2] Less than 0.001 per cent.

These values, recalculated on the basis of the original sample, show the following:

	Per cent.	Per cent
HCl soluble part:		
Iron	89. 89	
Nickel	7. 65	
Cobalt	0. 45	
Sulphur	0. 122	
Phosphorus	0. 007	
Copper	Trace.	
Total		98. 119
Residue from HCl treatment:		
Iron	1. 05	
Nickel	0. 572	
Cobalt	0. 012	
Phosphorus	0. 248	
Silica	0. 003	
Platinum	Trace.	
Iridium	Trace.	
Total		1. 885
Separated material:		
Combined carbon	0. 019	
Graphitic carbon	0. 013	
Total		0. 032
Total		100. 036

The results given above need little discussion other than to say that they corroborate fully what I have previously written with particular reference to the minor constituents in meteorites,[3] and incidentally substantiate the work of Doctor Whitfield. It may be well to note that platinum was found only in the insoluble portion, and that it showed traces of iridium as did that found by Mingaye in the iron of Mount Dyrring, Australia. No traces of palladium, osmium, rhodium, or ruthenium were detected, however, nor of gold or tin. It is well to state here that having still in mind Derby's determination of tin in the Canon Diablo meteorite, and my failure to corroborate him, as noted in a recent paper,[4] I took advantage of the present opportunity to make still another separation of the insoluble constituent of this much discussed iron, 20 grams of which were referred to Professor Brinkley who reported: "The Canon Diablo sample to be tested gave no evidence at all of the presence of tin."

It is with a feeling of no little satisfaction that the careful work of so efficient an analyst as Professor Brinkley is found to corroborate that of Whitfield and others as published in my previous papers.

---

[3] Amer. Journ. Sci., vol. 35, 1913, pp. 509-525; Mem. Nat. Acad. Sci., vol. 14, 1916, pp. 7-29; Proc. Nat. Acad. Sci., vol. 418, 19, pp. 175-180.

[4] Proc. Nat. Acad. Sci., vol. 4, 1918, p. 177.