Art. XXVII.—*Granodiorite and other intermediate rocks;* by Waldemar Lindgren.

Introduction.—Along the great mountain chain which follows the Pacific Coast of America from Cape Horn to Alaska the intrusive rocks and the phenomena accompanying them are displayed upon a scale hardly rivaled elsewhere. Moreover, these intrusions have taken place in comparatively recent times, during Jurassic, Cretaceous and even Tertiary times. The result was the formation or the accentuation of the great ranges now overlooking the Pacific Ocean. The uplift which accompanied the displacing intrusion of enormous masses of magma, was followed by a period of erosion of scarcely appreciated magnitude. This erosion brought to light the deeply buried, intruded granular rocks as great, irregular bodies, *batholiths*, sometimes continuous for hundreds of miles. Before these remarkable relations had been elucidated, the granular rocks of the Pacific Coast were often regarded as Archean; and a close scrutiny of supposedly older areas brings almost yearly additions to the Mesozoic and Tertiary batholiths.

Looking over the results thus far obtained by investigations of these rocks, one cannot fail to note the prevalence of rocks occupying intermediate places between granite and quartz-diorite. The latter are fairly common; the true granites are relatively rare; most common appears an intermediate rock in which the soda-lime feldspars predominate over the orthoclase, and in which the silica varies from 60 to 70 per cent.

Granodiorite, origin of name.—Soon after the beginning of the geological mapping of the Sierra Nevada in California in 1886, it became apparent that the rocks of that region which had previously been referred to as granite were, to a large extent, of intermediate character and could properly be referred neither to the granites, nor to the quartz-diorites. Besides these intermediate rocks, quartz-diorites, diorites, and gabbros were recognized. The prevailing intermediate rock from different parts of the Sierra Nevada was studied by the geologists then working there (G. F. Becker, H. W. Turner, and W. Lindgren) and was found to have a fairly constant character, consisting of a medium to coarse-grained aggregate of quartz, oligoclase or andesine, orthoclase, biotite, hornblende and various accessory constituents, among which titanite was most prominent.

A series of separations by the Thoulet solution were made by the writer of rocks from various points of the Sierra Nevada, partly from the foothills, partly from the Yosemite Valley, and partly from the eastern slope of the Sierra, in the State of

Nevada. The series also included a variety carrying large orthoclase crystals, and extensively developed in Tuolumne County. The result showed that all these rocks were characterized by about the same amount of quartz and that in all of them the soda-lime feldspar (andesine or oligoclase) greatly predominated over the alkali feldspars, both always being present.

A great number of slides had been examined, but at that time (in 1891) the analytical data were less complete than might have been desired. The first analysis considered as representing the composition of granodiorite was the one published by Mr. Clarence King in the volumes of the "Exploration of the 40th Parallel," the locality being El Capitan. Yosemite Valley. This analysis runs as follows:

SiO_2	66·40
Al_2O_3	17·13
FeO	3·77
MnO	·30
CaO	4·05
MgO	·97
K_2O	2·08
Na_2O	4·49
Ignition	1·03
	100·22

For the rock described above the name of *granodiorite* was proposed, the term being suggested by Mr. G. F. Becker. The name was intended to cover intermediate acid rocks which were more closely related to a quartz-diorite than to a granite, but was not proposed as a synonym for quartz-mica-diorite.

Further definitions.—In the text to the older folios of the gold belt the term granodiorite is defined as follows (Sacramento Folio, No. 5, 1894): It should be remembered that these brief descriptions are chiefly intended for the non-technical reader.

"*Granodiorite* (quartz-mica-diorite).—A granular intrusive rock having the habitus of granite and carrying feldspar, quartz, biotite, and hornblende. The soda-lime feldspars are usually considerably and to a variable extent in excess of the alkali feldspars. This granitic rock might be called quartz-mica-diorite, but this term, besides being awkward, does not sufficiently suggest its close relationship with granite; it has, therefore, been decided to name it *granodiorite*.

In the later folios (Truckee No. 39, 1897) the definition is slightly altered in form and reads as follows:

"*Granodiorite.*—A granular intrusive rock having the habitus of granite and carrying feldspar, quartz, biotite and hornblende. The soda-lime feldspars are usually considerably and to a variable extent in excess of the alkali feldspar. This granitoid rock occupies a position intermediate between a granite and a quartz-diorite, and is in fact closely related to the latter. The large areas occupied by it and the constancy of the type justify the special name."

In 1893 I attempted to limit the rocks from a chemical point of view.* On account of the few analyses available this first attempt could not be as precise as the later definitions, but requires only slight correction. The statement is as follows: "A light gray granitic rock occupies the larger part of the area of the map . . . The rock is in general identical with the gray so-called granite that occupies such large areas in the Sierra Nevada and which probably extends through Southern California far down into the peninsula of Lower California. The rock consists in typical development of feldspar, quartz, biotite and hornblende with medium-grained, hypidiomorphic structure. The soda-lime feldspars are usually considerably and to a variable extent in excess of the alkali feldspars. The silica varies between 60 and 73 per cent; the amount of lime is variable but it rarely exceeds, while it usually falls somewhat short of, the sum of the alkalies. While in some varieties that cannot be distinguished from the others in the field there is more potash than soda, a frequently occurring relation is 2 per cent K_2O to 4 per cent Na_2O. It will be seen that the rock very closely approaches some quartz-mica-diorites and often might be indicated by that name. This term, however, besides being clumsy does not sufficiently express its close relationship to granite, brought out by its frequently high percentage of silica and low percentage of lime, by its variable percentage of alkali feldspar, and by the muscovite sometimes occurring in it."

The last part of this sentence refers to a facies from Rocklin, Placer County and other places which probably should not be included in the granodiorites.

In a report on the veins of Grass Valley and Nevada City, Cal.,† the following definition is given:

"Under the name *granodiorite* are included coarsely granular rocks, intruded and consolidated at considerable depths below the surface, having a normal granitic (eu-granitic) structure, and a mineralogical composition of quartz, soda-lime feldspars, orthoclase, hornblende, and nearly always biotite. Titanite and magnetite are always present as accessory constituents. This rock, which in the Sierra Nevada occurs in enormous areas, forms an intermediate group between the quartz-mica-diorites and the granites, being, however, more

* This Journal, lxvi, 201. The Auriferous Veins of Meadow Lake, Cal.
† 17th Ann. Rept., 1896, U. S. G. S., Part II, p. 35.

closely allied to the quartz-mica-diorite than to the granite. Comparison of numerous analyses from various parts of the Sierra Nevada shows that the chemical composition varies between that of a quartz-mica-diorite and a quartz-monzonite (adamellite, banatite, Brögger). Its geological occurrence and in general entirely similar habit preclude the possibility of dividing it into subgroups.

The rock is very characteristic and cannot easily be mistaken. The feldspars are generally white; the quartz is not very conspicuous and does not occur in large grains, as in some true granites of the High Sierra; the hornblende is dark-green, often in long, rough prisms; the biotite is of the usual dark-brown color. The general effect is a light-grayish color."

The following table is also quoted from the same place:

LIMITS OF VARIATION AND AVERAGE COMPOSITION OF GRANODIORITE.

	Limits of variation. Per cent.	Average composition. Per cent.
SiO_2	59 to 68½	65·
Al_2O_3	14 to 17	16·
Fe_2O_3	1½ to 2¼	1·50
FeO	1½ to 4½	3·
CaO	3 to 6½	5·
MgO	1 to 2½	2·
K_2O	1 to 3½	2·25
Na_2O	2½ to 4½	3·50
Remainder	------	1·75
		100·

In 1897* in a paper on the granitic rocks of the Pyramid Peak Folio, I characterized the granodiorite of the High Sierra as follows: Comparing the analytical and microscopical results with the field notes, it is clear that the granodiorite, as it appears in the High Sierra, is a rock of well-defined and fairly constant composition, structure and appearance. It is neither a normal diorite, nor is it a granite; it is clearly an *intermediate* type, occupying a place between normal quartz-mica-diorite and quartz-monzonite (Brögger).† All transitions toward

* This Journal, vol. iii, 1897, p. 312.

† Though it is often difficult in practice to separate the normal quartz-mica-diorite from the granodiorite, it would seem suitable to restrict granodiorite to the following limits:

SiO_2	59–69 per cent.
Al_2O_3	14–17 "
Fe_2O_3	1½–2¼ "
FeO	1½–4½ "
CaO	3–6½ "
MgO	1–2½ "
K_2O	1–3¾ "
Na_2O	2½–4½ "

diorite and, more rarely, toward granite, may be found, but they are local and do not cover large areas, while the normal granodiorite is the prevailing rock of the Sierras. Comparing the type here described with the granodiorites of the many smaller areas enclosed in the slates on the western flank of the range, it can be stated that the latter as a rule approach more closely to the quartz-diorites, the percentage of lime being higher and the percentage of potash more often smaller than equal to that of soda. A few of these smaller granitic areas could, in fact, almost as well be indicated as quartz-mica-diorites. In the general habit, however, in the percentage of quartz, hornblende, and biotite, and in the constant presence of titanite, they are entirely similar to the granodiorites of the High Sierra. Microcline, not common in the granodiorites of the foothill region, occurs abundantly in those of the High Sierra.

A. Table of Complete Analyses.

	Granodiorite.					
	I.	II.	III.	IV.	V.	VI.
SiO_2	65·54	66·65	63·85	67·45	66·40	59·48
TiO_2	·39	·38	·58	·58	----	·93
Al_2O_3	16·52	16·15	15·84	15·51	17·13	17·25
Fe_2O_3	1·40	1·52	1·91	1·76	----	2·15
FeO	2·49	2·36	2·75	2·21	3·77	4·06
MnO	·06	·10	·07	----	----	·11
CaO	4·88	4·53	4·76	3·60	4·05	6·50
SrO	----	tr.	tr.	----	----	tr.
BaO	----	·07	·06	----	---	·09
MgO	2·52	1·74	2·07	1·10	·97	2·67
K_2O	1·95	2 65	3·08	3·66	2·08	2·27
Na_2O	4·09	3·40	3·29	3·47	4·49	3.53
Li_2O	----	tr.	tr.	----	----	tr.
H_2O below 100°C.	----	·18	·28	·14	----	·09
H_2O above 100°C.	·59	·72	1·65	·63	1·03	·71
P_2O_5	·18	·10	·13	·12	----	·33
	100·73	100·55	100·32	100·23	100·22	100·17

I. Lincoln, Placer Co., Sacramento Folio, W. F. Hillebrand analyst.
II. Nevada City, Nevada Co., Smartsville Folio, W. F. Hillebrand analyst.
III. Grass Valley, Nevada Co., Smartsville Folio, W. F. Hillebrand analyst.
IV. 103 Pyr. Pk., Silver Lake, Pyramid Pk. Folio, Geo. Steiger analyst.
V. El Capitan, Yosemite, Cl. King.
VI. 398 Placer Co., Donner Pass, Truckee Folio, W. F. Hillebrand analyst.

The following of the rocks in table B belong to smaller areas enclosed in metamorphic rocks: IV, V, VII, VIII, IX, X. The following numbers represent the great areas in the higher part of the Sierra Nevada: I, II, III, VI, XI, XII, XIII, XIV, XV, XVI, XVII.

B. TABLE OF PARTIAL ANALYSES OF GRANODIORITES.

	I	II	III	IV	V	VI	VII	VIII	IX
SiO_2	59·48	63·54	62 17	----	----	----	----	65·54	63·85
CaO	6·50	6·11	5·80	5·64	5·64	5·41	5·37	4·88	4·76
K_2O	2·27	1 91	2·23	1·18	1·18	1·82	1·60	1·95	3·08
Na_2O	3·51	2 97	2·86	3·74	3·74	3 15	3·81	4·09	3·29

	X	XI	XII	XIII	XIV	XV	XVI	XVII
SiO_2	66·65	65·88	67·14	66·40	68·13	67·45	68·32	69·85
CaO	4 53	4·11	4·07	4·05	3·51	3·60	3·21	3·08
K_2O	2·65	2·88	2·70	2·08	3·58	3·66	3·37	2·28
Na_2O	3 40	2 41	3 09	4·49	3·13	3 47	2·51	4 13

LOCALITIES OF SPECIMENS IN TABLE B.

I. 398 Placer Co. Donner Pass, Truckee Folio. Geo. Steiger analyst.
II. 225 Nevada Co., 2 miles S. of Faucherie Lake, Colfax Folio, Geo. Steiger analyst.
III. 221 Nevada Co., 1 mile S. W. of Faucherie Lake, Colfax Folio, Geo. Steiger analyst.
IV. 338 El Dorado Co, 1¼ mi. S. of Fairplay, Placerville Folio, W. H. Melville analyst.
V. 293 Placer Co., Penryn, Sacramento Folio, W. H. Melville analyst.
VI. 305 El Dorado Co. Point between Soldier Creek and South Fork of American River, Placerville Folio, W. H. Melville analyst.
VII. 104 El Dorado Co White Rock Cr., Placerville, Placerville Folio, W. H. Melville analyst.
VIII. Lincoln, Placer Co., Sacramento Folio, W. F. Hillebrand analyst.
IX. Nevada City, Nevada Co., Smartsville Folio, W. F. Hillebrand analyst.
X. Grass Valley, Nevada Co., Smartsville Folio, W. F. Hillebrand analyst.
XI. 177 Pyramid Pk., Meeks Creek, Lake Tahoe, Truckee Folio, Geo. Steiger analyst.
XII. 86 Pyramid Pk., Rockbound Lake, Truckee Folio, Geo. Steiger analyst.
XIII. El Capitan, Yosemite, Cl. King.
XIV. 69 Pyramid Pk., 1½ mi. S. of Rubicon Point, Truckee Folio, Geo. Steiger analyst.
XV. 103 Pyramid Pk., Silver Lake, Pyramid Pk. Folio, Geo. Steiger analyst.
XVI. 120 Pyramid Pk., Big Mud Lake, Pyramid Pk. Folio, Geo. Steiger analyst.
XVII. 231 Nevada Co., Rattlesnake Cr., 2 m. N. E. of Cisco, Truckee Folio, Geo. Steiger analyst.

Characteristic features and limits of granodiorite.—Under the term granodiorite are included light-colored granular rocks, composed of quartz, oligoclase or andesine, orthoclase, biotite or hornblende or both, titanite, magnetite, apatite and zircon. The average grain ranges from 1 to 4^{mm}, but certain of the minerals sometimes considerably exceed this. Thus the hornblende prisms are often 10^{mm} long and those of orthoclase may be still larger. The fresh outcrops are brilliantly grayish white, and even when decomposed the amount of ferric oxide set free is rarely sufficient to impart a red color to the rock.

In thin section the structure is typically hypidiomorphic. The biotite and hornblende are sometimes, the soda-lime feldsspars nearly always partly idiomorphic; these minerals are usually cemented by a later consolidated mass of orthoclase and quartz. The orthoclase may, in types relatively rich in K_2O, assume the form of microcline; albite and perthitic growths are ordinarily absent, but the latter have been noted in small amounts. The soda-lime feldspar generally ranges from Ab_7An_3 to Ab_2An_1; and is always either a basic oligoclase or an andesine; acid oligoclase or varieties containing more lime than andesine are absent. The biotite is a dark brown normal variety with small but distinct angle between the optic axes. The hornblende is green or brownish-green with a maximum extinction of 18°–20°. Pyroxene (augite) is known as kernels in hornblende, though the latter is certainly not of secondary origin. It is by no means impossible that granodiorites with a notable amount of pyroxene may be found, but they certainly are not very common and represent no widely spread type. In the normal types both biotite and hornblende are usually present. But either one may occasionally be sparingly represented or even absent. Titanite is an always present constituent of the rock. Magnetite is only present in small quantities.

C. Table of Mineralogical Composition of Granodiorite.

Numbers correspond to Table A.

	II	III	IV
Potassium feldspar	15·	18·	17·75
Sodium feldspar	29·^{a}	28·$^{a'}$	29·41$^{a''}$
Calcium feldspar	15·^{b}	12·10$^{b'}$	11·91$^{b''}$
Biotite / Hornblende	16·		12·79
Hornblende		16·60	
Quartz	22·	20·80	25·71
Apatite	·24	·30	·30
Magnetite	1·50	1·50	·84
Titanite	1·	1·40	1·40
Total	99·74	98·70	100·11

$a + b = 44\cdot = Ab_2An_1$, with 34 per cent An.
$a_{\prime} + b_{\prime} = 40\cdot1 = Ab_7An_3$, with 30 per cent An.
$a_{\prime\prime} + b_{\prime\prime} = 41\cdot32 = Ab_7An_3$, with 29 per cent An.

The chemical composition of the granodiorites in the Sierra Nevada is characterized by a percentage of silica neither very high nor very low, ranging from 59 to 69 per cent. The iron and magnesia are relatively low, the lime on the contrary ranging between 3 per cent and 6·50 per cent, though the latter limit is rarely reached. The sum of the alkalies ranges from 4·92 to 7·13 and thus may notably exceed the lime, but never fall short of it more than one per cent. As to the relation between K_2O and Na_2O the latter is apt to predominate, ranging from 2·50 per cent to 4½ per cent. K_2O varies in the analyses from 1·18 per cent to 3·66 per cent and may equal or even slightly exceed Na_2O, especially in the more acidic types from the High Sierra. Where the percentage goes below 1· the rocks should certainly be classed as quartz diorites.

The above tables give complete analyses of six granodiorites, partial analyses of seventeen rocks, and the calculated mineralogical composition of three rocks.

Regarding VI in Table A and I in Table B of incomplete analyses, it should be stated that, owing to the low percentage of silica and large amount of iron and magnesium, it stands close to the limit and may be considered as a quartz-diorite or a granodiorite. That it has been included in this table is due to the fact that these changes from the composition of a normal granodiorite have only been effected by the addition of hornblende without much altering the proportion and composition of the feldspars.

Another somewhat doubtful rock is XVI in the second table, which has a high percentage of K_2O coupled with an unusually small amount of Na_2O, and it is probable that it represents a local facies of the prevailing rock. Its composition would probably place the rock close to the quartz-monzonites.

The last tables give the calculated mineralogical composition of three representative rocks. For the determination of the potash feldspar all of the K_2O except the quantity needed for biotite has been used. Similarly all of the Na_2O, deducting a small amount for the hornblende, has been calculated as albite. All of the albite has been added to the anorthite as soda-lime feldspar. The potash-feldspar undoubtedly contains some soda but that it is only a small amount, is shown by the fact that microperthite, albite and anorthoclase are not generally present and, furthermore, because the calculated soda-lime feldspar closely agrees in composition with that inferred from optical measurements.

Regarding the "average composition" quoted above from my report on Nevada City and Grass Valley, it should be borne in mind that most of the analyses available in 1896 were made of the more basic type of granodiorite, so that the lime is a little higher and potash lower than would be the case if the large areas of the somewhat more acidic type of the High Sierra were considered. It is clear besides that it will be very difficult to obtain such an average, for not only the analyses but the weight in proportion to the rock masses should be considered.

I have no radical change to propose in the chemical limits of the rock given in the paper on the Pyramid Peak region, referred to on page 272. Only, as to the percentage of silica it should be stated that the granodiorites *of the Sierra Nevada* vary between 59 and 69 per cent; but just as granites and quartz-diorites include rocks with up to 74 per cent or even more of silica, so should the family of the granodiorites include similar acidic types, though they do not appear to be of very common occurrence.

In regard to the lime it may be said that the upper limit (6·50 per cent) is rarely reached and when at the same time the potash approaches 1 per cent the rock should rather be classed as a quartz-diorite. When the percentage of silica falls below 59 the percentage of orthoclase is usually also lowered to such a degree that the rocks become diorites.

With high silica in rocks which otherwise correspond exactly to the composition of a granodiorite the lime is apt to fall low and may in rocks closely related to monzonites even descend to 2·80 per cent.

The truly characteristic features of the granodiorites is that the soda-lime feldspar, which always is a calcareous oligoclase or an andesine, is *at least* equal to double the amount of the alkali feldspar. The latter may be taken to vary from 8 per cent to 20 per cent. Below the lower limit the rock becomes a quartz-diorite: above the upper a quartz-monzonite.

Distribution of types.—As with all other classes of rocks, granodiorite presents somewhat varying types in different localities. Many of the intrusive areas in the foothill region and on the middle slopes of the Sierra Nevada are associated with normal diorites, quartz-diorites and gabbros. As a consequence of the generally more basic character of the magma, the granodiorite of the foothills shows a basic type with relatively higher percentage of lime and lower of potash (see IV, V, VI, VII). In the great granitic areas of the Sierra the general type of the magma is more acidic, hence the granodiorite tends more towards an acidic type without exceeding the limits of the family. However, extensive masses of granodiorites of the more basic type (as well as diorites) exist on the quadrangles of Truckee and Colfax, in the High Sierra. These two types resemble each other so much that their separation in the field appears entirely impracticable. From a cursory examination it appears probable that much of the granitic masses of Southern California belong to the granodiorites. A large part of those of the peninsular range of Lower California are certainly granodiorites, as I have shown by microscopical examination and separation by Thoulet Solution.*

Relation to allied rocks.—In 1895 Prof. W. C. Brögger established the new family of the monzonites,† rocks intermediate in composition between granite and diorite.

* Proc. Cal. Acad. Sci., 2nd Ser., vol. i, part 2, p. 6, 1888.

† Die Eruptions folge der triadischen Eruptivgesteinen bei Predazzo in Südtyrol. Kristiania, 1895, p. 19.

In view of this it may be profitable to inquire into the limits assigned to this rock and to its relation to granodiorite.

In order to make accurate comparisons it is necessary to have accurately defined standards; the lack of these is very much felt in attempts at rock classification. "Granite" is a term concerning the petrographic meaning of which there can be little doubt. True, certain geologists have fallen into the habit of using this name as a synonym for "granular rocks," but this is a practice which should not be encouraged.*

A granite means petrographically a granular rock composed of quartz and alkali feldspar with a micaceous mineral or hornblende. There are, however, but few rocks which exactly correspond to this type, more or less soda-lime feldspar being ordinarily present; it may be referred to as an *extreme* type from which the rock can vary only one way, and the majority of our granites are therefore more or less pronouncedly intermediate between granite and diorite.

Diorite is ordinarily defined (Rosenbusch) as a granular rock composed of soda-lime feldspar, and biotite, pyroxene, or amphibole singly or severally; with added quartz the family of the quartz-diorites is formed. While this is the most generally accepted definition, some petrographers deny admission into this family to the varieties carrying pyroxene. It will be apparent at a glance that unless the very wide term soda-lime feldspar is qualified, this family would include diabases and gabbros as well, and to make separate families of the latter is to sacrifice logical classification. What is really done for practical purposes is expressed by Brögger as follows:† "Die einzige moegliche Trennung wird hier nach meiner ansicht diejenige sein, den Begriff Diorit für mittelsaure Tiefengesteine, den Begriff Gabbro für basische Tiefengesteine der Plagioklasreihe, den Namen Diabas für entsprechende hypabyssische Gesteine und für palaiotype‡ Ergussteine zu reserviren." Assenting to this limitation, it is still true that diorite and quartz-diorite, owing to the variation of soda-lime feldspars, is a less precise term than granite.

It became apparent to Prof. Brögger, as it did to the Californian geologists, that the terms granite, diorite and quartz-diorite were no longer sufficient for present purposes, and this necessity of special names for transition types or intermediate rocks is often expressed in his writings. The result was the

* "Granolites" has been proposed as a convenient word, embracing all rocks of granular structure, and though open to criticism in some respects certainly offers some advantages. See H. W. Turner, Journal of Geology, 1899, p. 141.

† l. c. p. 17.

‡ American petrographers will probably object to this limiting of diabase; the Columbia (Miocene) lava formation, for example, contains abundant instances of diabase flows.

proposal to establish the new family of the monzonites intermediate between the syenites and the diorites, and that of the quartz-monzonites intermediate between the granites and the quartz-diorites. The kernel of the definition of these rocks is contained in the following words:* "Das wirklich characterische bei diesen Gesteinen, ist dass sie in der Regel Orthoklas und Plagioklas ungefähr gleich reichlich oder jedenfalls beide reichlich führen." On the same page we read "Die Monzonite characterisiren sich dadurch dass sie weder zu den Orthoklas-Gesteinen noch zu den Plagioklas-Gesteinen, sondern zu einer Uebergangsgruppe zwischen beiden gehören, sie sind eben: Orthoklas-Plagioklas-Gesteine." In the same place Prof. Brögger states that in his opinion, in order to apply the name diorite, the soda-lime feldspars must strongly predominate; in granite, on the other hand, the alkali feldspars must strongly predominate or (see footnote) the plagioclase must be so acid that the rock is very poor in lime.

In the above definition there is no special limit assigned to the soda-lime feldspars, so that the permissible variation becomes rather large. It must be apparent, however, that the author intended the rock in its most typical development to be placed exactly half way between the granites and the quartz-diorites so far as the feldspars were concerned. This view is corroborated by the fact that of the two calculated analyses given, the first —a monzonite—has 30 per cent orthoclase and 32 per cent soda-lime feldspar (Ab_3An_2) and the second—a quartz-monzonite—(p. 62, l. c.), 35·5 per cent orthoclase and 31·5 per cent Ab_2An_3.

Thus the term quartz-monzonite becomes a *central* type embracing a series of rocks on each side of the definition. Just how far Brögger intended to extend these limits is not clearly stated.

There is undoubtedly ample justification for the introduction of the term quartz-monzonite as defined by Brögger, but reasonable limits should be assigned to it. It would manifestly be incorrect to define a family as having approximately equal amounts of orthoclase and soda-lime feldspars and then include in it rocks having three or four times as much of one as of the other. The definition of granodiorite would give it, say from 8 per cent to 20 per cent orthoclase. In the quartz-monzonites I would give this mineral a range from 20 per cent to 40 per cent, all in an assumed total of 60 per cent feldspars. The rocks containing more than 40 per cent orthoclase would then be classed as granites, there being scarcely room for another family between the quartz-monzonites and the granites.

*l. c. p. 21.

In this manner the former family becomes quite extensive and certainly includes wider limits than does granodiorite. In a postscript to his discussion of the rocks from Monzoni (p. 182) Prof. Brögger devotes a few paragraphs to granodiorites, stating that according to the analysis (No. I in Table A) the rock clearly belongs to the quartz-diorites or rather to the small group between the diorites and the quartz-diorites. He finally concludes that granodiorite is not used in the same sense as quartz-monzonite but rather as a synonym for tonalite. This view is clearly due to the fact that Brögger only recognizes one intermediate group, placing it exactly in the middle between the granites and the quartz-diorites. The above discussion has sufficiently set forth that granodiorite is not a synonym for quartz-mica-diorite or tonalite, which is a typical rock of that kind, except in this sense that many petrographers have formerly used the term quartz-mica-diorite, in absence of others, for rocks comparatively rich in orthoclase.

It has been proposed* by Mr. Turner to class rocks of the composition of IV (and consequently also rocks like III) in Table A as quartz-monzonites. This can only be done by disregarding the definition given by Prof. Brögger of this latter rock. No. IV contains 17·75 per cent orthoclase and 41·40 per cent soda-lime feldspars; this is clearly a rock in which the latter feldspars *greatly predominate* and not a rock with approximately equal quantities of the two feldspars.

Taking an example to the point, there are in Idaho large areas of a granular rock having the following composition :

SiO_2	68·48
Al_2O_3	15·01
FeO	2·90
CaO	2·60
MgO	1·21
K_2O	4·25
Na_2O	3·22
Rest.	2·33
	100·00

From the data obtained by microscopic examination, this rock may be calculated as follows:

Alkali feldspar	21·
Oligoclase	34·
Biotite	13·
Quartz	29·
Accessories	3.
	100·

* H. W. Turner, The Granitic Rocks of the Sierra Nevada. Journal of Geology, 1899, p. 141.

Owing to the low percentage of CaO and large amount of K_2O this rock would fall outside of the limits of granodiorite and may approximately be referred to as a quartz-monzonite. This rock has all the appearance of a granite, and from field examination was supposed to belong to that family.

In the critical examination of proposed rock types the definition is clearly first to be considered, secondarily the analyses. Turning now to the analyses of quartz-monzonites given by Brögger, a perusal will convince that representatives of his definition are few in number. The group with less silica or the banatites is represented by five analyses, four of which easily fall within the limits of the granodiorites. The mean of the analyses is as follows:

	Adamellite.	Banatite.
SiO_2	69·27	64·39
Al_2O_3	13·47	15·90
Fe_2O_3	4·82	4·69
CaO	3·25	4·15
MgO	1·02	1·93
K_2O	3·85	3·52
Na_2O	3·29	3·58

By reason of the high potash the adamellite of this average falls outside of the granodiorites though it hardly corresponds to Brögger's definition. The banatite, on the other hand, would be identical with some types of granodiorite if the analyses were actually representative. Brögger's average of banatite is thus not only on one side of his definition but very much so, inasmuch as the soda-lime feldspar will be equal to about three times the quantity of orthoclase, provided that the mineral composition of the rocks is similar to that of a granodiorite.

I think in fact that it will be difficult to obtain any considerable number of analyses of granular rocks, having the average silica content of 65 per cent and about equal quantities of alkali and soda-lime feldspars. In other words, it does not appear probable that the banatite, which corresponds to Brögger's definition, is a very common and widespread family of rocks.

Granodiorite porphyry.—Minor intrusive masses and dikes, having the composition of granodiorite combined with a porphyritic holocrystalline groundmass, are not uncommon. For these I propose the name granodiorite porphyry, in analogy with granite porphyry and diorite porphyry.

Conclusions.—Granodiorite, a member of the great family of rocks with predominating soda-lime feldspars, is distinguished by a granular texture, grayish color and a mineral composition of quartz, oligoclase or andesine, orthoclase or microcline, hornblende or biotite (usually both); the accessories being titanite, apatite, magnetite and zircon. The quartz may average 23 per cent, the soda-lime feldspars 44 per cent, the orthoclase (with microcline and albite) 14 per cent, varying from 8 per cent to 20 per cent, the ferro-magnesian silicates 14 per cent. These figures are not claimed to be an exact average, which in the nature of the case is difficult to obtain, but they correspond to a fairly typical rock. The family is proposed to represent a very important and very widespread type of rocks, especially common along the Pacific slopes of the Cordilleran Ranges. This family has been clearly defined; the name has for many years been in use in the folios of the U. S. Geological Survey. It has found rapid and general acceptance by reason of its simple construction and its implied definition. But chiefly and above all it deserves to stand because representing a natural group of rocks.

Washington, D. C., December, 1899.