MINERALOGICAL SOCIETY OF AMERICA, SPECIAL PAPER 1, 1963
INTERNATIONAL MINERALOGICAL ASSOCIATION, PAPERS, THIRD GENERAL MEETING

LAYERED PICRITE-ANORTHOSITIC GABBRO SHEET, WEST HUMBOLDT RANGE, NEVADA

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ABSTRACT

The West Humboldt layered intrusion is a two-layer sheet exposed over a half square mile in the West Humboldt Range, Nevada. The body is composed of 235+ feet of hornblende picrite overlain by at least 100 feet of anorthositic hornblende gabbro. The strong segregation of cumulus minerals into an ultramafic basal layer and anorthositic upper layer is remarkable in view of the absence of variations in the composition of the cumulus phases throughout the body and the lack of sorting or rhythms within each layer.

The layering apparently resulted from the separation of plagioclase from olivine and clinopyroxene during sedimentation following emplacement of a highly crystalline basaltic magma. The picritic layer contains all the mafic cumulates and much plagioclase that was dragged down by the sinking mafic grains. The anorthositic layer is composed chiefly of feldspar that was not carried down by the cloud of mafic crystals.

Tabular plagioclase in both layers has a strong preferred orientation. Fabric attitudes are similar in both layers and lie at high angles to the picrite-leucogabbro contact. The planar fabric appears to have formed in response to folding of the igneous body prior to complete consolidation.

INTRODUCTION

A two-layer stratiform intrusion composed of basal hornblende picrite and overlying anorthositic hornblende gabbro is exposed over a half square mile in the West Humboldt Range, northwestern Nevada. The strong bistratal segregation of early crystallized minerals in this body is quite remarkable in view of the absence of cryptic layering (as defined by Hess, 1960), grain size sorting, or mineral rhythms within each layer. A second striking feature of this intrusion is the pervasive planar fabric defined by tabular plagioclase. The attitude of this foliation is similar in both layers and lies at high angles to the interface of the two layers and the base of the sheet.

The layering and fabric of this body are clearly unlike those of other layered gabbros reported in the literature and in this symposium. The object of this paper is to suggest a possible origin of the layered body which accounts for these unusual features. Detailed study of the intrusion is yet to be completed, but the problems mentioned above are sufficiently well established and of such an unusual nature that presentation at this symposium seems warranted.

GEOLOGIC SETTING

The West Humboldt layered intrusion is part of the Humboldt gabbroic complex (Speed, 1962), a large mass of hornblende gabbro with minor picrite, anorthosite, dolerite, keratophyre, and gabbroic pegmatite. The complex crops out in the adjacent northerly-trending West Humboldt, Stillwater, and Clan Alpine ranges in northwestern Nevada and has a known extent of at least 35 miles in maximum dimension. The gabbroic rocks were studied chiefly in the West Humboldt Range (Fig. 1) where they form a quasi-tabular body which dips east off the east flank of the range under the Quarternary deposits of the adjacent basin. Stratigraphic evidence indicates that the age of the complex is between Lower Jurassic and Upper Tertiary. Emplacement of the complex was at a shallow depth, probably less than 2500 feet, and was apparently synchronous with regional deformation of the intruded Mesozoic sediments.

Hornblende picrite and strongly foliate hornblende leucogabbro which compose the West Humboldt layered body crop out chiefly along the western periphery of the Humboldt gabbroic complex in the West Humboldt Range. These units were earliest in the sequence of rock types forming the complex. Some of the relatively large bodies of these two facies are shown in Fig. 1. The consistent areal association of picrite and foliate leucogabbro indicates that these facies are cogenetic. Structural evidence suggests that all of these bodies are contemporaneous and may once have been contiguous. Deformation, widespread deuteric alteration, and poor exposures preclude more definite correlation of these bodies.

WEST HUMBOLDT LAYERED SHEET

Structure. The West Humboldt layered intrusion, shown in Fig. 2, is tabular and consists simply of

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235+feet of hornblende picrite overlain by at least 100 feet of anorthositic hornblende gabbro. The contact of the two layers is not exposed, and an approximate contact was mapped by tracing the sharp mineralogical change in the surficial debris. Field examination in nearly vertical sections through the body indicated that the contact is either sharp or gradational through no more than 15 feet.

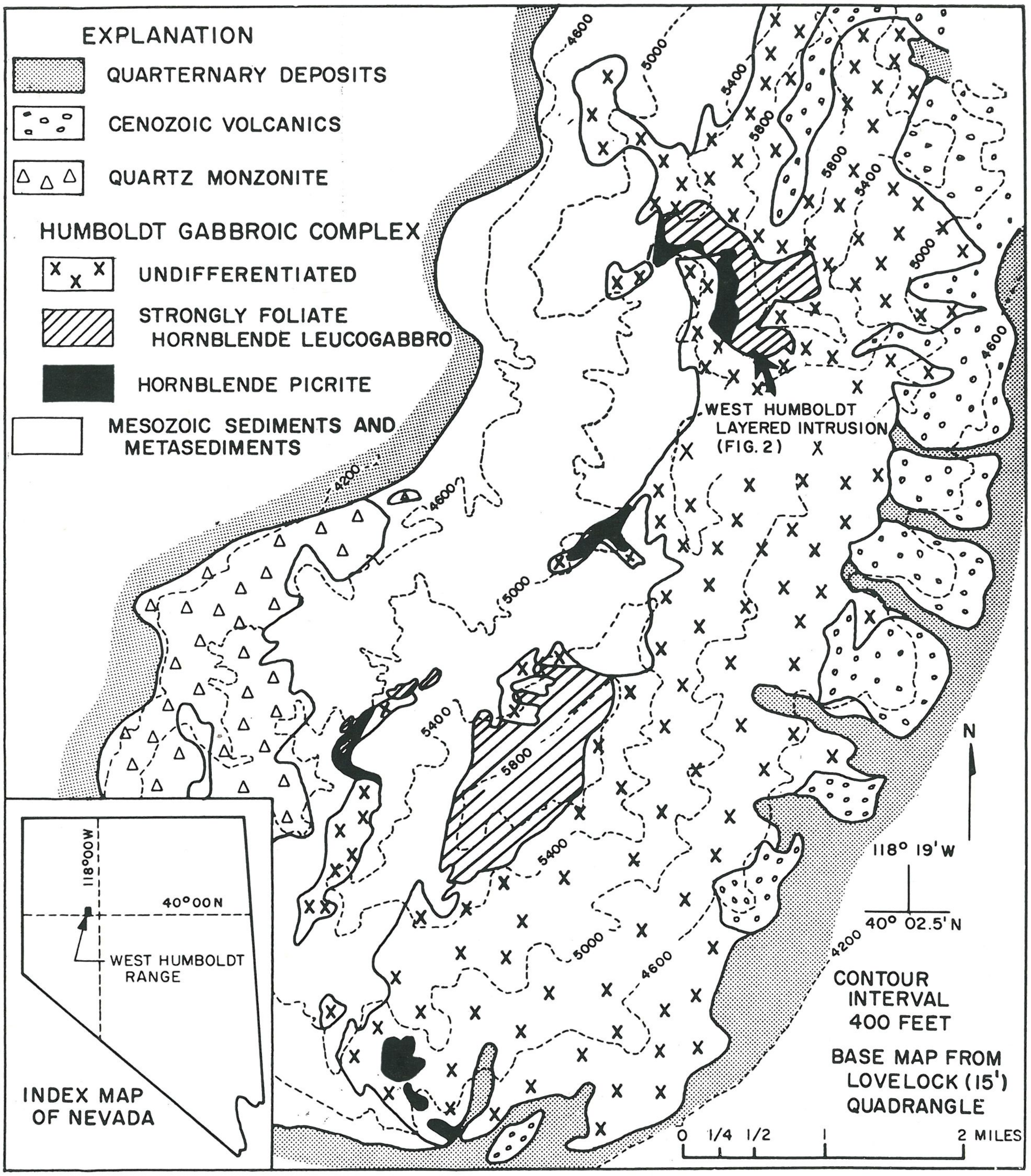

FIG. 1. Generalized geologic map of West Humboldt Range, Nevada, showing distribution of gabbroic rocks and location of West Humboldt layered intrusion.

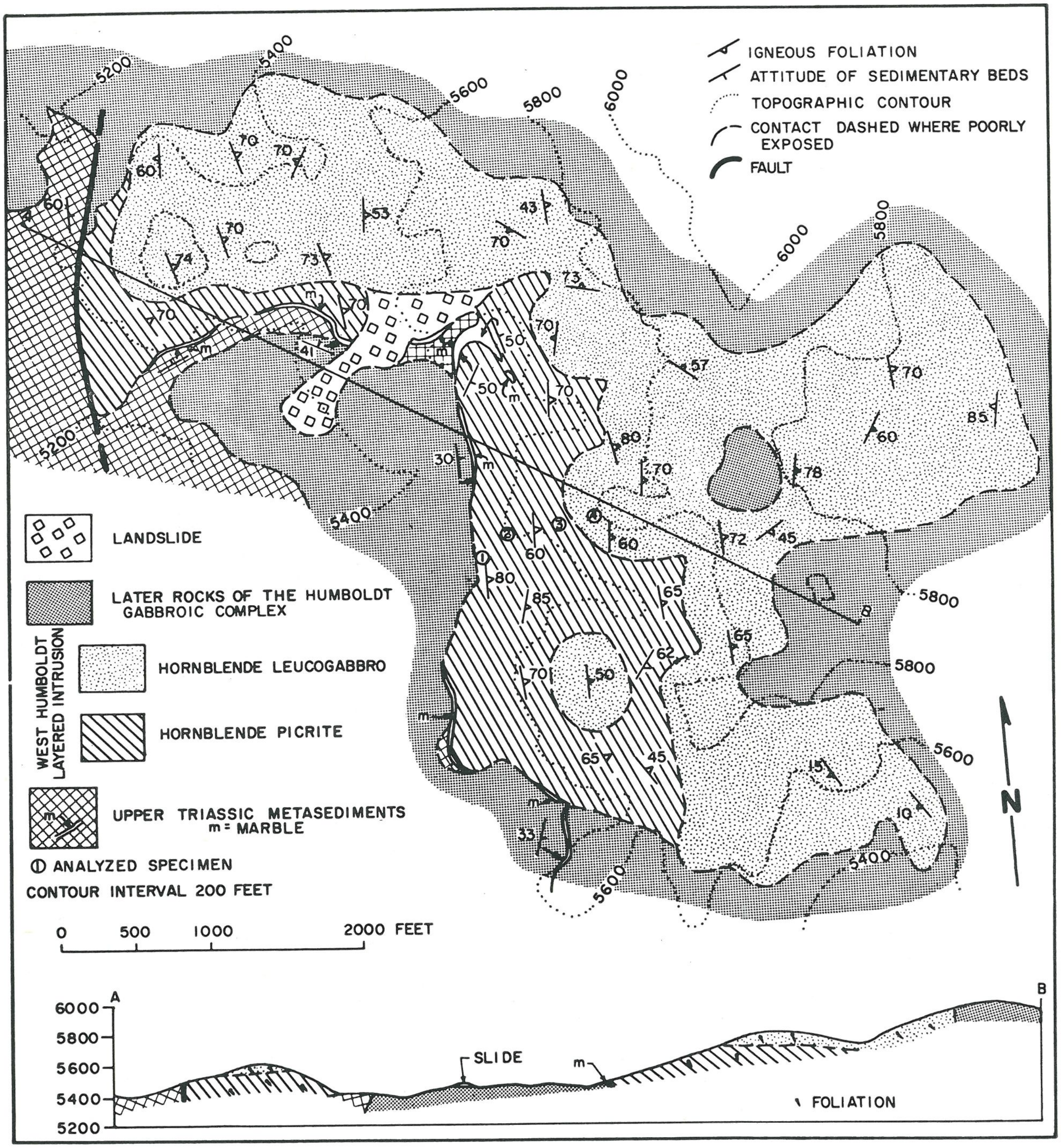

FIG. 2. Geologic map of the West Humboldt layered sheet.

The roof of the intrusion has been completely eroded, and the maximum thickness of the leucogabbro above exposed picrite is about 100 feet. This layer may thicken in the eastern part of the body if the picrite-leucogabbro contact maintains a constant attitude east of its easternmost exposure. The picrite is estimated to be around 235 feet thick in the western part of the body. The thickness of other parts of the picrite is poorly known because of the lack of vertical exposures through this layer and uncertainty in the attitude of the base of the sheet. The picrite, however, appears to thicken in the eastern part of the body.

The base of the picrite lies partly on deformed marble and hornfels and partly on younger hornblende gabbro. The concordance between the igneous sheet and the marble suggests that the body is a sill. Marble, however, is also widespread in thrust zones in the West Humboldt Range; therefore, the structural setting of the intrusion is uncertain. Attitudes of the marble segments form an anticlinal pattern, the axis of which roughly parallels axes of folds in the metasedimentary terrane which trend about N.10°E. and plunge shallowly. Most of these folds are overturned to the west. The degree of folding of the layered intrusion, however, cannot be determined as most of the western limb of the body is faulted. The internal fabric of the layered sheet suggests that the intrusion was deformed prior to final consolidation.

Hornblende picrite. Hornblende picrite forms a rather homogeneous petrographic unit in which internal layering is absent. Modal variation in the picrite consists chiefly of a gradual increase in color index vertically in the layer. Modal and chemical analyses of specimens taken near the bottom, middle, and top of the picrite are reported in Table 1. Analyses 1 and 3 represent the approximate limits of mineralogical and chemical variation in the picrite.

Textures in both the picrite and the leucogabbro clearly indicate a sequence of crystallization of mineral assemblages. The early crystallizing assemblage in both facies is believed to be composed of accumulative minerals. This is indicated by the strong segregation of these minerals into two layers on the basis of their densities. The later crystallizing assemblages formed by reaction of the cumulus minerals with the intercumulus liquid and by *in situ* precipitation of this liquid. Terminology is taken from Wager *et al.* (1960).

The early crystallizing assemblage in the picrite is composed of olivine, labradorite, and clinopyroxene. That crystallization of olivine started first is indicated by the inclusion of small olivine grains in clinopyroxene and labradorite. Olivine has a wide range of grain size and idiomorphism. Maximum dimension of olivine grains in thin section ranges from 0.5 to 5.0 mm. This range of grain intercepts is believed to indicate variation in actual size of olivine grains. In some sections olivine grains with small intercepts are clustered in a manner which indicates that all the grains in the cluster could not have been considerably larger at levels above or below the plane of the thin section. Furthermore, euhedral olivine grains whose intercepts differ by an order of magnitude are in near-contact; it is difficult to envision how the two grains

TABLE 1. CHEMICAL AND MODAL ANALYSES OF ROCKS FROM THE WEST HUMBOLDT LAYERED INTRUSION

	1	2	3	4
Chemical Analyses				
SiO_2	46.56	45.25	43.85	51.30
TiO_2	0.54	0.44	0.49	0.49
Al_2O_3	9.91	9.74	7.85	20.01
Fe_2O_3	3.16	2.46	3.27	1.29
FeO	5.34	6.17	6.10	2.93
MnO	0.14	0.14	0.17	0.05
MgO	18.69	22.78	23.40	6.11
CaO	7.91	6.70	6.33	10.75
Na_2O	1.47	1.48	1.15	3.63
K_2O	0.48	0.36	0.30	0.60
H_2O^+	3.90	3.02	5.12	1.86
H_2O^-	0.91	1.04	1.14	0.35
P_2O_5	0.11	0.10	0.14	0.14
CO_2	0.18	0.17	0.14	0.15
Cl	0.06	0.05	0.05	0.05
F	0.02	0.01	0.02	0.01
Total	99.38	99.91	99.52	99.72
Norms				
Or	3.06	2.26	1.93	3.74
Ab	13.23	13.15	10.43	31.60
An	20.20	19.80	16.60	37.50
Di	16.29	11.32	12.90	12.75
Hy	22.98	14.48	19.93	6.17
Ol	18.09	34.51	32.25	4.89
Ap	0.26	0.23	0.33	0.33
Il	1.08	0.88	1.02	0.96
Mt	4.86	3.75	5.10	1.92
$\frac{MgO\ \%}{MgO+FeO}$	90	90	90	85
An %	59	59	60	53
Modes				
Olivine	25.4	34.0	38.5	—
Fo%	(85–87)	(87–92)	(85–90)	
Bronzite	3.5	2.5	3.3	—
En%	(80–82)	(82–84)	(81–83)	
Clinopyroxene	13.1	14.7	13.2	5.0
Kaersutite	11.4	10.5	8.5	18.0
Plagiocalse	27.8	28.1	21.6	73.7
An%	(55–60)	(55–60)	(50–58)	(49–57)
Magnetite	2.3	2.3	3.8	0.3
Titanobiotite	2.2	2.0	3.2	—
Chlorite[1]	14.2	6.1	6.7	2.4
Sphene	—	—	—	0.5

[1] Deuteric chlorite replacing both plagioclase and olivine.
1—Hornblende picrite—10 feet above base.
2—Hornblende picrite—170 feet below leucogabbro contact.
3—Hornblende picrite—15 feet below leucogabbro contact.
4—Hornblende lexcogabbro—30 feet above picrite contact.

Specimen locations shown on Fig. 2.
Analyst: Y. Chiba.

could have similar actual dimensions. Perfectly euhedral and highly irregular anhedral olivines are both abundant. Optical measurements indicate a composition range of Fo_{85-92}, but it is probable that the spread is due to errors in measurement as the majority of measurements indicates Fo_{87}. Zoning is absent in olivine. Layering with respect to composition, size, or shape of olivine was not observed.

Labradorite in the picrite occurs chiefly in tablets which are as long as 12 mm. The tablets contain as many as 50 oscillatory zones. The most calcic zone is An_{67}, but most zone compositions are in the range An_{55-65}. Some labradorite tablets have a thin rim of normally zoned plagioclase, the periphery of which is as sodic as An_{25}. The rims probably crystallized after accumulation. Labradorite forms irregular monomineralic clusters at a few places. Long dimensions of the clusters generally parallel the planar feldspar fabric.

Clinopyroxene occurs both as discrete subhedral and euhedral grains and in monomineralic glomeroporphyritic clusters in which component grains are highly intergrown. Many clinopyroxenes have oscillatory zoning, but others are apparently of uniform composition. Optical variations in zoning are chiefly in optic angle (52–54° and 58–60°) whereas differences in refractive index ($\beta = 1.682 - 1.686$) and $Z \wedge c$ (40–42°) between zones are small. Unzoned clinopyroxene optic angles are 53–57°. Accordingly, clinopyroxene compositions fall in the interval $Ca_{43-50}Mg_{39-48}Fe_{7-10}$. Maximum grain intercepts of clinopyroxene clusters and single grains are 4.0 mm.

Two intercumulus assemblages occur in the picrite. The earlier consists of orthopyroxene and sodic rims on cumulus labradorite. The later assemblage is composed of kaersutite, titanobiotite, and magnetite. Orthopyroxene is virtually restricted to sinuous poikilitic nets which envelop and replace olivine grains. In other picrite bodies in the West Humboldt Range, however, orthopyroxene occurs in large (12 mm) poikilitic nets enclosing clinopyroxene and plagioclase as well as olivine. This texture indicates that orthopyroxene was a product both of reaction of olivine with the intercumulus liquid and continued direct precipitation from the liquid. Orthopyroxene compositions range from En_{80} to En_{87}.

The foregoing minerals are enveloped by large poikilitic nets of kaersutite (4.9% TiO_2) and titanobiotite. Amoeboid grains of magnetite occur only in kaersutite and titanobiotite and are apparently contemporaneous with the latter minerals. These three minerals compose the late assemblage which crystallized from the intercumulus liquid. Clinopyroxene and, to a less extent, orthopyroxene are highly replaced by kaersutite and titanobiotite, but replacement of olivine and plagioclase by these minerals did not occur.

Most of the rocks of the layered sheet were strongly hydrated in the deuteric stage. Much of the olivine and orthopyroxene was altered to talc, tremolite, bowlingite, magnetite, and serpentine minerals. Labradorite was partly replaced by combinations of prehnite, chlorite, pumpellyite, grossular, analcite, albite and white mica. Kaersutite was partly altered to actinolite, chlorite and sphene. Reciprocal movement of Ca and Mg is indicated by the replacement of labradorite by chlorite and olivine by tremolite at places where the two primary minerals were in contact. The original grain contacts are obscured by the alteration, and the amount of chlorite representing former olivine or plagioclase cannot be ascertained. This chlorite is reported separately in the modes in Table 1, but textures indicate that the chlorite chiefly replaces plagioclase.

Hornblende leucogabbro. Modal variations in hornblende leucogabbro are largely in the relative amount of plagioclase (70–95%) and late amphibole. Clinopyroxene rarely forms more than 5% of the leucogabbro, and in many specimens, it is absent. Systematic vertical or lateral trends in these variations in the leucogabbro were not found. Chemical and modal analyses of a representative leucogabbro are given in Table 1.

Labradorite and clinopyroxene form the early crystallizing assemblage in the hornblende leucogabbro facies. Relics or alteration products of olivine or orthopyroxene were not observed in the leucogabbro. Plagioclase tablets are generally larger and the peripheral jackets are thicker in the leucogabbro than the picrite. The contrast in zoning and composition of the jackets and the core suggests that the two crystallized under considerably different conditions. The cores almost certainly are part of the cumulus assemblage; it is suggested, therefore, that the rims grew from the intercumulus liquid. The average composition of the cumulus parts of the leucogabbro plagioclase appears to be uniform throughout the layer and to differ little from that of the picrite plagioclase. Clinopyroxene in the leucogabbro occurs both in equant and highly elongate subhedra. Clinopyroxene compositional limits in the leucogabbro are similar to those in the picrite.

The intercumulus assemblage in the leucogabbro is composed chiefly of kaersutite with a little magnetite and apatite. Titanobiotite does not occur in the

FIG. 3. Planar fabric of tabular plagioclase in hornblende picrite, West Humboldt layered intrusion. Trace of fabric (strike N. 10° W., dip 80° E.) about parallel to hammer handle.

leucogabbro. Modal apatite appears to be far more abundant in the leucogabbro than the picrite, though normative apatite is similar in the two facies. The abundance of the intercumulus minerals in the leucogabbro is between 1.5 and 2 times that in the picrite.

Fabric. One of the most striking features of the West Humboldt layered sheet is the strong planar fabric formed by the alignment of plagioclase tablets in both layers of the body (Fig. 3). Foliation symbols in Fig. 2 indicate the similarity of attitude of the fabric in the two layers and the fact that the planar fabric is at a high angle to the interface of the two layers and the projected base of the sheet. Figure 4, an equal area plot of poles to the feldspar fabric, shows that the preferred orientation is generally similar throughout the body.

Bent twins, shattered grains, and other evidence of protoclasis are absent. Discordant plagioclase tablets contact one another without deformation. Clearly, the fabric must have been formed in a benign manner. Sawed slabs of leucogabbro were examined for lineation, and it is clear that prominent lineation is absent. It is possible, however, that if a large number of careful measurements were made, a slight lineation might be discovered.

Vertical variations. Vertical variations in the West Humboldt layered intrusion are summarized as follows:

A. Mineral Layering
1. Restriction of olivine, orthopyroxene, and titanobiotite to the picrite.
2. Greater content of clinopyroxene in the picrite than the leucogabbro.
3. Greater amount of plagioclase, kaersutite, and apatite in the leucogabbro than the picrite.
4. Ratio of olivine and clinopyroxene to plagioclase increasing stratigraphically upward in the picrite.

B. Textural Variations.
1. Average plagioclase grain size larger in the leucogabbro than the picrite.
2. Clinopyroxene single grains and clusters a little larger in the picrite than the leucogabbro; clinopyroxene in the leucogabbro more elongate.

The mineral variations indicate the strong separation of the cumulus minerals into two layers on the basis of density. The greater content of the intercumulus minerals in the leucogabbro than the picrite indicates the higher intercumulus porosity (lower crystal/liquid ratio) in the upper layer prior to crystallization of the intercumulus liquid.

Cryptic layering of the cumulus phases is apparently absent within the intrusion. Olivine composition is constant throughout the picrite, and the range of 2V and β of clinopyroxene at different levels in the sheet is similar. The consistent values of normative MgO/MgO+FeO on the analyzed picrites in Table 1 supports the modal evidence that the mafic minerals do not become more iron-rich at higher stratigraphic levels. Magnetite is a product of deuteric alteration of olivine in the picrite. Consequently, normative magnetite content of the picrites

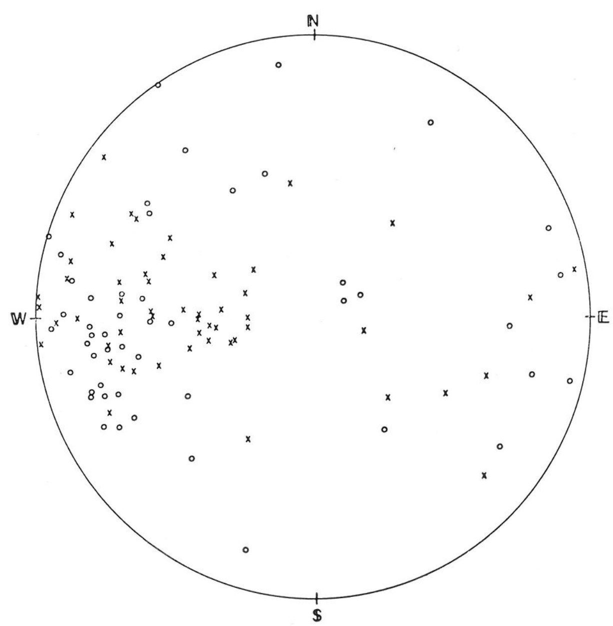

FIG. 4. Equal area projection of poles to planar fabric (circles) in West Humboldt layered intrusion and to bedding (X) in metasedimentary rocks within one mile of the layered intrusion. Plotted on lower hemisphere.

is higher than that of modal magnetite, and the ratio of normative $MgO/MgO+FeO$ is higher than it was prior to alteration. Bulk modal plagioclase composition, though difficult to estimate because of complex zoning, appears not to differ at succeeding stratigraphic levels in what is taken to the cumulus part of the mineral. This is supported by the similar values for normative plagioclase in the analyzed picrites of Table 1. The larger average volume of the intercumulus plagioclase rims in the leucogabbro, however, makes the normative plagioclase in the leucogabbro more albitic than that of the picrite.

Glomeroporphyritic clots of clinopyroxene and plagioclase are the only monomineralic aggregates in the intrusion. The clinopyroxene clots are generally equant; the plagioclase clots are both equant and lensoid, the latter type lying parallel to the planar fabric of the rock. Rhythmic mineral layering is absent. Sorting within each of the facies as a function of grain size or shape was not observed.

Petrology of the Layered Intrusion

The rocks along the base of the sheet are so altered that the existence of a chilled zone could not be determined. Consequently, the composition of the parent magma or the degree of crystallinity of the magma on emplacement are unknown. In a qualitative way, however, the two facies appear to be complementary fractions of an olivine gabbro. This suggests that the two layers are differentiates of a single injection of basaltic magma. The continuity of the feldspar fabric between the two layers strongly supports the view that the layers were not separate injections. The fact that rocks throughout the complex have a late-crystallizing alkaline assemblage indicates an alkali magma type.

Differentiation of the magma consisted of two concomitant processes, vertical segregation of the early formed minerals into upper feldspathic and basal mafic layers and strong changes in the composition of the liquid phase with progressive crystallization. Following accumulation of olivine, plagioclase and clinopyroxene, succeeding events were: 1) crystallization of orthopyroxene and sodic plagioclase rims and development of the planar fabric, and 2) crystallization of kaersutite, titanobiotite, magnetite and apatite. The contemporaneity of the feldspar rims with orthopyroxene rather than the other intercumulus minerals is suggested by the coexistence of kaersutite with magmatic analcite in other rocks of the complex. The contrast of orthopyroxene textures in the foliate picrite of the layered intrusion to those in nonfoliate picrite to the south in the West Humboldt Range suggests that crystallization of large continuous orthopyroxene webs in the former picrite may have been mechanically prevented by concomitant reorientation of platy plagioclase.

The second group of intercumulus minerals filled the remaining pore space as well as partly replacing the earlier pyroxenes. The composition of this late crystallizing assemblage must be close to the nonvolatile composition of the intercumulus liquid near its final consolidation. The late magma contained only 31–40% SiO_2 but was enriched in iron (15–30% total iron as FeO), soda, and probably in volatiles. This liquid was probably highly fluid. The liquid line of descent shows a remarkable retention of iron in the liquid phase. An account of the differentiation of the entire complex will be presented elsewhere.

Origin of the Layering

The two-layer distribution of early crystallizing minerals strongly indicates the influence of gravity during differentiation. The absence of rhythms or sorting in either layer, however, indicates that deposition of the cumulates in this body did not involve the current mechanisms that were apparently operative in other layered gabbros (Wager and Deer, 1939; Hess, 1960). The original thickness of this body is unknown, but the known or inferred thickness of other parts of the gabbroic complex in the West Humboldt Range suggest that it did not greatly exceed 500 feet. The rate of cooling, therefore, was probably similar along all surfaces of the magma chamber, and the change of melting point of crystallizing phases with depth in the chamber was probably not a significant factor in their distribution.

The uniformity of composition of the cumulus minerals, each of which forms a solid solution series, indicates that they crystallized from magma of constant composition with respect to the ratios of high temperature to low temperature components of the series. Fresh magma, therefore, must have continually been brought to the cooling surfaces where crystallization occurred, and magma movement must be invoked to account for the absence of cryptic layering. Yet, convective overturn or other flow mechanisms cannot be called upon to circulate fresh magma considering the lack of rhythms or sorting of the cumulates which would have been deposited concomitantly with the rise of fresh magma. Another feature to be accounted for is the upward increase in color index in the picrite.

The layering can be explained in part by the suggestion that the cumulus minerals had largely crystallized before the magma was emplaced. Olivine, clinopyroxene, and plagioclase could have crystallized with little change of composition during rise of the magma through the conduit if the upward flow was turbulent enough to bring fresh magma to the walls and sweep the crystals away from the peripheral parts of the conduit. The complex zoning of the feldspar and some clinopyroxene suggests rapid crystallization under varying conditions. The relative movement of crystals and crystal aggregates of olivine, clinopyroxene, and plagioclase during sedimentation that followed magma emplacement may account for the layering and petrographic variations. The mafic phases would clearly have settled through the liquid, and it is suggested that plagioclase may have had a slight tendency to rise. The ratio of plagioclase to interstitial amphibole is lowest at the base of tabular bodies of feldspathic gabbro at other places in the complex. This suggests that plagioclase was less dense than the late liquid.

The settling of olivine and clinopyroxene simultaneously throughout the magma chamber probably involved increasing amounts of aggregation of the sinking grains with time. The sedimentation process might be viewed as the compaction of a cloud of crystal aggregates rather than as the settling of discrete particles. Sorting during deposition of this type should have been poor. Much plagioclase was probably dragged down by the descending mafics. Feldspar crystals near the chamber roof had fewer waves of mafic grains and aggregates sinking past than did feldspars at lower levels, and the opportunities for feldspar to have been swept down were less at higher levels in the chamber. On the other hand, feldspar at the base of the magma chamber was probably covered by cumulates immediately after emplacement and had little chance to move away from mafic crystals at this horizon. Consequently, it is suggested that the degree of separation of cumulus mafic grains and feldspar during sedimentation was a function of their height in the magma chamber just after emplacement (excepting, of course, the possibility of a thin chilled or rapidly crystallized layer along the roof of the chamber in which all the early phases were trapped as phenocrysts.

If this mechanism is correct, the top of the picrite contains mafic cumulates which were near the roof of the chamber just after emplacement. Olivine, clinopyroxene, and labradorite at the bottom of the picrite, however, probably did not move after emplacement, and their modal ratio should represent the ratio of these minerals in the magma on emplacement. Good modal data on basal specimens are lacking, but, roughly, labradorite appears to have been a little more abundant than olivine and olivine about twice the amount of clinopyroxene. The leucogabbro layer consists of plagioclase which successfully separated from the compacting cloud of mafic material. However, a major problem not covered by this explanation is the origin of the clinopyroxene in the leucogabbro. It seems unlikely that clinopyroxene in the leucogabbro was a member of the pre-emplacement assemblage that failed to accumulate completely. Olivine occurs only in the basal layer, and the difference in density of olivine and clinopyroxene is not enough to suggest that the former mineral should have settled more than the latter. The apparent difference in shape of clinopyroxenes in the leucogabbro and the picrite supports the view that they did not crystallize together. Yet, it is not clear why the composition of clinopyroxene from the two layers is apparently similar if clinopyroxene in the leucogabbro crystallized during or following accumulation.

Considering that the sheet was probably not much greater than 500 feet thick, the completeness of accumulation of the mafic grains is remarkable. The rate of settling of the cumulates must have vastly exceeded the rate of crystallization of the liquid in from the walls. In fact, the crystallization of the late intercumulus assembalge apparently did not occur until sedimentation was complete. The probable high fluidity of the liquid phase during sedimentation greatly assisted the rapid settling.

Some aspects of the Shonkin Sag laccolith (Hurlbut and Griggs, 1939) are similar to this intrusion. The laccolith is also highly differentiated for a thin body, and the color index of the lower shonkinite layer increases upward. The mode of the chilled basal layer of the Shonkin Sag body (47% phenocrysts) indicates that the magma was rather crystalline on emplacement. Unfortunately, petrographic coverage of that body does not show whether or not cryptic layering exists.

Origin of the Foliation

The feldspar fabric appears not to be primary but to have formed by reorientation of feldspars in place. Absence of prominent lineation of the feldspar and lack of feldspar crystals stemming from a planar surface indicate that this is not a growth fabric. The fact that the foliation lies at high angles to the base of the intrusion and the interface of the two layers indicates that laminar flow of plagioclase tablets past a planar surface did not cause alignment. It could be suggested that feldspar tablets were oriented during accumulation so that the tablets lay vertically. By this mechanism, however, the normals to the tablets should be randomly distributed in the horizontal plane rather than strongly aligned as shown in Fig. 4. Thus, the fabric could not have developed by sedimentation alone. As noted previously, the contrast between orthopyroxene textures in the foliate picrite of the layered body and in a non-foliate picrite a few miles south suggests that plagioclase alignment and orthopyroxene crystallization were contemporaneous. Finally, it is clear from the undeformed poikilitic texture of the late intercumulus kaersutite and titanobiotite that these minerals crystallized after the fabric had formed. Together, these points indicate that reorientation occurred after accumulation but before final consolidation.

Formation of a strong planar fabric by reorientation of crystals in a liquid requires that the abundance of crystals be high enough that differential movement of crystals and liquid can occur. A change of shape of the chamber is necessary for this differential movement. Figure 4 shows a definite relation between the preferred orientation in the igneous body and the attitudes of the bedding of the intruded metasediments. The bedding orientation is largely controlled by near-isoclinal overturned folds. The comparable orientation of igneous and country rock fabrics suggest that the foliation is an axial plane fabric and that the foliation resulted from deformation of the chamber in response to external stress.

The attitude of the fold axis defined by the base of the picrite roughly corresponds to attitudes of axes of major and minor folds in the surrounding rocks. This relation and the similar orientation of the igneous foliation and axial planes of folds in the country rocks suggest that intrusion occurred before regional deformation but that folding occurred before final consolidation of the igneous body.

The absence of protoclastic textures in these rocks indicates that reorientation occurred in a benign manner. It is suggested that the tabular grains were aligned by the flow of intercumulus liquid during deformation. The grains were reoriented by the moving liquid so that their largest surface lay in the plane of maximum liquid flow. The cumulus porosity of the rocks (12–25%) seems low compared to estimates from other cumulus rocks and to results of packing experiments (Hess, 1960; Wager *et al.* 1960). This supports the view that some of the intercumulus liquid was pressed out, but the poor sorting of these cumulates may also have yielded low porosities.

Acknowledgments

I am grateful to C. O. Hutton and R. R. Compton of Stanford University for helpful criticism of this manuscript and to my colleague, A. A. Loomis, for his valuable discussion and advice on the problem as well as for manuscript comments.

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