PETROLOGY AND GEOCHEMISTRY OF THE PRECAMBRIAN METAVOLCANICS OF LADRON MOUNTAIN, NEW MEXICO

An Independent Study

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ABSTRACT

This independent study was an investigation of a metamorphosed sequence of rocks exposed along a northwest trending, three mile long ridge system of Ladron Mountain.

The Sierra Ladrones are located in central New Mexico, and Ladron Mountain, its largest unit, is a Precambrian system of igneous rocks faulted into place.

It is concluded from field and lab studies that the rocks were once flows and sills of porphyritic volcanics of rhyolitic to rhyodacitic composition, intruded by gabbroic dikes and sills. The sequence has been metamorphosed and altered by albitization, potassium metasomatism, and epidotization to create the metavolcanics seen.

INTRODUCTION

The metavolcanic sequence composes most of the northwestern quarter and peak area of Ladron Mountain, which is the largest single unit of the Sierra Ladrones. This small mountain range is located in central New Mexico on the western margin of the Rio Grande Valley, approximately 43 kilometers north of Socorro. The area under study includes Canyon del Norte, its bordering ridges, and the Ladron Peak area. The elevation at the base of the section, abutting the long pediment ramp of Canyon del Norte, is 2067 meters. The sequence creates the ridges and encompasses the peak and area south of it to a maximum height of 3060 meters. On the fifteen minute United States Geological Survey Riley quadrangle map, this includes sections 6, 25, 30, 31, and 36 of township two north and range two west. The metavolcanic sequence is tilted and faulted into place, as is most of the mountain, and the beds dip 50 to 80 degrees to the south. The area has gone through at least two stages of metamorphism, though not of great intensity, and is faulted in several areas, with a north-south fracture pattern overlaying most of these faults.

The topography is rugged, with steep canyons, sharp ridges, and little cover. The flora and fauna range from Upper Sonoran through the Transition Zone of Merriam's Life Zone classification (Bailey, 1913). Compared to the abrupt rise of Ladron Mountain, most of the north and northwest land surrounding the area is flat and uniform, and is owned either by private ranchers or is under Bureau of Land Management control.

Methods of Investigation

Field mapping was done the summer of 1975. The field work consisted of exploration, mapping to create a stratigraphic column, and sampling of the porphyritic metavolcanics and amphibolites. The mapping was done with the use of photographic blowups of the Riley Quadrangle map (USGS number 4552 Series V781) and by brunton compass and pacing. The strata of the section stand nearly vertical, having been faulted in place before Tertiary times, and are at a steep angle to the ridges. The intense state of weathering alteration in the rocks, and inaccessibility and ruggedness of terrain are the main problems encountered in the field.

Thin sections were cut from the samples gathered, and through petrographic work, mineral compositions were determined by modal analysis. Any indications of origin and emplacement were looked for. Geochemical studies involving neutron activation and X-ray flourescence were used to determine major and trace element concentrations and distributions.

Mapping

The stratigraphic column was mapped along, what appeared to be, the most complete and longest sequence of metavolcanics. This section was the northwest ridge of Del Norte Canyon and across the peak, and was sampled in three traverses (A, B, C), traveling up slope and up dip (see Figure 2). The average strike of the beds vary, trending N55°W at the topographic bottom of the section, and N45°W through the peak area. Traverse A has an average slope (computed from the difference in elevation) of 40 degrees. The angle between the traverse and the average strike of the beds is 55 degrees (divergence angle of 35 degrees) and the true horizontal distance, allowing for slope, is about 818 meters. Traverse B is much longer, a 1976 meter walk up a series of resistant plateaus similar to giant steps. This traverse is almost parallel to the strike, 10 degrees difference, and has an average slope of 18 degrees. Traverse C has only a 9 degree elevation difference in a 963 meter horizontal distance, which is at a 67 degree angle to the general strike.

Using these figures in Kottlowski's (1965) formula for oblique thickness measurements:

$$\text{Thickness} = (\text{horizontal distance})(\cos \text{divergence angle})(\text{dip angle}) \pm (\text{elevation distance})(\text{dip angle})$$

one arrives at a figure of 1892 meters for the true thickness of the stratigraphic section. This is not a continuous sequence of metavolcanics; besides having been faulted into place at the bottom and top contacts, the sequence contains at least one large fault, possibly two, which have erased part of one area and doubled over another small section (see map).

Rock Sequence, tectonics and progressions

The major rock type of this sequence has few continuous characteristics stratigraphically. Phenocrysts of translucence quartz and whitish feldspar occur in different proportions, sizes, and concentrations throughout the sequence, with a recrystallized fine-grained matrix. The weathering changes from a rather blocky, fractured outcrop pattern forming cliff-like blocks to a more rounded shell-like appearance sloughing plate-like rocks onto the talus slopes created in large fractures. The color also changes through the section. The volcanics at the base have an orange-brown coloration, which grades stratigraphically into a brown-to-tan color. At an elevation of 2400 meters this color is replaced by a sugary, crystalline, purplish-blue; with pink phenocrysts which further up-section appear white. The contact between the brown metavolcanic and the blue is gradational and hard to define, though this color change does correspond to the change in weathering phenomena from blocky to shell.

Throughout the section are intruded basic dikes and sills of two types. One is a medium-grained intrusive with xenomorphic granulate texture; the patches are composed of black amphibole and plagioclase. The other basic rock is a fine-grained biotite schist, the schistocity a result of local tectonic movement along faults. These dikes are infrequently gradational with one another and are often parallel to fabric planes and pehnocryst orientations, but have a general strike of N45°W. They often occur in saddles and through fault zones, sometimes as small dike swarms. They are rarely more than a few meters wide, with their thickness varying through the individual unit, and are often hard to trace laterally.

Also intruding the metavolcanics are two thin (one to three meter) granite dikes, which can be traced and whose strikes are almost concordant with the strike of the surrounding units.

Occurring in an area of faulting and definite tectonic bending are pink silicious dikes and sills, very fine-grained and in close association with amphibolites and sheared versions of the basal brown metavolcanic. These dikes and sills, some quite thick, have a strike of N40°W, in an area where the metavolcanics trend N65°W. Laterally to the east this system bends north-south and ends at the ridge of traverse B.

The topographic top of the section, south of Ladron Peak, ends in a highly faulted and sheared saddle. This saddle is a mixture of porphyritic metavolcanics and amphibolite dikes. Most of these are of the hornblende schist variety. The southern boundary of this depression is composed of Capiroite granite and metasediments, schist and quartzites, termed by Condie, the Quartzite Sequence (Condie, 1976). The topographic bottom of the section is covered by the pediment surfaces created by the drainage from Canyon del Norte and its tributaries. This canyon contains large (two to three meters square) and small boulders of the various rock types which compose the ridges.

To the west and southwest the metavolcanics discordantly abut the Ladron fault, of Cenozoic age. This high angle normal fault (Black, 1964) runs most of the length of the section and brings the metavolcanics into contact with the Ladron quartz monzonite. This fault is probably a continuation of the fault which truncates the top of the section, south of Ladron Peak.

There is no progressive phenocryst change along the length of the section, either in size or abundance. There is a definite, noticeable change in the feldspar composition through the section, which will be described later. Matrix grain size also varies through the sequence from medium to a fine-grained, almost indistinguishable collection of grains.

The areas where a medium-grain size occurs can usually be correlated with a tectonically active area.

There is also no definite progression of occurrence, size, or appearance in the amphibolites, though they tend to occur with more frequency in the bottom third of the section. In thicker amphibolite units the rock is gradational in the dike or sill, from a medium-grained spotted type in the center of the unit to a more fine-grained, fissile version on the borders.

As mentioned earlier, there is a definite north-south fracture trend, which is later than any other noticeable tectonic activity. The fractures appear to crosscut all units of the section, but do not cause any displacement or reorientation.

Mineralogy

The single most prevalent rock type is a metamorphosed porphyritic volcanic with a recrystallized granoblastic groundmass and relic phenocrysts of quartz, plagioclase, and microcline. The occurrence, size, form, alteration, and primary or secondary nature of the phenocrysts vary with position in the section. Secondary and/or accessory minerals which occur are biotite, chlorite, muscovite, sericite, magnetite, hematite, pyrite, hornblende, calcite, epidote and leucoxene.

The groundmass is fairly equigranular, but too fine-grained to distinguish individual minerals. Occassionally recrystallization has proceeded enough to create a size in which albite and carlsbad twinning are evident.

In the phenocrysts of quartz and feldspar all stages of alteration and deterioration are evident (Figure 3), often with several stages noticeable in the same slide. Aspects such as sieve texture, or myrmekitic or granophyric textures alter many of the fledspars. In one or two instances resorption of rectangular plagioclase phenocrysts by the groundmass can be seen in hand specimens.

There are tectonic areas in the Ladron sequence that contain rocks similar to the metavolcanics just described, however due to shearing and/or migmatization they have been metamorphosed into versions which are almost unrecognizable in the field. These metavolcanics still contain quartz and feldspar as recrystallized relic phenocryst, but in much smaller percentages. They are ususally flooded with epidote and with traces of hornblende. Many are very fine-grained and fissile.

Basic rocks in the sequence are of two types. One type is a xenomorphic granular, medium-grained ortho-amphibolite composed of plagioclase, hornblende, magnetite, hematite, epidote, and minor amounts of calcite, biotite, and muscovite. The hornblende concentration varies from amounts equal to the plagioclase concentration, to amounts three times that of the feldspar. The hornblende needles, which are often over two millimeters in length, are either radially dispersed through the rock, or have a lineation noticeable in thin section. In one amphibolite sample from a dike swarm associated with a large fault, the plagioclase has been remobilized into long thin lens and stringers several centimeters in length, which are parallel to the strike of the dike.

The other basic metavolcanic is also an intrusive; it is lepidoblastic, fine-grained, and composed of, as much as, fifty percent biotite. The groundmass is plagioclase, with accessory and secondary minerals such as; calcite, magnetite, hematite, epidote, muscovite, and minor amounts of pyrite and quartz. These basic rocks contain phenocrysts of feldspar in small amounts, which are partially assimilated by the groundmass.

Individual Minerals

Quartz

Relic quartz phenocrysts are translucent blue in hand specimen, either as lenses or as irregular polyhedrons. When the lens is a single grain, and is either in a lenticular form or in the partially hexagonal or diamond shape characteristic of quartz, it is probably primary. The recrystallized state of the phenocryst occurs as a grain with a composite nature similar to granoblastic texture.

All gradations from single unit to composite occur in the rock sequence with several stages noticeable in the same slide (Figure 3). Grain resorption shows a similar progression of stages. The borders of the primary lenses are usually clear, but rarely blebs of the groundmass will encroach upon the border. With recrystallization, resorption tends to increase, though not always. Rectangular, very assimilated quartz phenocrysts are in close proximity to clear composite grains of quartz. These composite grains often retain the lens or diamond shape of the original grain, until a majority of the grain is recrystallized. Infrequently, boudin-type stretching might be detected in the composite phenocryst, but the irregular nature of the borders of totally composite grains makes such recognition difficult.

This composite texture is also observed in the numerous veins filled with quartz, or in a vein with a combination of quartz and plagioclase.

The quartz phenocrysts will occassionally be fractured and broken, and contain inclusions of plagioclase or feldspar. As single units, quartz grains exhibit undulatory extinction with a biaxial figure indicating strain. The grains also occur in light grey, subhedral shapes exhibiting a uniaxial positive figure.

Quartz forms as an alteration product of feldspar, appearing as an amorphous coating where a feldspar phenocryst existed. This process occurs in gradational stages leaving patches on the feldspar grain where twinning, both of plagioclase or microcline show through.

As a groundmass constituent, the percentage of quartz in the granophyric background can neither be computed nor any definitive characteristics be recognized.

Feldspars

Plagioclase

In the field, plagioclase phenocrysts appear in color ranging from pink to white, often quite large (over three millimeters) and in several shapes. The grains are either lensoidal or rectangular, or in irregular patches often tectonically stretched.

In thin section they also appear in many forms. The grains can be euhedral lathes, fresh and sharp in appearance, with or without distinctive twins. At times the lathes are subhedral and fractured, and show assimilated and resorbed textures in all gradational stages. The final remains of a total resorbed phenocryst appear as a groundmass area with an indistinct shadow of the former grain exhibiting extinction.

Sieve textures occur on many of the phenocrysts, especially noticeable on grains with resorbed borders. When recrystallized, plagioclase displays composite textures similar to recrystallized quartz grains.

Plagioclase altering to calcite is not as common as alteration to quartz (mentioned earlier), but it is quite distinctive in its complete replacement of the plagioclase lathe while retaining the shape of the grain.

Carlsbad, albite, and pericline twinning are evident in groundmass and plagioclase grains. These twins are occassionally bent by tectonic movement, but in very tectonized areas, twinning is absent.

Plagioclase filled veins are uncommon, but when they do occur they display a composite texture. More commonly, plagioclase will be a minor constituent in a quartz vein.

Inclusions other than quartz are uncommon in the phenocrysts, but occasionally are found as fine-grained, light and dark bubbles. The optic sign for plagioclase varies through the section, switching from biaxial positive to biaxial negative with no progressive sequence stratigraphically.

Microcline

Microcline is not as prevalent as plagioclase, and does not occur in the groundmass. When seen as a relic phenocryst, it is usually very assimilated and resorbed into the groundmass and is often replaced by quartz. Because of the alteration and resorption, the twinning typical of microcline is only seen in patches scattered through the phenocrysts.

Micas

Biotite

Biotite is found throughout the sequence in different concentrations, as is its alteration product, chlorite. Biotite, in thin section, occurs in large individual lathes scattered through the slide, or as swarms of tiny lathes which almost swamp the slide. The lathes usually have a distinct lineation to them, and form as stringers and curved trails, often around porphyroblast and phenocryst, or as filling in veins or fractures in the rock. Biotite commonly clusters into patches. As in the plagioclase twins, the individual biotite lathes will infrequently be tectonically bent. Also, while under uncrossed nicols they will display color gradations from brown to green to an almost translucent tan. When very chloritized, biotite looses much of its regular shape. The standard situation in these rocks is for most of the biotite to be partially altered in varying degrees to chlorite. There are few samples which contain either pure biotite or pure chlorite grains.

Biotite often associates with large crystals of hematite and magnetite, or as a minor associate of hornblende in the amphibolites.

Muscovite

The main occurrence of muscovite is as sericite, which will frequently flood a slide in association with plagioclase alteration. It occurs as large flakes very rarely, and never with more than a ten percent abundance. These large flakes form in stringers, or in veins and large patches associated with biotite and or epidote. Infrequently a brown stain will develop on the flakes, masking the interference colors.

Epidote

In the Ladron sequence epidote is a mineral with many forms and occurrences. Epidotization proceeds to such an extent in some cases that the phenocrysts or augens of plagioclase will completely be replaced by epidote, and in mineral modes will constitute 25 percent of several tectonized samples. The most common form of epidote is as a coloform aggregate collecting in large patches throughout the slide. It is associated with magnetite, biotite and muscovite, and is common in tectonized areas.

<u>Opaques</u>

Magnetite

Euhedral to anhedral grains of magnetite occur consistently in the Ladron metavolcanics. The grains form stringers, trails or patches, and are often very fractured. Magnetite occurs as a fine, dusty particulate pervasive through the slide. There is a faint indication of a bimodal size distribution between large and small subhedral grains. The large crystal forms will infrequently have rims of illmenite or occur with thin lathes of exsolved illmenite.

Hematite

Hematite is often in close association with magnetite and biotite. The subhedral crystals are a brilliant red, with some translucence, and can be traced gradationally into magnetite. Only one zoned crystal was observed.

Hornblende

Prismatic crystals of hornblende occur predominantly in the amphibolites. They display a microscopic lineation, and appear either as a translucent yellow with good cleavage traces, or as a brilliant yellow-green with more indistinct lines and a masked interference figure. Usually the crystal will appear sharp and complete, but on occassion will have an assimilitated and deteriorated look. The usual prismatic habit of hornblende will be deformed into lens by tectonic forces.

Calcite

Calcite is not observed frequently, but as mentioned earlier, is noticeable in the biotite schist for its complete replacement of large subhedral plagioclase grains. The alteration retains the twins of the plagioclase, resulting in a crystal with a combination of albite, pericline, and rhombohedral twins. Calcite also fills veins and forms very tiny crystals dessiminated through the groundmass.

Geochemistry

According to Rittman's classification of igneous rocks, and the chemical data of the Ladron metavolcanics determined through X-ray flourescence, the rocks range from a classification of rhyolite to dacite. The ridge east of the measured section contains most of the rhyolites, while the measured section is composed of quartz latites and dacites (Figure 4). Rittman's classification is in close agreement with plots calculated on the ternary An-Ab-Or normative diagram of Bowen & Tuttle (1958). The only exceptions are three quartz keratophyres, which Rittman labels rhyolites.

Alteration of the metavolcanics has created stratigraphic variations in geochemistry. The plots of concentrations versus stratigraphic height display several facts:

a) more siliceous rocks in the bottom one-third,
b) slight increase in Na_2O, MgO, and TiO_2 towards the top of the sequence,
c) slight tendency for zirconium to be in greater amounts in the less deformed middle section.

Stratigraphic variation in composition of the phenocrysts is quite noticeable in thin section (see stratigraphic column). No phenocrysts of plagioclase occur among the bottom metavolcanics, and very few are noticeable until traverse C. The first indication of complete, solid plagioclase lathes occurs below Ladron Peak. The Ab-An content is approximately consistent throughout the section, ranging from albite to oligoclase. The many quartz phenocrysts preserved in the bottom section all have a composite texture. The lenses and rectangles of primary quartz phenocrysts are not seen until later in the section. Microcline appears only in the lower and middle regions of the stratigraphic section. Occasionally, very assimilated phenocrysts appear after the first 400 meters of thickness. The amount of phenocrysts increase to less than three percent of the rock and then disappears beolow the peak. This amounts to a total thickness less than 600 meters.

The plots of various elements and modes against each other display certain useful trends. The most noticeable factor is the bimodal distribution between the basic and siliceous rocks.

Ternary diagrams such as A-M-F plots, K_2O-CaO-Na_2O plots, Ab-An-Or and Ab-Or-Q normative plots, when computed with values for New Mexico Precambrian metavolcanics, create fields which are similar to fields delineating Ladron metavolcanics. The Ladron samples often display more scattering, especially where potassium is concerned.

A Rb/Sr diagram plotted with Ladron data displays a field which falls within one of Condie's grid delineations (1967), which indicates a parental magma chamber occupying a depth between 20 and 30 kilometers. There are three samples which are exceptions to this, the two biotite schist, and the one very migmatized amphibolite, CLD10 (see Figure 9).

A plot of potassium against rubidium (K/Rb) displays a positive linear trend similar to plots by Payne and Shawn (1967). This trend falls between K/Rb lines equal to 100 and 1000. No stratigraphic progression is evinced, except that the bottom five samples are among the bottom half of the trend, as are the amphibolites (see Figure 10).

Origin and Metamorphism of Amphibolites

Chemical compositions and geochemical trends are often used as parameters for interpretation of the origin of amphibolites, especially when field relations are confusing. The mafic rocks sampled in the Ladron sequence contained four true amphibolites (CLD2, CLD9a, CLD48, LDER 3aa), one very migmatized amphibolite (CLD10) and two biotite schists (CLD17a, LDPK1da). When the data for these rocks are compared with data published in the literature, an igneous parentage for the Ladron amphibolites is suggested.

The dikes or sills of these mafic rocks are occassionally interlayered with the surrounding metavolcanics, often displaying lit-par-lit structures at their contacts (Figure 11). These borders are often sheared and fissile. Dikes show a definite, though small discordant relationship to the trend of the surrounding units.

Stratigraphically, there are several trends or progressions displayed by the geochemistry. In the amphibolites there is a decrease in SiO_2 and an increase in Fe_2O_3, FeO, and TiO_2 content grading from the exposed base to the top of the section (see Table 1&2). The Rb/Sr ratios range between .297 and .758, three out of these four are in the gabbroic range of .03 to .33. Compared to the surrounding porphyritic metavolcanics, the amphibolites are high in calcium, titanium, magnesium and iron, though the iron values are lower than published values for average basalts.

The chemical values for Ladron data corresponds with data published by several authors for definite and probable ortho-amphibolites (Engel and Engel, 1962, Elliot, 1962). Ladron values are anomalous in K_2O and Na_2O, which have been mobile throughout the section.

Plots comparing different chemical values for the Ladron mafics, both binary and ternary diagrams, tend to fall into fields delineated by standard basalt and gabbro values. Ternary $FeO-Al_2O_3-MgO/CaO$ plots are in close correlation with data by Edwards (1957), as are binary plots of either $Na_2O + K_2O$ or Al_2O_3/SiO_2 against $FeO + 1/2(MgO + CaO)$. The negative correlation of TiO_2 weight per-cent with Ni observed in mafic igneous rocks, is also observed in Ladron mafics (Leake, 1963). Making allowances for albitization and epidote metasomatism, the ternary diagram of CaO-Na_2O-K_2O and standard AMF plot used by Wilcox and Poldervarrt (1958) and others create basalt fields in agreement with Ladron amphibolites.

From the evidence recorded, it is proposed that the amphibolites are metamorphosed basalts or gabbros that were intruded as dikes and sills in the metavolcanic sequence. Several authors propose that metasomatism is a retrograde metamorphic process (Eckleman and Poldervarrt, 1957, Elliot, 1973).

Several stages are proposed in the change from a gabbro to an amphibolite, whether progressive or retrograde:

a) Introduction of H_2O into the system.
b) Albitization of the feldspars--introduction of sodium and release of calcium and aluminum.
c) These two elements combine with the pyroxenes, hypersthene and diopside, to create hornblende.

Further introduction of sodium turns the hornblende blue-green. A later stage of potassium metasomatism released the sodium from the hornblende matrix, forming biotite and epidote.

The few biotite schist found in the Ladron sequence were created in this manner. Ecklemann and Poldervarrt have documented a case in the Beartooths Mountains, where a biotite schist is formed by progressive potassium metamorphism of amphibolites. The rock compositions they record for their metasomatic products are in close agreement with Ladron data from CLD17a and LDER3aa. Sen, 1958, has documented a case where in direct contact with granite and pegmatitic veins, pyroxenes and amphiboles are completely converted to biotite, yielding a biotite schist.

The excess elements necessary for metasomatic flooding originated from either of the two adjacent granites, the Ladron quartz monzonite or the Caproite granite (see Condie's map).

Metamorphic Processes

Several features are present which indicate that the metasomatic processes of albitization, chloritization, seritization, and epidotization have altered the Ladron sequence. According to Ecklemann and Poldervarrt (1957) these features, and the presence of epidote and calcite in association with hornblende, are all linked to regressive mineral changes.

Below is a list of some of the processes which are believed to have occurred in the Ladrons:

Sericitization--alteration of alkali-rich silicates
    potassic feldspar---hydrolysis----> white mica (Hatch, Wells, Wells, 1973)
    potassium feldspar-------> muscovite and quartz (Orville, 1969)

Chloritization--alteration of biotite to chlorite, releasing magnetite.
    alteration of mica and amphibole-------> penninite
    anorthite-----> augite and hornblende
    anorthite-----> associated with chlorite

Epidotization
    colored silicates and plagioclase---dynamothermal metamorphism----> epidote
    hornblende----> Na^{+} + biotite + epidote

The bottom portion of the Ladron section demonstrates a large influx of silica. The plagioclase phenocrysts are altered in part to quartz, the rock silica content is the highest determined, and the only discordant quartz veins seen in the section occur here. The SiO_2 is presumed to have come from the emplacement of Ladron quartz monzonite.

This influx of silica has destroyed any indication of soda-metasomatism. All the plagioclase phenocrysts have a high sodium content. The Ladron samples drift away from normal Precambrian fields and towards sodium and alkali corners on the CaO-K_2O-Na_2O and A-M-F diagrams. These two factors are presumably created and caused by albitization. Another clue is the creation of amphibolites from gabbros discussed earlier.

Many of the plagioclase grains, have tiny flakes of sericite. This is especially noticeable in rocks within a proximity to the Capiroite granite. Related to this local relationship is the increase in sericite towards the top of the section.

As mentioned earlier, chlorite can be seen in thin section slides, either grading into biotite, or, as in many instances, the entire biotite lathe will be slightly or greatly chloritized. There is a positive correlation between the amount of chlorite from biotite and the formation and abundance of magnetite.

Epidotization of the feldspars is more prevalent among samples in the top third of the section. Again there is a positive correlation with alteration and abundance. The more altered the phenocrysts, and the more of them in the rock which are altered and assimilated into the groundmass, the greater the abundance of epidote in the rock. The more epidotized samples have higher concentrations of CaO in the geochemical data.

Economics

Few minerals of economic importance occur in the metavolcanic sequence, and none in any quantities to make them economic, especially considering the difficulty of transportation over such rough terrain.

The Sierra Ladrones compose part of the Hanson mining district (Jones, 1904). Considerable prospecting has been carried out in this area since the 1900's searching for gold, silver, or lead, but the district never produced. In 1957 a uranophane deposit was mined at the Jeter mine, but this area is not associated with the metavolcanics under discussion.

There are several prospect pits noticeable in the metavolcanic sequence, associated with former hot springs, amphibolite-crystalline dikes, and fault areas in contact with either of the granites. None of these pits are more than seven meters wide or very deep. There is a small magnetite deposit concurrent with an amphibolite-pink crystalline metavolcanic dike. Minor associations of pyrite, limonite, azurite and malachite are observed in the more tectonically active areas.

The Ladrones are purportedly the location of several large "treasure troves" of silver and gold, buried in any one of the numerous saddles along the ridges or in one of the few caves in the area. These "deposits" are property of the Catholic church or of the many Spanish and Indian thieves which used the mountain as their lair, and have never been recovered.

CONCLUSION

It is my belief that the Precambrian sequence of metavolcanics in the Ladron Mountains is a remnant of a series of porphyritic flows and sills of rhyolitic to rhyodacitic composition. The sequence was later intruded by gabbroic dikes and sills. The unit was subjected to low grade metamorphism and intruded and surrounded by two Precambrian granites, the Capiroite granite and the Ladron quartz monzinite. During the emplacement of these two bodies, the metavolcanics were subjected to several stages of metasomatism through the introduction of mobile elements from the granites.

REFERENCES

Balashov, V. A., Kremenetskiy, A. A., Shvets, V. M., 1972, Geochemical criteria of the nature of Precambrian amphibolites. Geoch, Int., vol. 9, no. 6, pp. 918-930.

Barth, T. W., 1969, Feldspars. Wiley Interscience, New York.

Black, B., 1964, Geology of the northern and eastern parts of the Ladron Mountains, Socorro County, New Mex. Thesis, Univ. of New Mexico.

Chayes, F., 1956, Petrographic Modal Analysis. John Wiley and Sons, Inc., New York.

Condie, K., 1967, Geochemistry of the Precambrian rocks of the Ladron Mountains, Socorro County, New Mexico, in print.

Condie, K., 1967, Geologic Map 38, Geologic map of Precambrian rocks of the Ladron Mountains, Socorro County, New Mexico. in print.

Eckelman, F. D., Poldervaart, A., 1957, Geological evolution of the Beartooth Mountains, Montana and Wyoming, Bull. Geol. Soc. Am., vol. 68, pp.1225-1262.

Edwards, A. B., 1957, Amphibolites from the Broken Hill district. J. of Geol. Soc. Australia, vol. 5, pt. 1, pp. 1-32.

Elliot, R. B., 1973, Chemistry of gabbro/amphibolite transitions in S. Norway. Contr. Mineral. and Petrol., 38, pp. 71-79.

Engel, A. E., Engel, C. G., 1962, Progressive metamorphism of amphibolite, NW Adirondack Mountains, New York, pp. 37-82 in Engel, A. E., James, W. L., and Leonard, R. F., Editors, Petrologic studies: A volume in honor of A. F. Buddington: Geol. Soc. of Amer.

Engel, A. E., Engel, C. G., Havens, R. G., 1964, Mineralogy of amphibolites interlayers in the gneiss complex, NW Adirondack Mountains, New York. J. of Geol., vol. 72, no. 2, pp131-156.

Evans, B. W., Leake, B. E., 1960, Composition and origin of striped amphibolites of Connemara, Ireland, J. of Petrol., vol. 1, pt. 3, pp. 337-363.

Hatch, F. H., Wells, A. K., Wells, M. K., 1973, Petrology of the Igneous Rocks. Hafner Press, New York.

Heir, K. S., 1962, Possible origins of amphibolites in an area of high metamorphic grade. Norsk Geologisk Tidssknift, vol. 42, pp.157-165.

Kottlowski, F. E., 1965, Measuring Stratigraphic Section. Holt, Rinehart, and Wilson, New York.

Leake, B. E., 1964, Chemical distinction between ortho- and para-amphibolites, J. of Petrol., vol. 5, pt. 2, pp. 238-254.

Mackenzie, W. S., Zussman, J., 1974, The Feldspars, Proceedings of a NATO Advanced Study Institute. Manchester Univ. Press, New York.

Noble, F., 1950, Geology of Southern Ladron Mountains, Socorro County, New Mexico. Thesis, Univ. of New Mexico.

Orville, P. M., 1962, Alkali metasomatism and feldspars. Norsk Geol. Tidsskr., vol. 42, no. 2, Halvbind(feldspar vol.), pp. 283-316.

Orville, P. M., 1969, Model for metamorphic differentation origin of thin-layered amphibolites. Amer. Jour. of Science, vol. 267, Jan., pp. 64-86.

Payne, J., Shawn, D. M., 1967, K-Rb relations in the Blue Mountain nepheline synite. Earth Planet Sci. Letters, vol. 2, pp. 289-291.

Poldervaart, A., 1953, Metamorphism of basaltic rocks. Bull. Geol. Soc. of America, vol. 64, pp. 259-274.

Poldervaart, A., Wilcox, R. E., 1958, Metadolerite dike swarm in Bakersville-Roan Mountain area, N. Carolina, vol. 69, pp. 1323-1368.

Ramberg, H., 1952, Origin of Metamorphic and Metasomatic Rocks. Univ of Chicago Press, Chicago, Illinois.

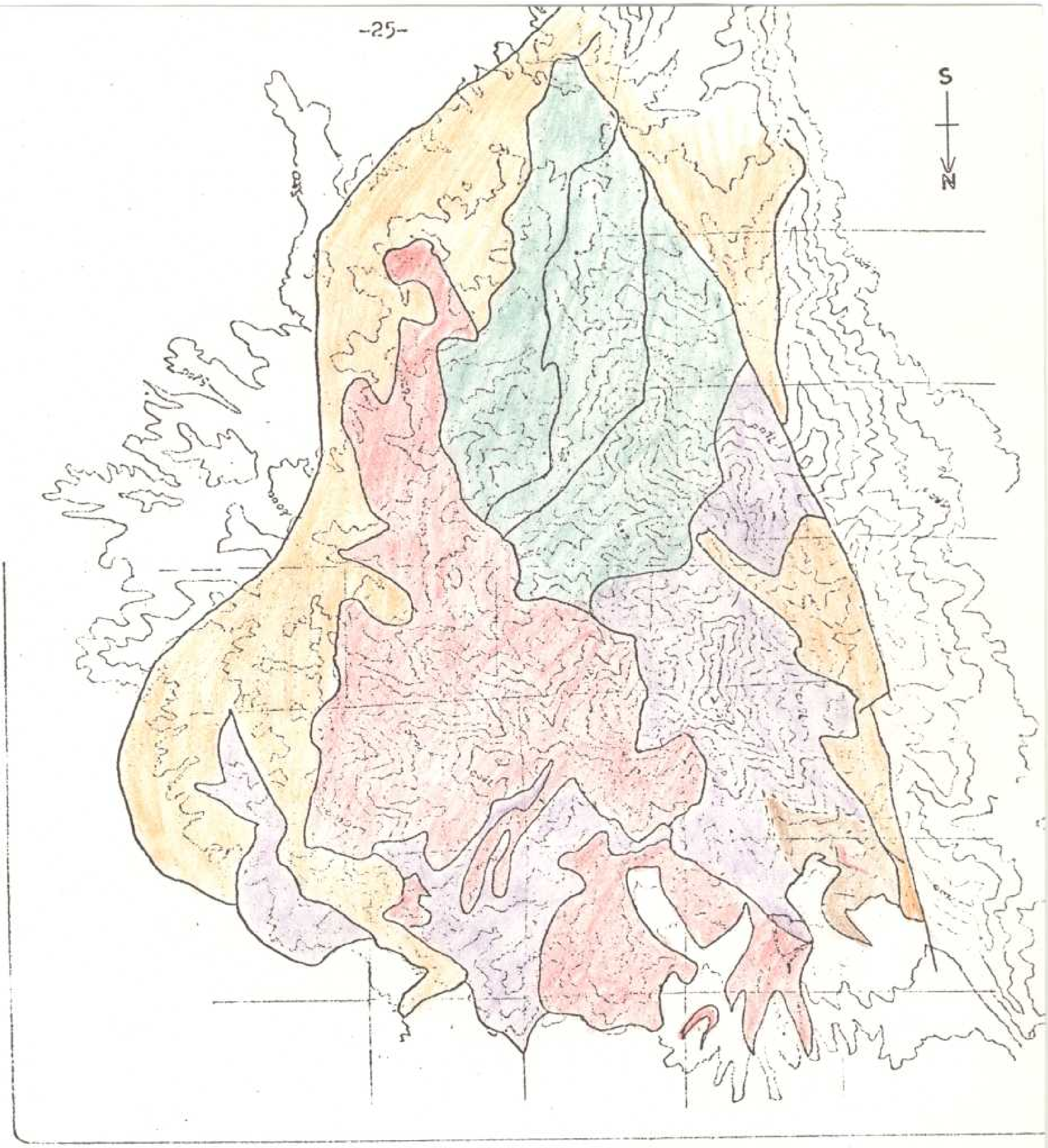
Rittman, A., 1973, Stable Mineral Assemblages of Igneous Rocks. Springer-Verlag, New York.

Sen, S., 1958, Mineralogenitic trends in the evolution of metamorphic rocks of granites of E Manbhum, India.

United States Geological Survey, 1958, Suggestions to Authors of the Reports of the United States Geological Survey, fifth ed., U. S. Geol. Printing Office, Washington.

van de Kamp, P. C., 1969, Origin of amphibolites in the Beartooth Mountains Wyoming and Montana: new data and interpretation. Geol. Soc. Amer. Bull., vol. 80, pp. 1127-1136.

Yoder, H. S., Tilley, C. E., 1962, Origin of basaltic magma: an experimental study of natural and synthetic rock systems. J. of Petrol., pt.3, pp. 342-532.

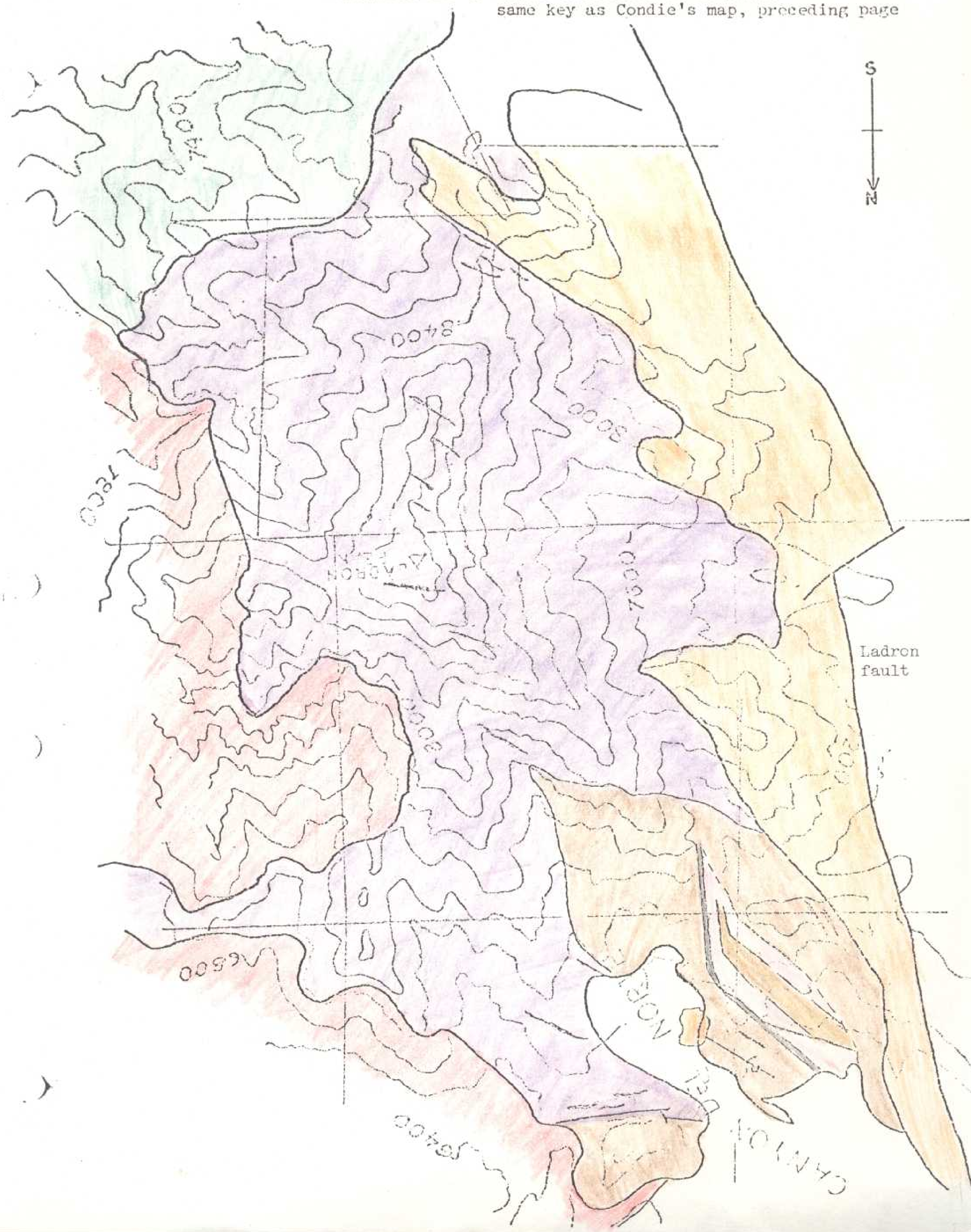


GEOLOGIC MAP OF THE LADRON MOUNTAINS from Condie (1967)
[Precambrian rocks only]

KEY -

	Porphyritic metavolcanics
	Quartzites, phyllites, and schist
	Capirote granite
	Ladron quartz monzonite
	amphibolite dikes

GEOLOGIC MAP OF LADRON METAVOLCANIC SEQUENCE
same key as Condie's map, preceding page



continued

Figure 1 - STRATIGRAPHIC COLUMN OF LADRON METAVOLCANICS
Key same as in Condie's map, page 25

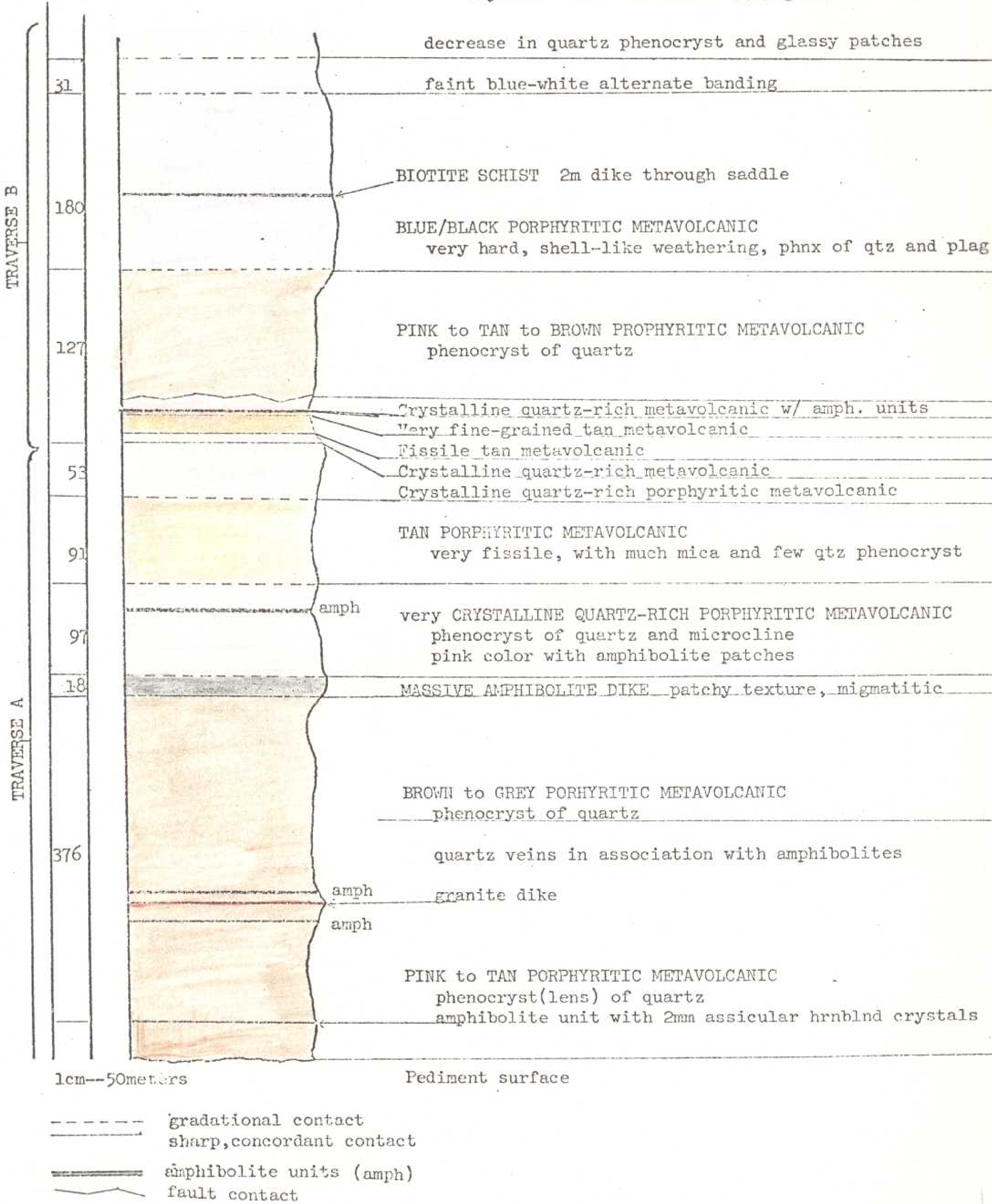


Figure 1 continued

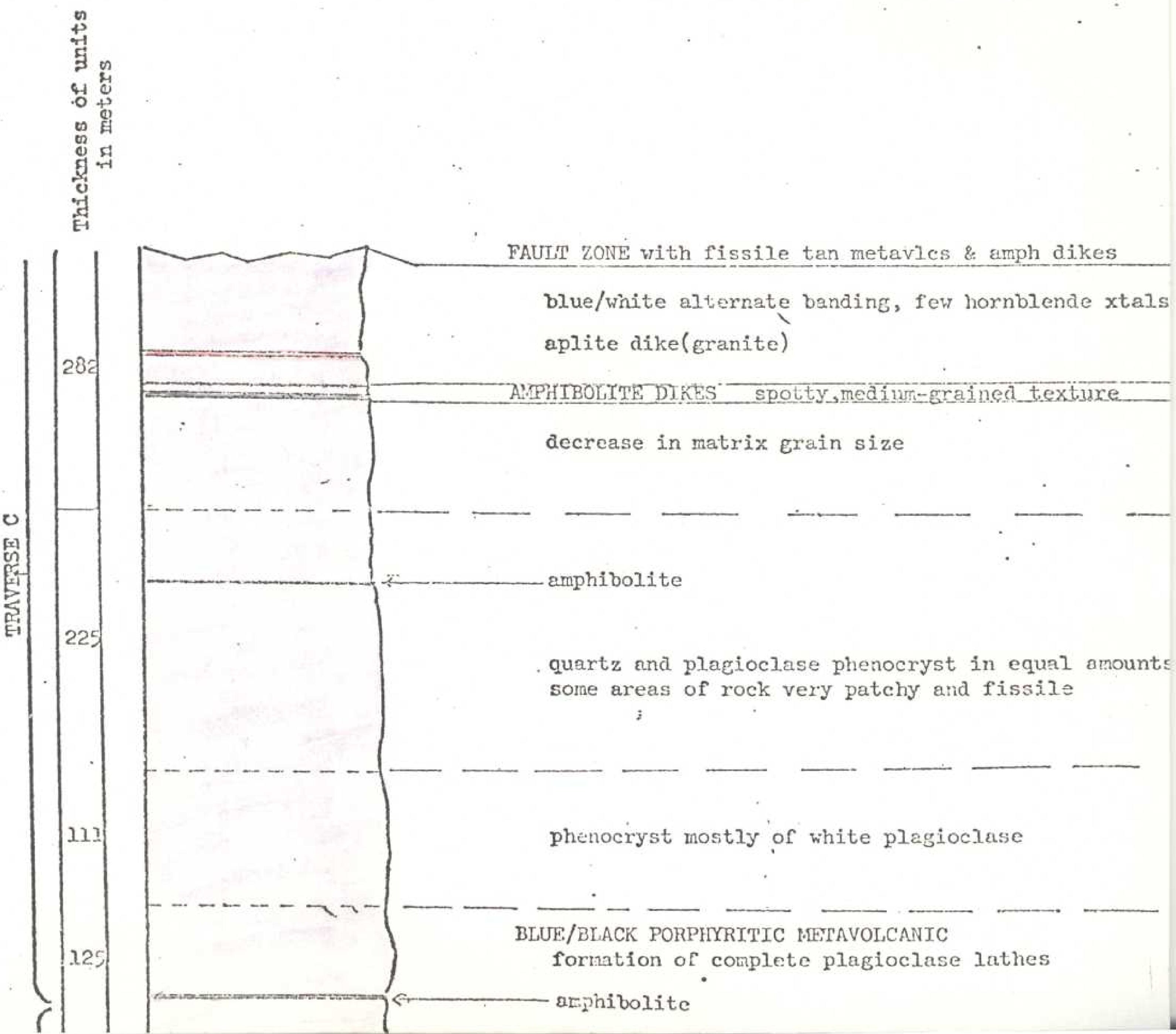


Figure 2 - SAMPLE LOCATIONS

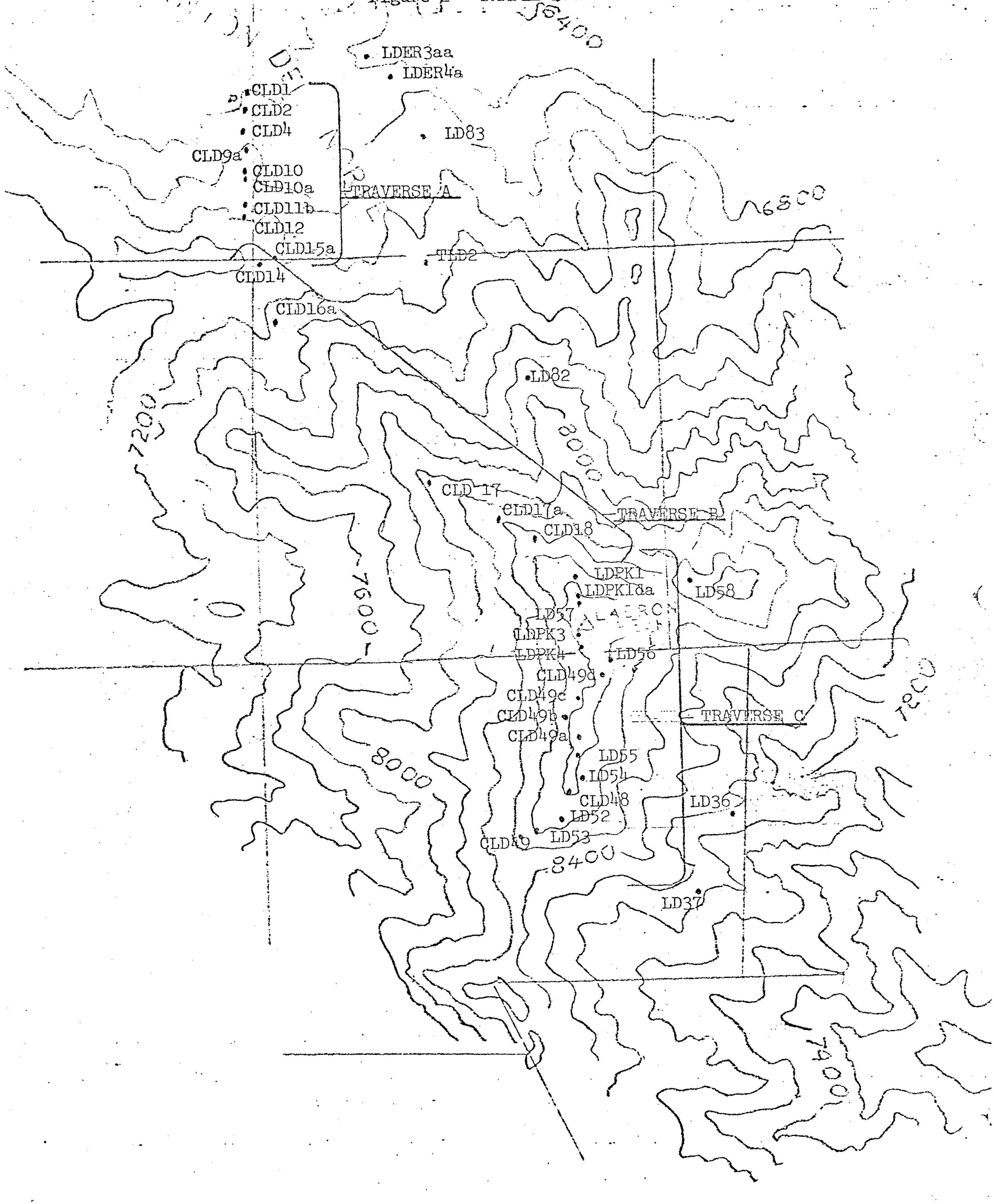


Figure 3 - GRADATIONAL STAGES IN THE ALTERATION OF PHENOCRYST

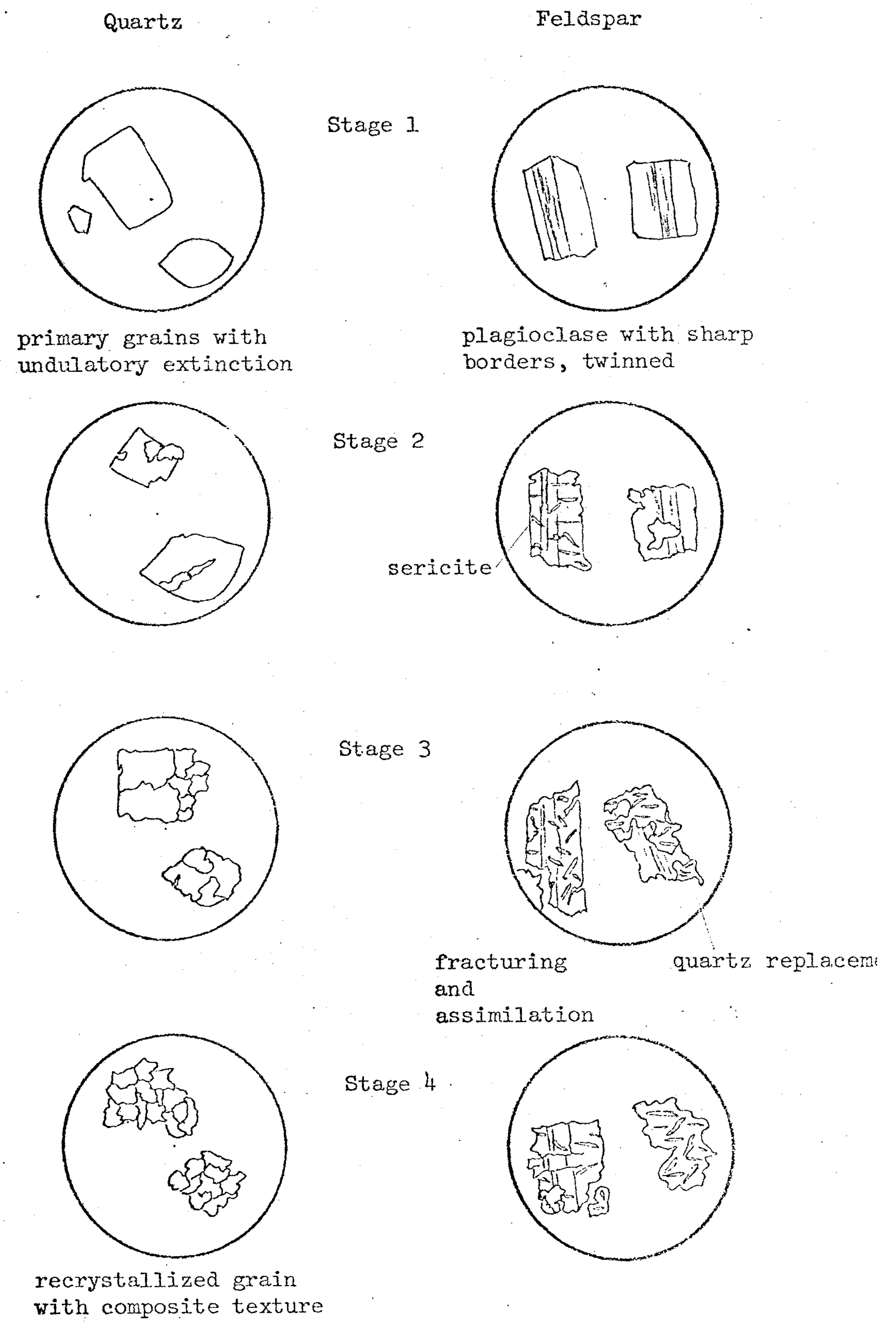


Table 1 - GEOCHEMICAL VALUES FOR PORPHYRITIC METAVOLCANICS

HEM	/LDER4a	LDER4ar	TLD2	CLD1	CLD4	UN4f	UN10q	CLD12	CLD16a	CLD49c	LD36	LD52	LD55	LD57	LD82	LD
iO_2	77.2	75.9	73.8	79.4	80.3	79.8	64.4	73.5	77.3	76.4	75.2	75.5	65.8	71.0	72.0	70
l_2O_3	12.0	11.6	11.2	11.0	10.6	11.8	11.7	14.0	10.9	11.7	13.4	12.8	15.6	12.0	12.0	14
e_2O_3	3.3	3.3	5.9	2.6	2.6	1.8	8.9	3.6	3.2	3.4	2.5	3.0	5.4	6.5	5.7	3
iO_2	.30	2.19	.46	.24	.25	.16	.08	.30	.33	.34	.34	.35	.67	.62	.47	
gO	.10	.10	.83	.16	.10	.10	.10	.10	.51	.23	.23	.35	1.07	1.04	.30	
aO	1.50	1.34	1.18	.99	.75	.69	.74	1.65	1.29	.76	.59	.80	2.73	2.54	.54	1
a_2O	4.10	3.54	2.69	2.73	3.60	3.29	3.09	3.92	2.99	2.13	5.28	4.23	6.18	1.35	1.55	6
$_2O$	1.00	1.65	3.49	2.48	1.41	1.91	3.91	2.46	2.98	4.47	2.00	2.49	2.03	4.11	6.59	
b	33.	41.	141.	84.	60.	52.	173.	97.	118.	32.	49.	102.	114.	141.	203.	37
r	175.	158.	90.	47.	26.	63.	61.	132.	50.	175.	64.	67.	221.	60.	44.	96
r	260.	271.	502.	249.	241.	145.	102.	350.	300.	412.	185.	192.	168.	512.	526.	192
eO	2.97	2.94	5.33	2.33	2.29	1.63	8.01	3.25	2.87	3.1	2.23	2.68	4.88	5.89	5.09	3
b/Sr	.19	.26	1.57	1.78	2.34	.83	2.84	.74	2.37	.19	.77	1.5	.52	2.4	4.6	
/Rb	254.	330	205.	244.	193.	304.	187.	210.	209.	1135.	339.	203.	148.	242.	270.	18
/Sr	47.	87.	323.	434.	454.	251.	533.	154.	496.	212.	259.	308.	76.	569.	1243.	7
$_2O/Na_2O$	.24	.47	1.29	.91	.39	.58	1.26	.63	1.0	2.1	.35	.59	.33	3.0	4.2	
eO/MgO	29.7	29.4	3.4	14.6	22.9	16.3	80.1	48.5	5.6	13.5	9.7	7.7	4.6	5.7	17.0	6
	8300	13695	28967	20584	11703	15853	32453	20418	24734	37101	16600	20668	16850	34110	54700	68
	20476	19358	12700	14924	13044	19986	20259	18217	15347	13900						

Table 2

GEOCHEMICAL VALUES FOR MAFIC METAVOLCANICS

ELEMENT	LDER3aa	CLD2	CLD9a	CLD48	CLD10	CLD17a	LDPK1da
SiO	48.4	47.3	47.3	46.8	65.2	54.1	54.6
Al O	14.9	12.9	15.0	11.5	14.7	12.6	13.9
Fe O	12.7	14.1	14.2	16.8	5.5	14.9	15.6
TiO	1.4	1.4	1.7	2.0	.5	1.6	1.6
MgO	6.2	8.9	7.1	8.5	2.9	4.2	3.3
CaO	9.0	9.5	9.7	7.3	6.7	3.6	4.4
Na O	4.6	1.8	2.1	3.0	3.4	3.6	.7
K O	.8	2.2	.8	2.1	.6	4.8	5.5
Ni	46.8	72.1	62.1	52.4		15.7	11.6
Rb	55.	119.	76.	59.	208.	218.	274.
Sr	146.	157.	256.	181.	188.	110.	50.
Zr	141.	154.	107.	198.	166.	160.	154.
FeO	11.4	12.7	12.8	15.2	5.0	13.4	14.0
Rb/Sr	.38	.76	.30	.33	1.11	1.99	5.55
K/Rb	115.	150.	85.	294.	23.	183.	165.
K/Sr	43.	114.	25.	96.	25.	365.	919.
K O/Na O	.17	1.2	.37	.70	.17	1.3	8.0
FeO/MgO	1.9	1.4	1.8	1.7	1.7	3.2	4.3
K	6308	17845	6474	17430	4731	40006	45484
Na	28145	13044	10186	19108	20024	18082	2773

Table 3 - NORMATIVE VALUES FOR GEOCHEMICAL DATA

SAMP. NO	SIO2	AL2O3	FEO	MGO	NA2O	K2O	CAO
.DER4A	80.50052	12.51303	0.0	0.10428	4.27529	1.00000	1.56413
.LD1	81.42757	11.28089	0.77941	0.16409	2.78946	2.48000	1.01528
.LD4	81.50609	10.75040	1.79478	0.10151	3.65453	1.41000	0.76136
IN4F	81.03421	11.93739	0.94809	0.10151	3.33963	1.91000	0.70041
IN10Q	75.73479	13.81274	1.22832	0.11766	3.63555	3.91000	0.87065
.LD12	76.82176	14.67852	0.0	0.10455	4.09828	2.46000	1.72504
.LD16A	78.76616	11.10387	2.21466	0.51954	3.04592	2.98000	1.31413
.LD49C	77.87407	11.94456	2.44598	0.23441	2.17061	4.47000	0.77456
.D36	77.76628	13.85729	0.0	0.23785	5.46019	2.00000	0.61013
.D52	76.91997	13.04073	2.02131	0.35658	4.30956	2.49000	0.81505
.D55	67.90648	16.09940	3.59966	1.10425	6.37784	2.03000	2.81740
.D57	73.81227	12.47531	4.31438	1.08119	1.40347	4.11000	2.64061
.D83	74.07410	15.27517	0.51266	0.58590	7.19816	0.82000	1.49613
R3AA	50.10353	15.42444	13.17806	6.39752	4.79296	0.76000	9.31677
.LD2	52.06386	14.24326	9.19098	9.78536	1.92625	2.15000	10.42378
.LD9A	54.16794	17.13638	6.08760	8.16182	2.43824	0.78000	11.11518
.LD17A	58.50410	13.67403	10.22091	4.56522	3.91614	4.82000	3.90532
KIDA	58.87369	14.99094	11.18762	3.51839	0.73390	5.48000	4.78113
.LD48	53.64760	13.18263	9.24618	9.74368	3.40456	2.10000	8.36810

** MESONORM **

SAMP. NO	AN	AB	BI	OR	Q	C	AB RAT	AN RAT	OR RAT
.DER4A	7.75984	36.17781	0.34423	5.66981	48.45164	1.55384	0.72928	0.15642	0.11429
.LD1	5.03694	23.60461	2.32757	13.27213	53.53346	2.16190	0.56317	0.12017	0.31665
.LD4	3.77720	30.92490	4.44758	5.78148	53.21930	1.82814	0.76389	0.09330	0.14281
IN4F	3.47481	28.26019	2.50750	9.82975	52.79614	3.10278	0.67991	0.08360	0.23649
IN10Q	4.31941	30.76433	3.20291	21.25023	37.75574	2.01705	0.54611	0.07667	0.37722
.LD12	8.55814	34.67992	0.34513	14.29743	39.86974	2.13770	0.60276	0.14875	0.24850
.LD16A	6.51955	25.77484	6.78965	13.55565	46.82607	0.47846	0.56216	0.14219	0.29565
.LD49C	3.84270	18.36957	6.37842	22.71861	46.47801	2.12700	0.40884	0.08552	0.50563
.D36	3.02695	46.20451	0.78518	11.27219	37.04184	1.60098	0.76366	0.05003	0.18631
.D52	4.04354	36.46779	5.80867	11.28453	40.57425	1.77435	0.70407	0.07807	0.21787
.D55	13.97746	53.96979	11.89341	4.80733	16.99902	-1.71203	0.74181	0.19212	0.06608
.D57	13.10039	11.87630	13.45495	16.22975	44.25874	0.91703	0.28821	0.31792	0.39386
.D83	7.42249	60.91139	3.10883	2.83573	25.85741	-0.17382	0.85586	0.10429	0.03984
R3AA	46.22168	40.55841	51.31479	-27.24780	-0.65205	-10.22179	0.68128	0.77641	-0.45770
.LD2	51.71368	16.30009	53.36288	-21.68054	10.29163	-10.20427	0.35180	1.11612	-0.46793
.LD9A	55.14381	20.63260	40.89236	-22.03333	13.17928	-7.92759	0.38391	1.02606	-0.40997
.LD17A	19.37477	33.13867	38.49025	4.78095	8.90663	-5.08559	0.57839	0.33816	0.08345
KIDA	23.71976	6.21030	37.24953	9.84198	23.38449	-0.84043	0.15615	0.59639	0.24746
.LD48	41.51521	28.80965	53.35179	-21.95142	7.87270	-9.90520	0.59557	[illegible]	[illegible]

Figure 4 - RITTMAN'S CLASSIFICATION

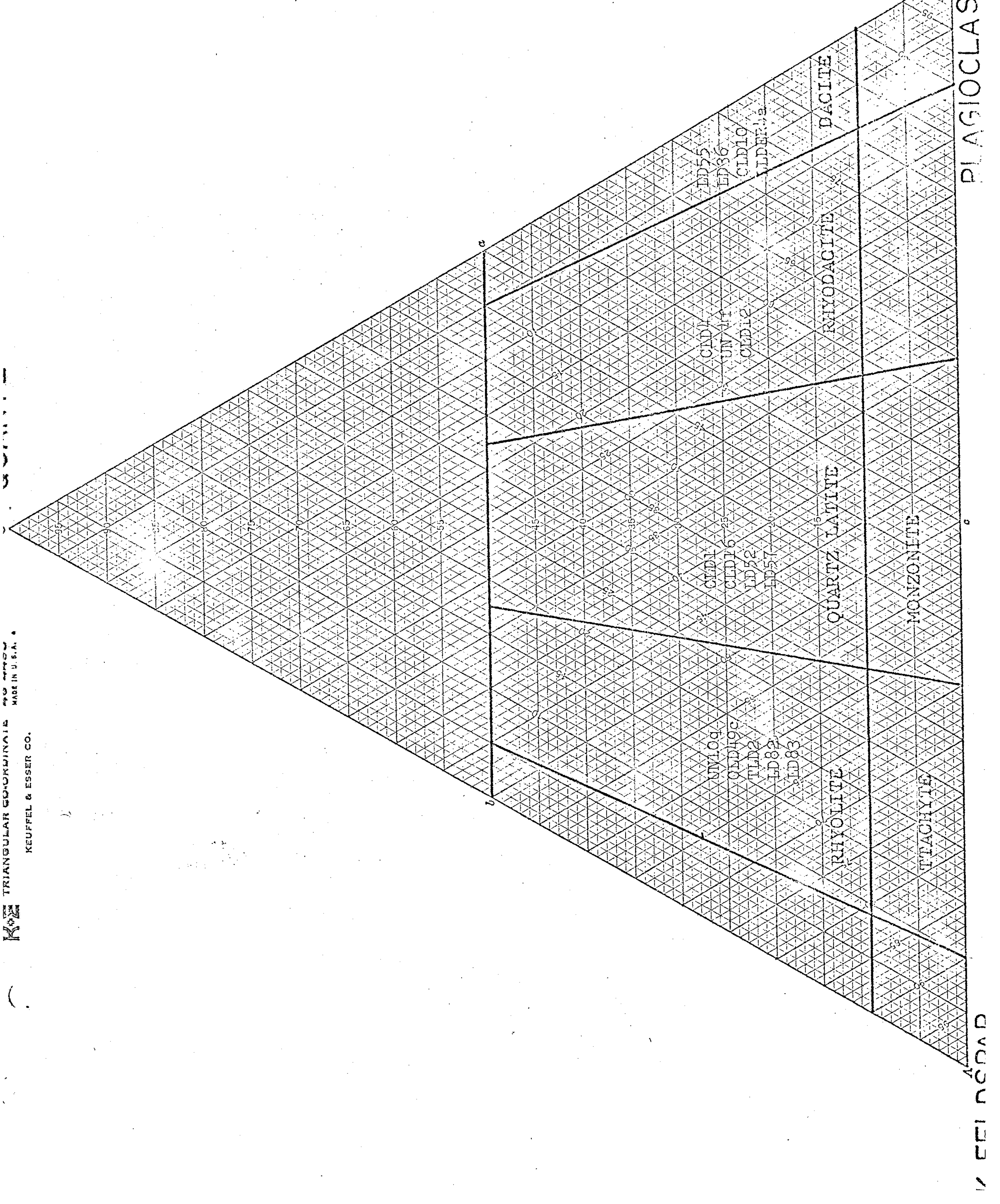


Figure 5 - NORMATIVE PLOT - AB - AN - OR
after Bowen and Tuttle (1958)

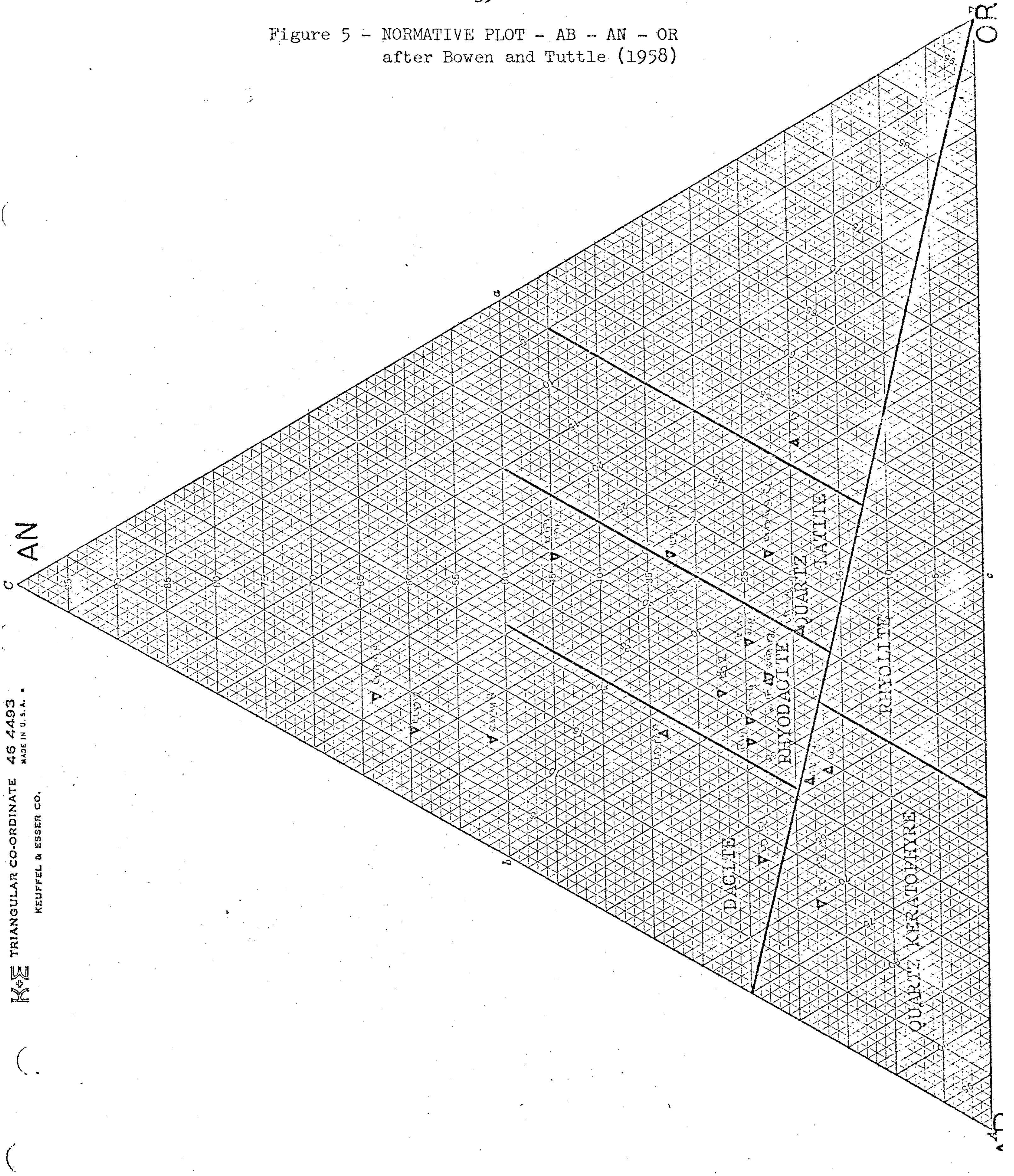


Figure 6 -
Geochemistry - A M F plot

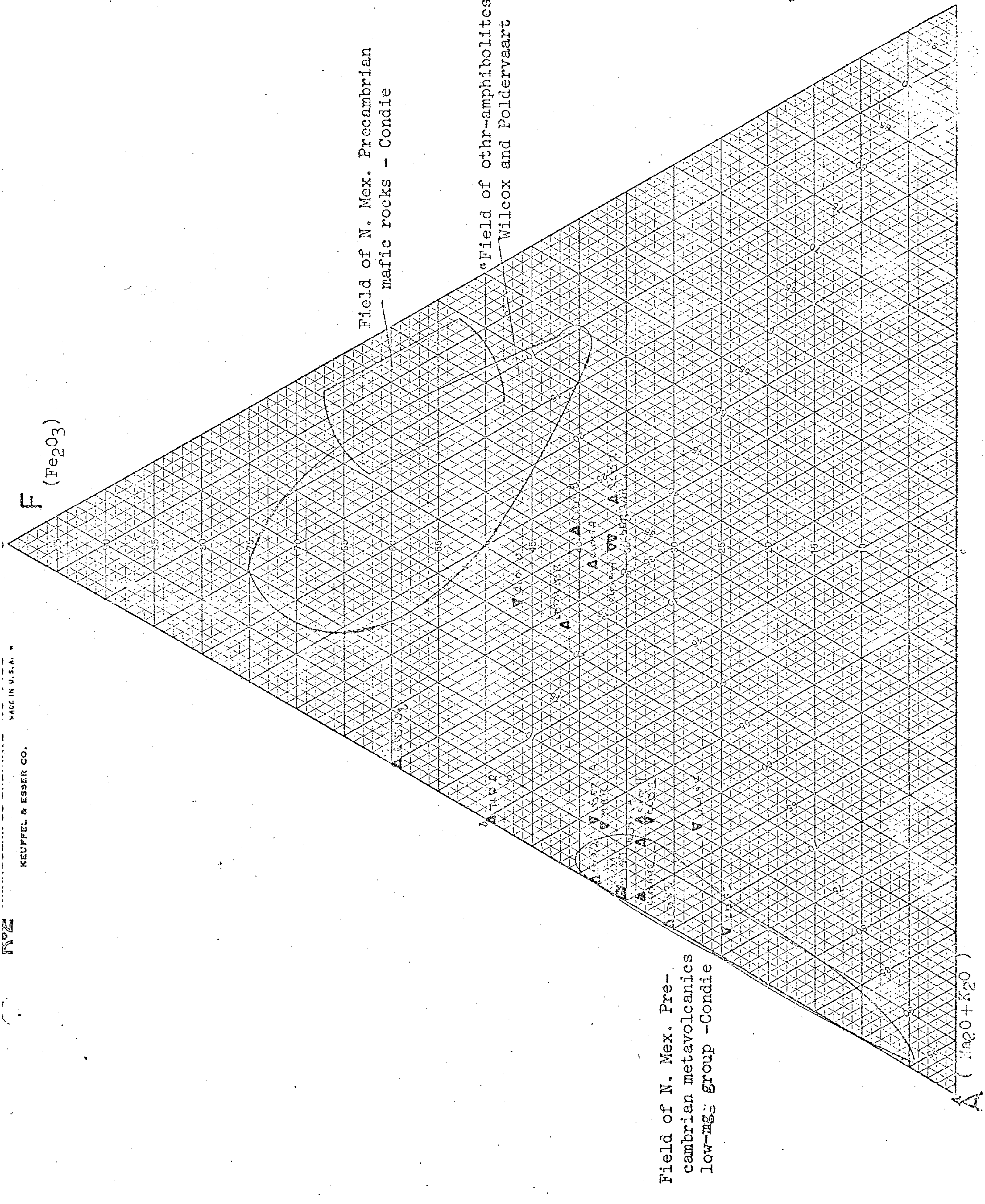


Figure 7 - Geochemical plot - CaO - Na_2O - K_2O

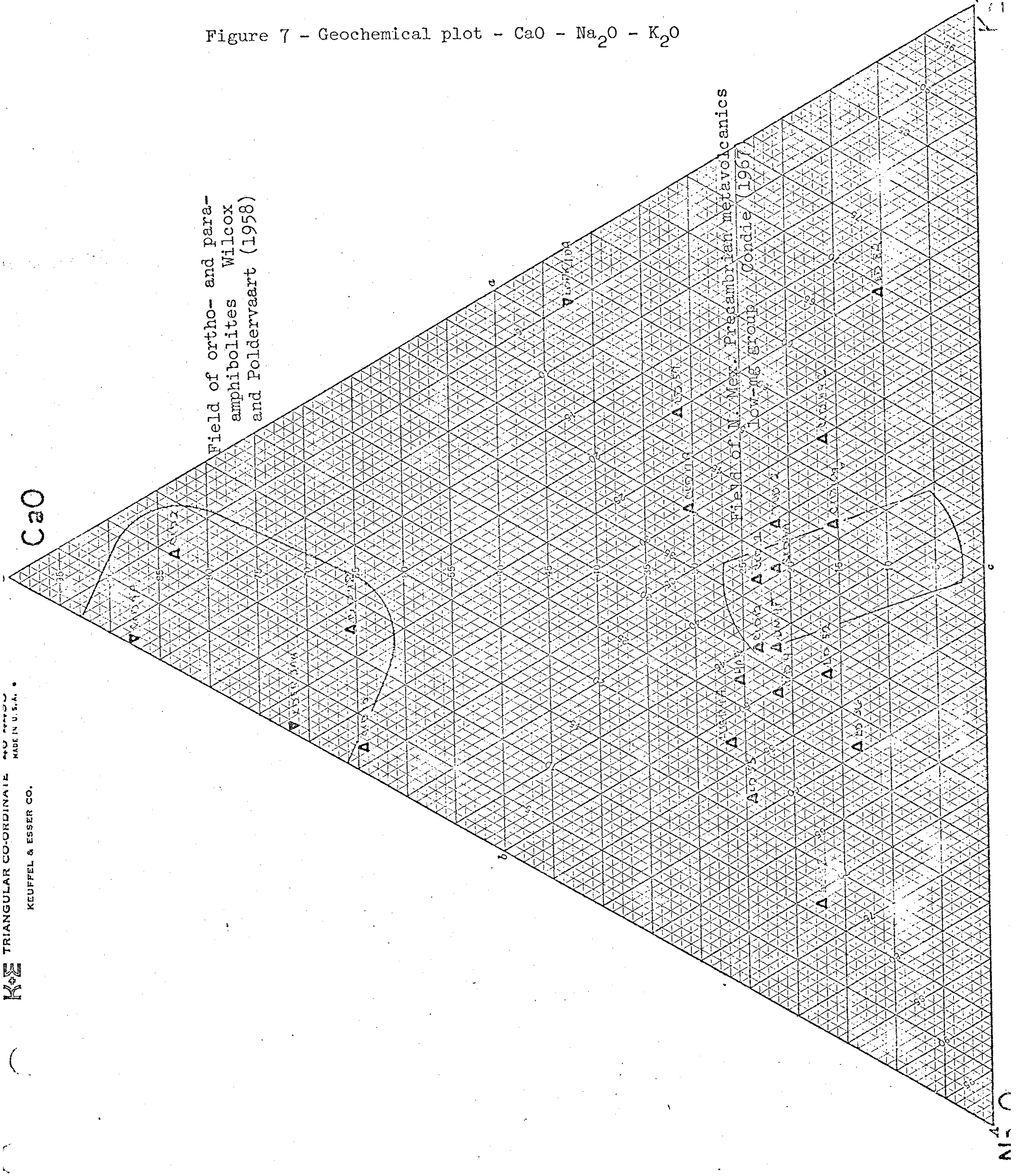


Figure 8 - NORMATIVE PLOT, OR - AB - Q

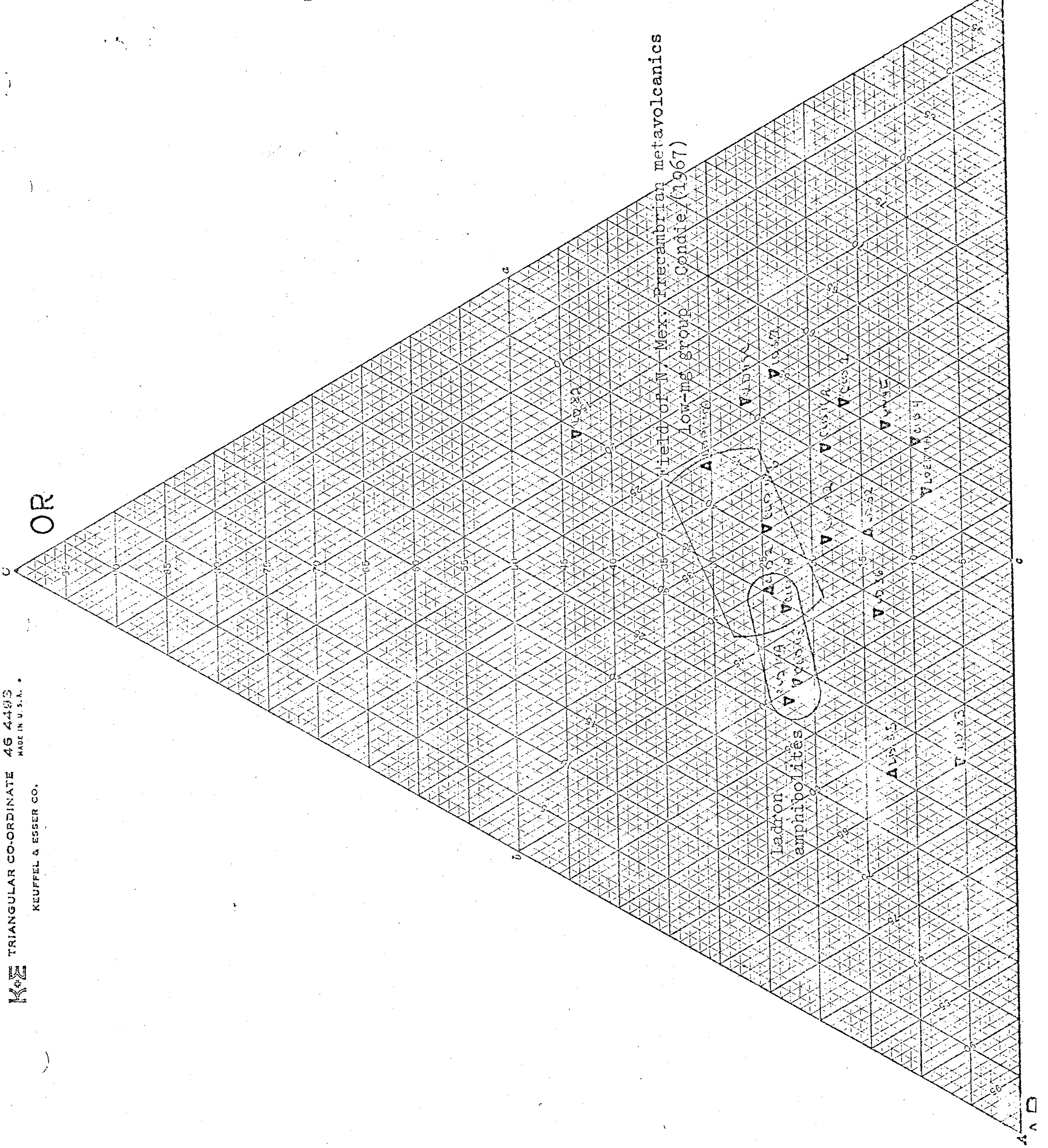


Figure 9 - Geochemistry plots - Rb / Sr in ppm
From Condie (1967)

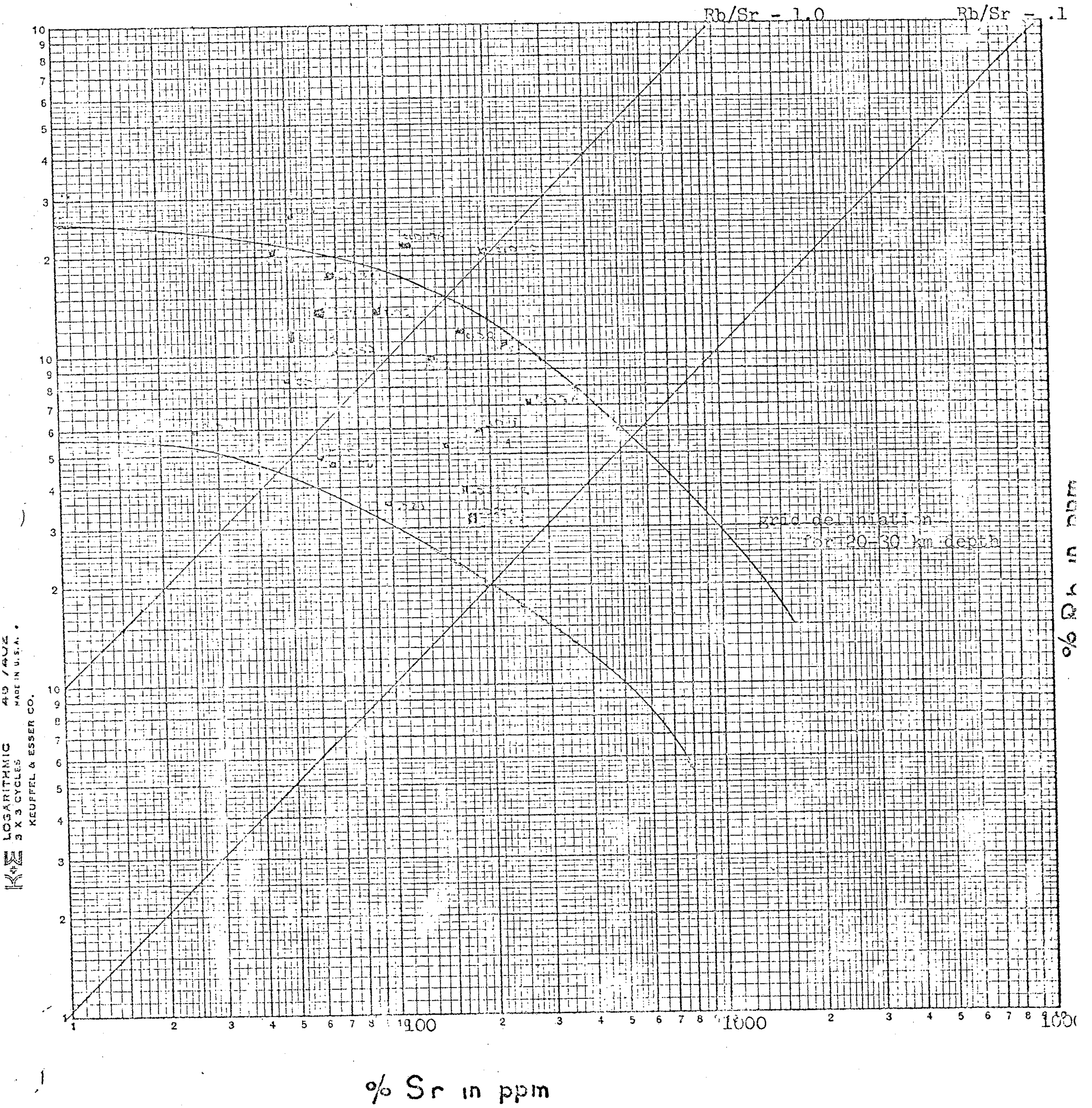
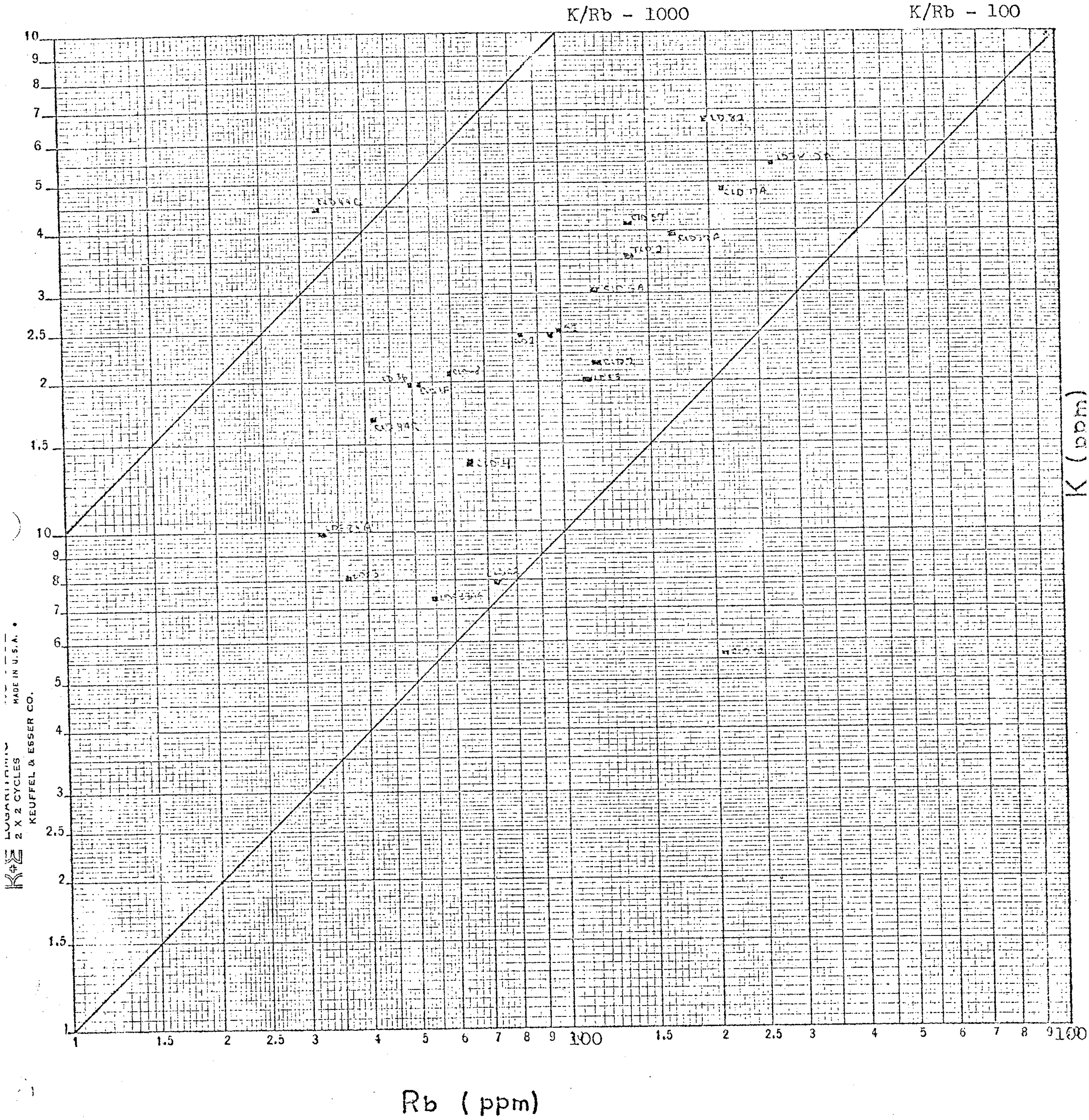


Figure 10
Geochemistry plot - K / Rb in ppm
from Payne and Shawn (1967)



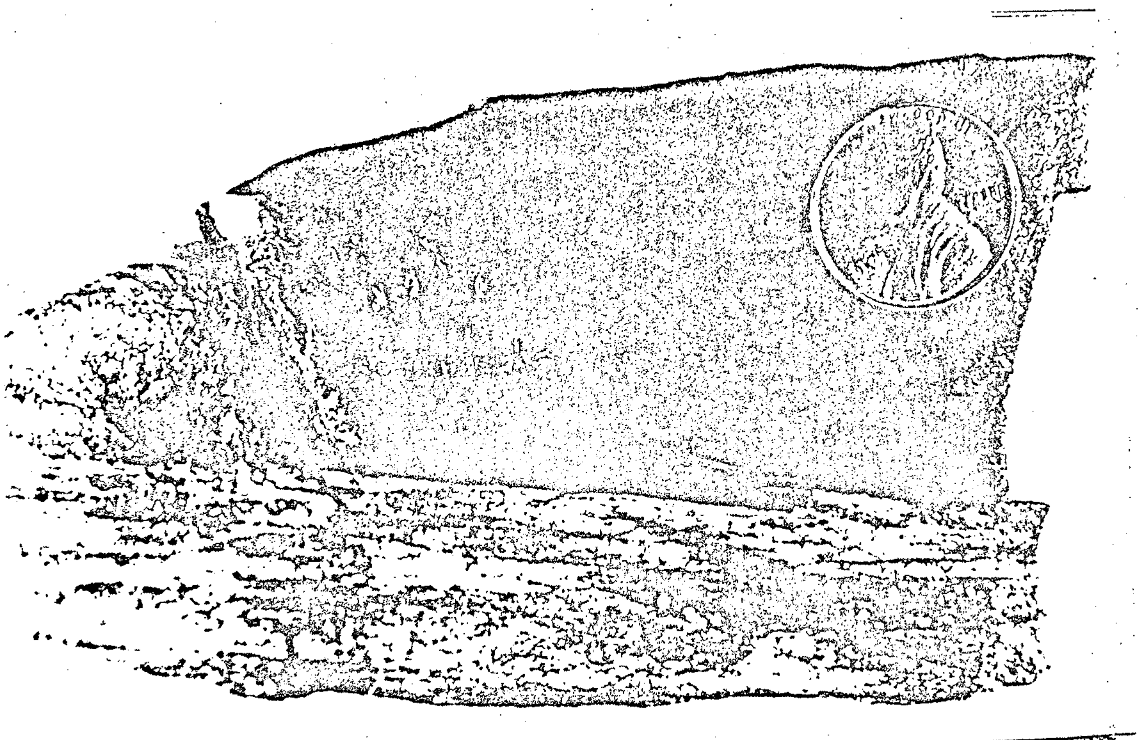


Figure 11a - Banding in contact zone of amphibolites and meta-volcanics- layers consist of amphibolite and plagioclase-rich quartz bands. Similar to Evans and Leake's (1960) striped amphibolites of Connemara, Ireland.

Figure 11b - Lit-par-lit contacts of amphibolite and metavolcanics - amphibolite is very sheared and fissile, parallel to lineations in porphyritic meta-volcanic

Figure 12 - GEOCHEMICAL PLOT, amphibolites
Al_2O_3 - FeO - MgO + CaO
Edwards (1957)

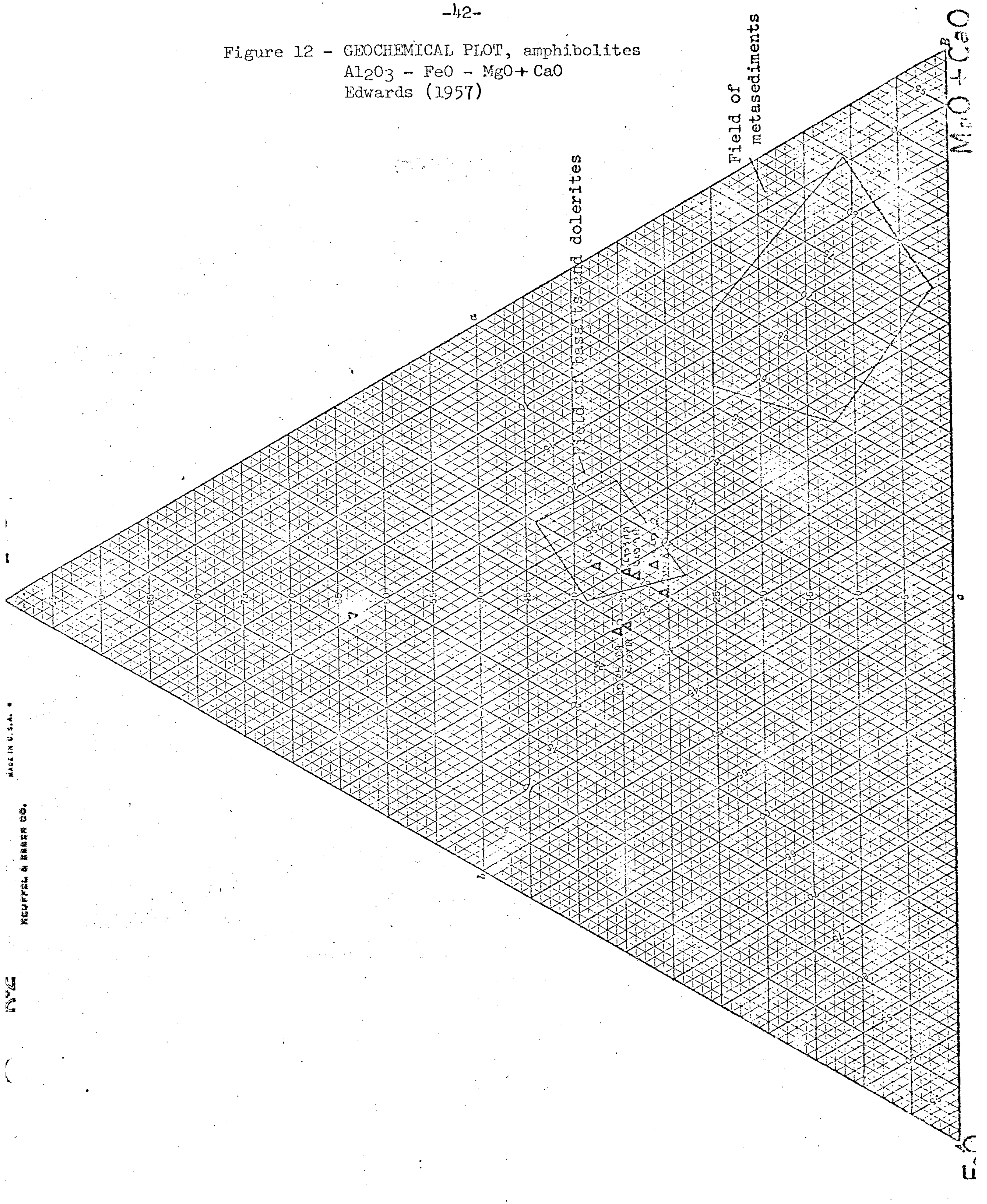


Figure 13 - GEOCHEMICAL PLOTS - $Fe_2O_3 + 1/2(MgO + CaO)$ - Na_2O K_2O
- $Fe_2O_3 + 1/2(MgO + CaO)$ - Al_2O_3/SiO_2

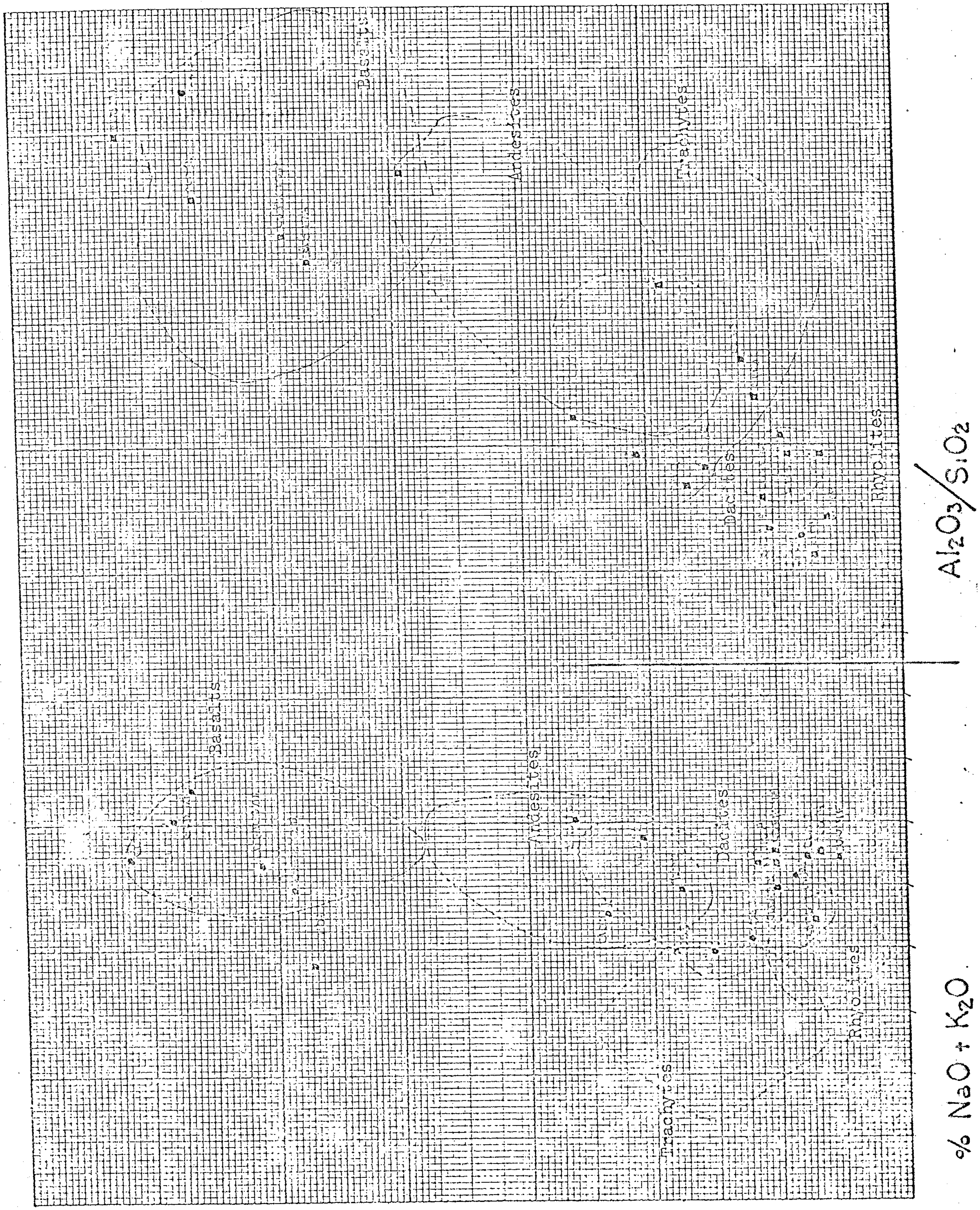


Figure 14 - GEOCHEMICAL PLOTS, amphibolites
Ni (in ppm) - TiO_2 wt percent
from Leake(1963)