THE GEOLOGY OF A PORTION OF THE RAND MOUNTAINS, CALIFORNIA

Thesis by

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* INTRODUCTION *

The Rand Mountains form a small desert range lying about 150 miles northeast of Los Angeles, and 40 miles east of Mojave, California. The town of Randsburg, in the northeast part of the range, has been the center of considerable mining activity for the past 40 years. Approximately 40 million dollars in gold and silver have been taken from the mines of the district, chiefly from the famous Yellow Aster and California Rand mines. Despite the mining activities, however, practically no geologic work had been done in this district prior to 1924. In 1909, Hess (1)[1] made a brief reconnaissance of the Randsburg district in which he noted the types of rocks in the Rand Mountains, their general structure, and the nature of the ore deposits. Hess' work remained the only significant study until 1924, when Hulin (2), under the direction of the California State Mining Bureau, made a detailed study of the entire Randsburg quadrangle, defining and mapping the formations, and studying the ore deposition in all the important mines of the quadrangle. It seemed to the writer, however, that the unusual rocks of the Rand Mountains merited a more detailed petrographic study than Hulin was able to make, and considerable time was spent during the spring of 1935 in a field and laboratory study of them.

The Randsburg quadrangle lies between 117°30′ and 117°45′ east longitude, and 35°15′ and 35°30′ north latitude. It was surveyed in 1900 by the U. S. Geological Survey on a scale of 1/62500 with a

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[1] notes in brackets ( ) refer to the bibliography on page 2. otherwise, notes are given on the same page, according to the customary method.

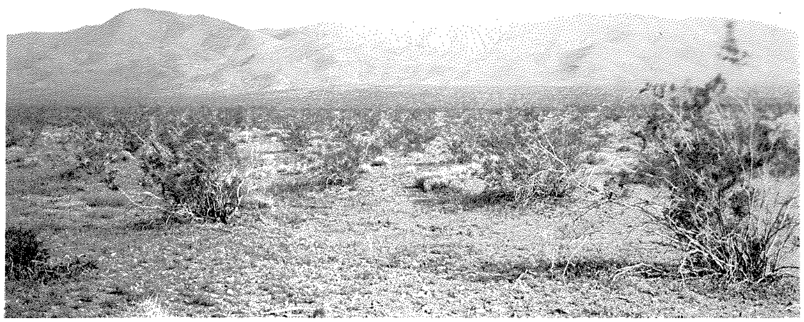

Fig. 1: The Rand Mountains from the north.

contour interval of 50 feet.[1] The Rand Mountains extend from near the center of the map southwest towards the western border. As a typical section for study, the writer chose a narrow area of about 5 square miles in the immediate vicinity of Randsburg.

Topography and Relief:

The Rand Mountains reach their highest elevation at Government Peak (4755') near Randsburg. To the northeast they merge into a group of hills, and to the southwest they gradually die out in the flat desert floor off the edge of the quadrangle. Thruout its entire length, the range is characterized by an abrupt northwest face and a gently sloping southeast face. From Government Peak northwest, an elevation of 3500' is reached in a horizontal distance of 1 mile, while southeast the same elevation is only reached in 3 miles. Under the desert conditions which prevail, this gives rise to extremely precipitous canyons in the northwest drainage and more gentle slopes to the south.

The climate is very arid, and water is brought in to Randsburg by pipe from Mountain Wells, a distance of 6 miles to the east. Winter rains are infrequent, but are usually torrential when they do occur. These floods give northern slopes which are almost free of debris and on which exposures are as numerous and as fresh as could be desired. The southern slopes have a deeper coating of detritus and much fewer exposures of fresh rock.

* BIBLIOGRAPHY *

1. C. D. Hulin---Geology and Ore Deposits of The Randsburg Quadrangle, Calif. State Min. Bur., Bull. 95, 1925.

2. F. L. Hess----Gold Mining in The Randsburg Quadrangle, California, U.S.G.S. Bull. 430, 1910.

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[1] A small area in the vicinity of Randsburg has also been photographically mapped by Fairchild Aerial Surveys, Inc., of Los Angeles.

Fig. 2: Outcrops of schist in the Rand Mountains.

* GEOLOGY *

General Outline:

Igneous, metamorphic, and sedimentary rocks outcrop in the area studied in considerable variety. The metamorphic rocks, believed to be Archean in age, cover about nine-tenths of the area, and represent schists derived from both igneous and sedimentary sources. The igneous rocks include a small plutonic mass and numerous dikes, pipes, and small plugs of volcanic rocks. The sedimentary rocks, which cover only a minute fraction of the area, are believed to be of Quaternary age.

Petrology:

* Rand Schist *

The Rand schists cover a large part of the Rand Mountains, and it was primarily to study them that this work was undertaken by the writer. The schists are divisible at once into three types: mica schists, amphibole schists, and greenstone schist. There are, in addition, many transitional schists, and many unusual types which only occur at a few localities and never over large areas.

1. Mica Schists: (plate I A,B; plate II A)

Over most of the area the predominant rock is a mica schist. This rock has a very highly developed schistosity and contains a high percentage of mica. When fresh, the color is a silvery grey, but oxidation during weathering has often changed the silvery sheen to a golden brown. Microscopically, the micas are seen to be much less important than would appear from the hand specimen. Quartz and albite are the most abundant constituents, either in ovoid grains or drawn out into long stringers parallel to the schistosity. The albite grains are almost always clouded by a multitude of small inclusions--quartz, orthoclase, biotite, graphite, needles of actinolite, short prisms of apatite, and occasionally small grains of the epidote group. Graphite is especially common, the albite grains being often rendered completely opaque by the quantity of included graphite. Twinning of the albite is rare. Orthoclase is much less common than albite, but occasionally becomes the chief constituent, having much the same appearance as albite.

Quartz occurs in much the same way as albite, but usually it is readily distinguishable by its freedom from inclusions and its wavy extinction.

The micas, both muscovite and biotite, are next in importance, forming long streamers which wrap around grains of the other constituents. The biotite is normally dark brown and highly pleochroic, but commonly it is more or less altered, either to a bleached variety, to a green, non-pleochroic variety, or completely changed to chlorite. A few long needles of actinolite oriented parallel to the schistosity often accompany the micas.

Zoisite, clino-zoisite, and epidote occur in many of these schists, in some rarely, and in others very abundantly(plate II A). These minerals form clouded, anhedral or subhedral grains which under the microscope stand out in high relief against the surrounding minerals. They are easily distinguished from one another by their interference colors under crossed nicols, the zoisite showing an anomalous blue, the clino-zoisite a characteristic yellow-green, or occasionally a pink of a higher order, and the epidote its usual brilliant reds and greens.

Minor amounts of magnetite, leucoxene, calcite, and titanite are also present.

2. Amphibole Schists: (plate II B; plate III A)

Thruout the entire Rand series, but especially along the northern face of the Rand Mountains, green amphibole schists are very widespread. These green schists are surprisingly uniform, forming an enormous series all along the northwest face of the range with scarcely any variation. The average amphibole schist in this part of the range is rather fine grained, and has a highly developed schistosity. On a cleavage surface the rock has a soft silvery-green luster from the abundance of minute interlocking amphibole crystals, but weathering commonly stains the surface a reddish-brown color; viewed perpendicularly to the schistosity, the layers of amphibole are seen to wrap around numerous grains of feldspar or greenish epidote.

Microscopically, these schists are found to be much the same as the ordinary mica schists described above, with many grains of albite, fewer grains of quartz, and occasionally grains of the epidote group. In place of biotite or muscovite, however, the schistosity is imparted by layers of actinolite needles oriented with their long dimensions parallel to the schistosity. The actinolite occurs in dense aggregates of very small needles which are a light green in color and usually somewhat pleochroic in shades of green. Small traces of chlorite often accompany the actinolite. As in the case of the mica schists, the "augen" of albite and quartz serve as poikilitic hosts for many inclusions, such as graphite, actinolite needles, prisms of apatite, and small grains of epidote or zoisite. The members of the epidote group are sometimes very numerous, forming large rectangular masses or long, drawn-out crystals, often rendered almost opaque by inclusions. Leucoxene, calcite, and a few other minerals occur in minor amounts.

The above described amphibole schist covers a large area along the northwest side of the range, but shows very little variation from place to place and never attains much purity. Scattered thru the grey mica schists at various horizons, however, occur thin beds of practically pure actinolite schist. These schists form bright green beds that are never over a few feet in thickness. Ordinarily the actinolite needles are only a fraction of an inch in length and form felty layers oriented parallel to the schistosity, but occasionally they may be up to several inches in length. In the latter case the needles are arranged in radiating groups without any noticeable orientation. Several varietal and transitional types can be recognized:

a. Pure actinolite schist (Plate III-B).

b. Actinolite-talc schist: (plate IV-A)

Thin beds of greenish-white actinolite-talc schist are very commonly associated with the pure actinolite members. They consist simply of bright green, euhedral needles of actinolite set in a matrix of white or greenish talc. All transitions occur between pure actinolite schist and:

c. Talc schist:

Locally, actinolite may completely disappear, leaving thin beds of pure talc. This schist is white or greenish in color and shows a highly developed schistosity. Microscopically, the only constituent is found to be talc, except for an occasional needle of actinolite.

d. Actinolite-graphite schist:

An unusual variety of schist occurs northwest of the Yellow Aster mine. This rock is fine grained and completely black in the hand specimen, except that reflection from numerous minute crystal faces can be seen. Under the microscope, it is seen to consist of minute, interlocking, colorless actinolite needles, clouded by much graphite. No other important constituent is present. Although graphite is a very common mineral thruout the Rand series, this particular variety of schist was found at only one locality.

Hornblende Schists:

It is believed that some of the pleochroic actinolite in the actinolite-albite schists may be hornblende, or at least approach hornblende as the iron-rich ferrotremolite[1]; the small size of the amphibole needles in these schists, and the similarity in optical properties of these minerals makes the determination a difficult one. Aside from this possibility, true hornblende schists do occur in the Rand series at several localities, the most notable of which is the summit of the hill just northwest of the Yellow Aster mine (hill 3950). On the eastern slope of this hill, near the top, a thick bed of black hornblende schist is exposed as a massive, resistant ridge.

In the hand specimen, this rock is black or greenish black in color, and has a silky luster from the numerous hornblende crystals. Augen of albite are rather sparsely distributed between the layers of hornblende. The schistosity is not highly marked. Microscopically, this schist is composed largely of greenish hornblende crystals grouped together in thick masses which wrap around grains of quartz and albite. This hornblende forms rather broad platy crystals rather than minute slender needles as in the other amphibole schists. It is strongly pleochroic in shades of green or blue-green. Some chlorite accompanies the hornblende. Quartz and albite grains are fairly numerous and are usually clouded by included crystals of hornblende. Irregular masses of an unknown mineral, densely packed with small dark inclusions, are also fairly common. Magnetite and titanite complete the mineral assemblage.

3. Greenstone Schist:

At numerous places along the northwest face of the Rand Mountains, outcrops of massive greenstone occur, which show no apparent schistosity and have no relation to the surrounding schists. Their manner of occurrence as isolated masses 100 feet or so across, and the complete lack of schistosity suggests that they were originally igneous

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[1]name suggested for the iron-rich end of the tremolite-actinolite series by A. N. Winchell: Am. Min. XVII, 1932, p. 472.

pipes which have been metamorphosed along with the schists. They are often badly weathered rocks, but fresh specimens are bright green in color and very fine grained. Microscopically, they are composed dominantly of small green needles of hornblende (ferrotremolite?) and small grains of albite. Epidote is also a very abundant constituent. The hornblende needles are oriented in all directions, with no suggestion of parallelism. No relic structure can be seen.

* Other Schists *

Quartz Schists: (plate V-B)

Beds of quartzite are found thruout the Rand series, in thicknesses ranging from a few inches to perhaps 50 feet. The color usually varies between white and reddish, depending on the purity. A relic texture of rounded grains can sometimes be seen with a hand lens, but in other cases may be completely lacking. Besides quartz, the only important constituent is biotite which forms thin layers parallel to the schistosity and imparts to the rock a coarse banded appearance.

Quartz-Albite Schist: (plate VI-A,B)

A very unusual schist is exposed at several outcrops on hill 3950, northwest of the Yellow Aster mine. This rock is composed of a light green matrix of quartz and a soft greenish mineral in which are imbedded numerous elongate laths of feldspar having no noticeable orientation. Microscopically the appearance is very striking. The groundmass is seen to consist of a peculiar aggregate of quartz grains which are drawn out in the direction of schistosity. A few imperfect needles of actinolite are usually scattered thru the quartz. In this matrix, are set large, elongate metacrysts of albite which are oriented in all directions and commonly push aside the schistose elements of the groundmass. The albite metacrysts have suffered considerable alteration on their borders; this is shown by their rounded outlines, zoned ex-

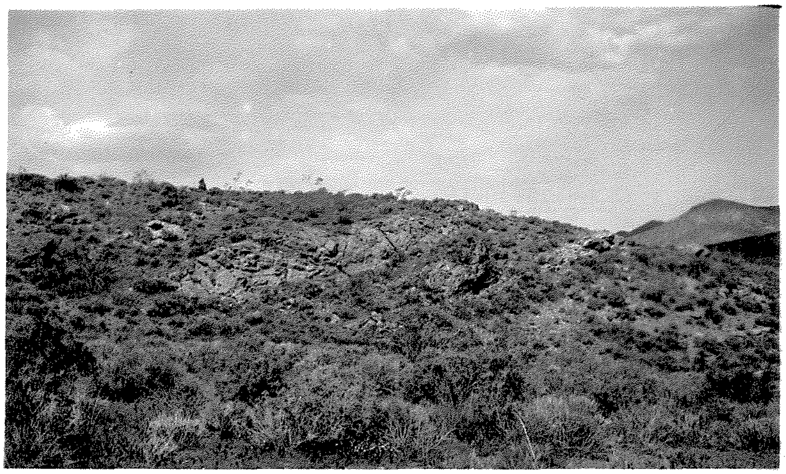

Fig. 3: Ridge of limestone in the Rand schist.

tinction, and by peculiar border zones which seem to consist sometimes of a fibrous mineral oriented perpendicular to the edges. This rock has evidently had a complex history of 3 seperate stages: the crystallization of the groundmass, the introduction of an albitic solution to form the metacrysts, and finally the attack of the metacrysts by another solution. The source of the albitic solution was probably the nearby batholith of quartz monzonite, which was intruded into the schists only a short distance away.

Limestone:

Limestones outcrop at 3 localities in the area studied: beside the main highway a half-mile south of Randsburg, on the north contact of the quartz monzonite batholith ¼ mile east of Randsburg, and at the top of hill 3950. At the first two localities named, the limestones have not suffered much from recrystallization or addition of material, but on hill 3950, an almost complete change to an aggregate of lime-silicate minerals has taken place. Microscopically, there is found to be abundant tremolite, plagioclase, and zoisite (?) developed where the alteration has proceeded far. The source of the silica-bearing solutions was probably the quartz monzonite intrusive mass, which lies near to this occurrence. These limestones have evidently been surprisingly resistant to both erosion and assimilation. The occurrence south of Randsburg forms a conspicuous ridge, around which the quartz monzonite contact sharply swings. The field relations are strongly suggestive of the conclusion that limestones are resistant to assimilation by an igneous rock.

Graphite schist:

Graphite is an abundant constituent of the Rand schists. It occurs very commonly in varying amounts accompanying the biotite or muscovite of the mica-albite schists and occasionally forms thin beds of practically pure graphite. These schists are black in color and thinly fissile. Microscopically, there is a continuous gradation from graphite schist to graphite-mica-albite schist.

Fuchsite-mariposite Rock: (plate IV-B)

In many of the actinolite schists, green plates of a chromium mica are rather common. Furthermore, fine grained nodules of this mica up to several inches in length are scattered thru the schist series at various horizons. The color of these nodules is rather variable as they sometimes consist of chrome-mica alone and at other times seem to contain considerable magnetite. They are rarely seen in place and are usually found weathered-out on the surface. A brief microscopic examination showed this mica to be bright green to colorless in thin flakes, and slightly pleochroic to non-pleochroic. According to the data given by Larsen and Berman[1], this mineral lies between fuchsite and mariposite. The index of refraction was approximately 1.60 and 2V around 15 . The optic character was biaxial negative.

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Age of The Rand Schist:

Dating of the Rand series of schists must be wholly inferential and based on petrologic characters rather than stratigraphic relations. The petrographic features of the schists make it plain that they have formed under conditions of rather severe metamorphism, and by comparison with rocks of known age in the same and adjacent regions, an estimate of their approximate age can be made.

The El Paso Mountains, a few miles to the north, consist largely of sediments believed to be middle Paleozoic in age, yet showing no metamorphic effects. Farther north in the Inyo Mountains, Paleozoic and pre-Paleozoic sediments are also unmetamorphosed[2]. To the east, lower and middle Cambrian sediments in the Bristol Range are unaltered[3].

Although this data is rather meager, it seems fairly clear

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[1] Larsen and Berman: Microscopic Determination of Non-Opaque Minerals, U.S.G.S. Bull. 848, 1934, p. 237

[2] A. Knopf and E. Kirk: Reconnaissance of the Inyo Range, USGS Prof. P. 110

[3] C.W. Clark: Lower and Middle Cambrian Formations of the Mojave Desert, Univ. of Calif. Bull., Vol. 13, 1921, pp. 1-7.

that the Rand schist is earlier than any of the above sediments. For this reason it is dated as Archean. To the objection that long-distance correlations as the above are inconclusive, it may be replied that it is inconceivable that metamorphic forces such as produced the Rand schist would not also affect a large area in the vicinity. Furthermore, the possibility of correlating the Rand schist with the Pelona schist 60 miles to the south[1] suggests that a schist series underlies much of this part of California. If this is true, it must be granted that the Rand and Pelona schists are much older than any sediments that occur in the entire region.

Structure:

After spending considerable time in the field, the writer is convinced that from a regional standpoint the Rand schists are flat-lying or dipping slightly to the south. Minor complications are numerous, especially around the intrusive body of quartz monzonite, and the schist is commonly found dipping in any direction or standing on edge. The attitude is indeed bewilderingly complicated unless viewed in its broadest aspects.

The green amphibole-albite schists are probably lower stratigraphically than the grey mica-albite schists. It is significant that the green schists outcrop only along the northwest face where the uplift has been the greatest. Even in the deep California Rand silver mine, located on the southern slope and in the grey schists, Hulin found only the grey mica-albite schists and a few beds of pure amphibole schist. If, therefore, the schist series is dominantly flat-lying or dipping slightly to the south, and if the amphibole-albite schists outcrop only along the foot of the steep upturned northern face, the conclusion must be that they are relatively low in the stratigraphic series. There is the further probability that the green schists are an inconstant member of the series. This is shown on the

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[1]discussed in detail be R. W. Webb: Master's Thesis, Calif. Inst. of Technology, 1932.

accompanying map and is very striking in the field. Towards the north the contact between green and grey schists seems to die out with no relation to topography. Towards the south, the expected relation seems to hold.

Everywhere in the Rand series , the schistosity is found to be parallel to the bedding. This is many times not clear, but wherever a bed of quartzite outcrops, the schist on either side has a schistosity parallel to the original bedding of the quartzite. The conclusion is therefore drawn that the schist body was uplifted to its present position after metamorphism in an essentially horizontal attitude, and that the folds, minor faults, and discordant dips were developed entirely subsequent to metamorphism.

No very accurate statement of thickness can be made with respect to the Rand schist. A vertical section of 1500 feet is exposed on the northwest face of the Rand Mountains and allowing for a southward dip, the total thickness would somewhat exceed this figure. This, of course, takes no account of the duplication that may exist, but the writer feels that while minor faulting and landsliding have undoubtedly caused some duplication, the topographic relief is nevertheless a true measure of the total thickness. It is therefore set at 1500-2000 feet.

Origin of The Rand Schists:

The entire Rand series of schists has clearly formed from a series of clastic sediments, predominantly of shales, sandstones, and limestones. The abundance of fine grained micaceous schists indicates that the dominant type of sediment was a fine gshale or sandy shale. Occasional variations in the deposition of shale gave rise to beds of pure sandstone which are now found as quartzites. Less frequently, limestones were deposited.

Two special conditions are indicated by the greenstone and the amphibole schists. The greenstone outcrops as small circular bodies with no trace of schistosity and no apparent relation to the surrounding schists. All of these characters point to the conclusion that the greenstone bodies were originally shallow plugs of a basic igneous rock which were intruded into the sedimentary series and metamorphosed along with the sediments.

The problem of the amphibole schists becomes clearer when two important facts are noted:

1. The great majority of the amphibole schists--that is, those exposed on the northern face of the mountains--are chemically and mineralogically very similar to the grey mica-albite schists except that amphibole replaces the micas.

2. The pure amphibole schists occur stratigraphically higher than the amphibole-albite schists, interbedded with the mica schists, and only as thin beds.

The first point shows that the amphibole-albite schist formed from normal shales containing an admixture of basic material. The second shows that this basic material was capable of being deposited in intense concentration and with sharp breaks in the normal shale deposition. The only explanation which fills these two conditions is the one suggested by Hulin (1) --namely, that the basic material consisted of volcanic tuff. Thus, in periods of intense volcanic activity thin beds of pure tuff would be deposited, and in periods of lesser activity the fine tuffaceous material would be thoroughly mixed with the normal sediments. In periods of quiet, only the normal shales would be deposited.

If this is the correct explanation we should expect to find a gradual transition upwards from the amphibole-albite schist to the mica schists rather than an abrupt changed. And along the southern portion of the contact between the two types of schist this is found to be true. Northwards, the true relations are much obscured by structural complications and the same condition cannot be said to hold. It is felt, however, that Hulin's explanation is undoubtedly the correct one, although it introduces some further difficulties.

The diversity of mineral species in the Rand schists permits still more detailed generalization on the characters of the original sediments:

1. The mica schists originated is sediments of very fine grain, having a high content in kaolin or aluminum hydrate, low in magnesium (chlorite), and rather low in iron oxides. These facts are clearly shown by the relations of epidote, Zoisite, and actinolite. The schist is characterized, furthermore, by a high percentage of lime minerals, indicating that the original sediment contained much calcite or lime-feldspar.

2. The volcanic tuff which gave rise to the amphibole schists must have been highly basic to form beds of pure actinolite. This introduces the difficulty of understanding how a sub-silicic lava having the composition of actinolite could possibly be ejected as a tuff. Highly basic lavas are in general very liquid and tend to flow much more readily than to consolidate and be ejected as a tuff. The field relations seem to compel that conclusion, however. The proportion of magnesium to iron in the original tuff was rather variable; this is shown by the variation from colorless actinolite to ferrotremolite and hornblende in the schists.

3. The greenstones were likewise formed from highly basic rocks. The simple composition and the abundance of hornblende, albite and epidote show that the original rock consisted essentially of calcic feldspar and a ferromagnesium mineral, perhaps a pyroxene. The fine grain size and the lack of a relic rexture point to a shallow intrusive rather than a plutonic rock. It is quite possible that these greenstone plugs represent the source of the tuffs which gave rise to the amphibole schists.

4. One remaining mineral is worthy of note in this respect--namely, the fuchsite-mariposite. The manner of occurrence in nodules, the presence of chromium, and the high percentage of magnetite, all show clearly that the nodules have been formed from fragments of a highly basic igneous rock.

Conditions of Metamorphism:

The prevailing attitude of the Rand schists and the universal concordance of bedding and schistosity plainly show that dynamic forces have played no part in their formation. Dynamic metamorphism is necessarily attended by the production of foliation at an angle to the original bedding, and leaves a rock so metamorphosed with two structural planes, bedding and schistosity. This is plainly not the case in the Rand schists. Nor is there any evidence of the intense folding that characterizes dynamic metamorphism. On the contrary, the faulting and folding in the Rand Mountains are entirely subsequent to the metamorphism and were produced as an element of uplift. It seems, therefore, that metamorphism must have been accomplished by simple downward pressure from deep burial, and by recrystallization at high temperatures.

It is true that the validity of load metamorphism as an agent of metamorphism has been called into serious question by many recent writers. The tendency has been to place an increasing emphasis on dynamic metamorphism and to deny to hydrostatic pressure coupled with high temperature the importance formerly assigned to it. It seems impossible, however, to account for the parallelism between bedding and schistosity and the undeformed attitude of the schists by any appeal to dynamic metamorphism. Daly[1], in defending load metamorphism, says in conclusion, ".......it seems eminently wise to provide load metamorphism a place in a general classification of rock changes, if that classification is to meet the needs of geologists who have to deal with the Precambrian formations."

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1 R.A. Daly: Metamorphism and Its Phases, Bull. Geol. Soc. Am., Vol. 28, no. 2, 1917.

The minerals which are regarded as diagnostic of the metamorphic conditions are:

actinolite and hornblende

zoisite, epidote and clinozoisite

muscovite, biotite and fuchsite-mariposite

albite

talc

These groups fall into the upper part of the Mesozone of Grubenmann's classification. Grubenmann's classification of the crystalline schists, based on depth, has fallen into some disrepute in recent years[1], but it is thought to be especially appropriate and accurate in the case of the Rand schists, where depth of burial and temperatures dependent on depth have been the controlling factors in recrystallization. The association of biotite, muscovite, and the epidote-zoisite group is clearly a Mesozone characteristic. The development of actinolite and ferrotremolite instead of hornblende is further characteristic of the middle or upper Mesozone rather than the lower. Albite is only confirmatory; it characterizes both the Epizone and the Mesozone. Talc is somewhat of a problem. Grubenmann places talc in the Epizone, while Harker[2] states that it is a stress mineral that may persist into rather high grades of metamorphism. In this case, talc is emphatically not a stress mineral, nor is it an Epizone mineral for it always occurs in association with pure actinolite schists. This leaves as the further possibility--which some field observations seemed to indicate--that the talc represents an alteration subsequent to uplift. The source might be actinolite, and the formation controlled by small anticlines or other structural features.

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1 see, for example, Leith and Mead: Metamorphic Geology, 1915
2 Alfred Harker: Metamorphism, 1932.

* Atolia Quartz Monzonite *

Just to the south of Randsburg, an elongate mass of a plutonic igneous rock is found intrusive into the Rand schist. This is believed by Hulin to be a part of a large batholith which outcrops over a large area in the southern and northern partions of the Randsburg quadrangle, and in a smaller area around Atolia, about 5 miles southeast of Randsburg. It was named by Hulin the Atolia Quartz Monzonite because of its occurrence at the latter locality.

Petrology: (plate VII-A,B)

In the area studied around Randsburg, the batholith is a long finger-like extension about 2½ miles in length and ¼ to ½ miles in width. Considerable variation is found in this rock, probably because of its small areal extent and because it has assimilated much schist. The freshest part has a medium grained granitic texture, and is composed of quartz, orthoclase, and plagioclase, with considerable dark hornblende and biotite, and unusually large crystals of titanite. Microscopically, the rock is found to have the composition of a quartz monzonite. Plagioclase having the composition of andesine, quartz, and orthoclase are the chief constituents, with subordinate amounts of strongly-pleochroic biotite and pleochroic green hornblende. In some specimens, the accessory minerals are very abundant, chiefly large, well-formed crystals of titanite, and lesser amounts of magnetite, apatite, and zircon. In others, however, there is a general lack of accessories. Strain effects are sometimes pronounced, in the form of bent plagioclase twinning-lamellae, distorted flakes of biotite, and strain-shadows in the quartz.

At many localities, especially along the contact with the Rand schist, the quartz monzonite has a very striking orbicular[1] structure. This is especially well shown a half-mile southeast of

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[1] an "orbicle" is here defined as any rounded or angular fragment of a foreign rock imbedded in a granitic groundmass.

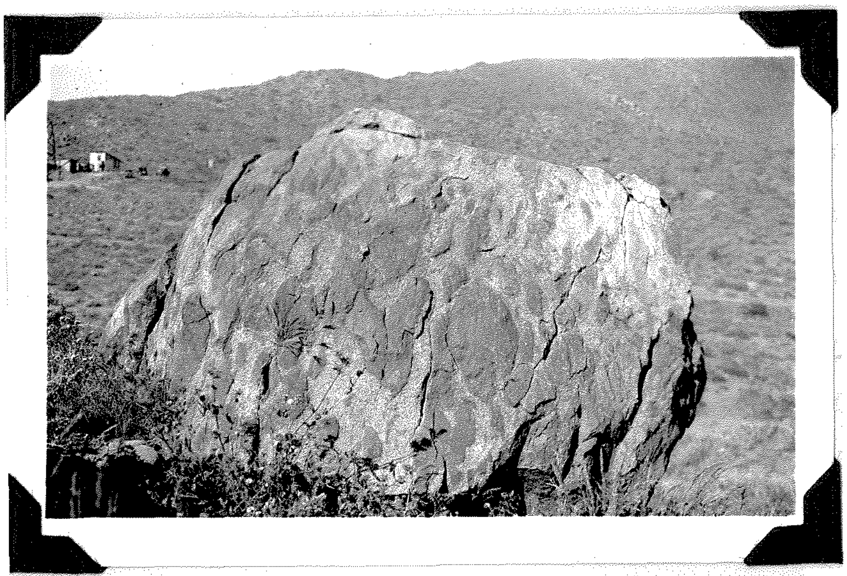

Fig. 4: Boulder of orbicular quartz monzonite

Randsburg, just east of the highway, and also near the tip of the batholith. Dark masses from several feet down to an inch in diameter are found scattered thru a granitic matrix, and in all stages of assimilation. These orbicles undoubtedly represent fragments of Rand schist, as all stages can be observed between sharp, angular fragments that still retain their schistosity, to those which are only indicated by a darkening of the quartz monzonite. Many times a number of adjacent orbicles are oriented with their schistosities parallel to one another. Near the western tip of the batholith, an outcrop was found where complete assimilation of included fragments had transformed the quartz monzonite into a dark, fine-grained rock. Under the microscope, this was found to have still the composition of a quartz monzonite, but to have an unusual texture. Plagioclase and quartz are the most important constituents. The plagioclase forms rather small elongate crystals having the composition of andesine. Many of them have been greatly altered, and "sick-looking" crystals showing zoned extinction are very common. Biotite and hornblende, especially the former, are the only dark minerals of importance. Texturally, this rock appears very basic, as the plagioclase tends to form euhedral crystals which seem to lie in a "groundmass" of quartz, yet the actual chemical composition is probably that of the normal quartz monzonite.

Another facies of the quartz monzonite outcrops beside the limestone ridge mentioned above about ½ mile south of Randsburg. This rock consists of large black hornblende crystals set in a very fine grained white matrix which is not determinable with a hand lens, and which gives to the rock a sugary feel. Radiating thru the rock in a criss-cross pattern are numerous little stringers of a dark mineral. The porphyritic appearance is confirmed under the microscope. It is found that the groundmass consists of a very fine mosaic of small anhedral plagioclase grains having the composition of andesine or andesinelabradorite. In this groundmass are set large and small crystals of hornblende and flakes of biotite. The minute veinlets are found to be composed of small grains of diopside. The general appearance of the plagioclase suggests that it has been crushed (the "mortar" texture), but the large hornblende phenocrysts and the veinlets of diopside show that the unusual texture is only the result of contact metamorphism, the effect being here an endomorphic one.

Emplacement of The Batholith:

It is certain that both assimilation and injection were important in the intrusion of the quartz monzonite. Proof of the former is given by the orbicular rocks described above, and further, as Hulin points out, by the fact that whenever limestones outcrop along the quartz monzonite contact, they invariably project into the igneous rock more than the adjacent schists. Injection has been a less important but nevertheless very potent process also. This is shown strikingly in the "glory hole" of the Yellow Aster mine and in other small mines along the contact. The contact shown on the map accompanying this report actually marks only an approximate zone of injection and is by no means a sharp line of contact between the two rocks.

After Effects of The Intrusion:

No aplite or pegmatite dikes were found in the area studied, but quartz veins are very common. Great numbers of these veins are exposed in some of the canyons west of Government Peak. The veins vary in thickness from 6 inches to a few feet, and commonly carry an abundance of coarsely crystalline epidote. The epidote is a light green in color and usually forms radiating groups of slender prisms. Individual crystals may be several inches in length. Large masses of barren white "bull" quartz are very common also, usually being quite devoid of any mineral other than the milky-white quartz. Similar, though much narrower veins occur in the quartz monzonite, and there can be little doubt that they were formed as the last stage in the intrusion

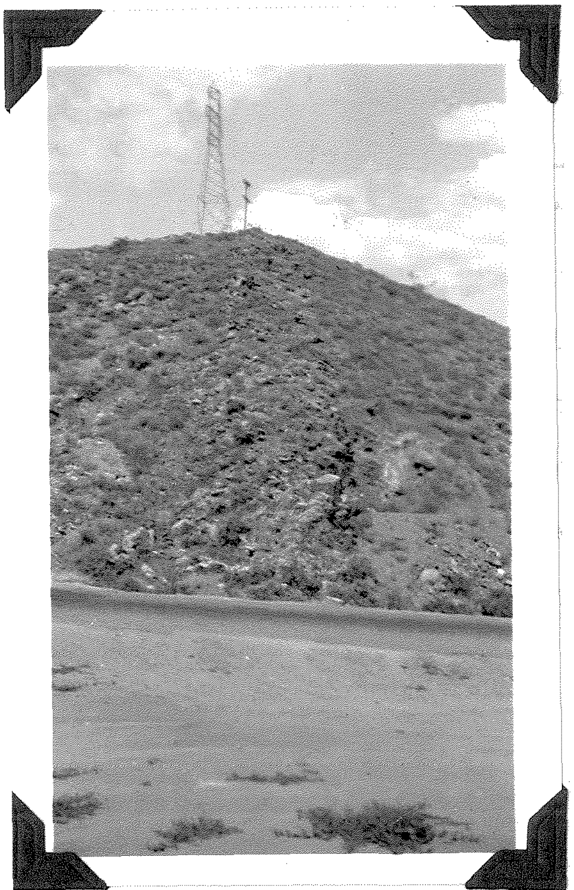

Fig. 5: Dike of rhyolite
cutting the Atolia
quartz monzonite.

of the quartz monzonite.

Age of The Atolia Quartz Monzonite:

Hulin (1) states that the quartz monzonite is younger than the Paleozoic (?) sediments in the northern part of the quadrangle and older than the Rosamond sediments of Tertiary (Miocene) age. Furthermore, the quartz monzonite outcrops as close as 15 miles to the nearest igneous rocks of the Sierra Nevada batholith. It seems very probable, therefore, that the Atolia quartz monzonite is the correlative of the Sierran granites and hence late Jurassic in age.

****

* Tertiary Volcanics *

Acid and basic volcanic rocks are very common in the Rand Mountains, in the form of dikes, pipes, and sills. Very little study was devoted to these rocks, and no attempt was made to map all their occurrences.

Acidic dikes having the composition of rhyolite are by far the most common of these types. They vary greatly in length, being at times only a few tens of feet in length, and sometimes traceable in segments for over a mile. The thickness is usually about 10 feet. These dikes form a conspicuous feature of the topography, especially on the south slopes of the mountains where they have often controlled the location of ridges. The attitude is usually vertical or nearly so, although in a small canyon ½ mile west of Government Peak, a series of parallel sills was found. The individual sills were from 1 to 10 feet in thickness, lying practically horizontal and parallel to the enclosing schist. Several small plugs of rhyolite occur near the highway just south of Randsburg, and near the Yellow Aster mine.

All of the above mentioned types are very similar in appearance. The surface of a hand specimen is whitish or brownish, stained by iron oxides or dendrites of manganese dioxide. A fractured specimen shows that the unoxidized interior is wholly aphanitic and even somewhat

Fig. 6: Quaternary gravels overlying amphibole schist. Note the large fragment of schist in the gravel in the lower right-hand corner of the picture.

glassy. In thin section, the rock is found to have a typical rhyolitic mosaic, but extremely fine grained and exhibiting only incipient crystallization.

A few dikes of basalt occur but were not examined microscopically.

In all cases there dikes seem to have had practically no effect on the intruded rocks other than slight injection when they are intrusive into the Rand schist. Endomorphic chilling is occasionally pronounced, however, especially in the case of the basalts that intrude the quartz monzonite. The resulting basalt is extremely fine grained and sometimes almost glassy on the borders.

In the eastern part of the quadrangle, Hulin found that the rhyolite intrusives intersect the lower 200 feet of the Rosamond formation, and that the basalts appear at a somewhat younger horizon, approximately 500 feet from the base. From this he was able to date the rhyolite as early upper Miocene, and the basalt as upper Miocene.

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* Sediments *

No sedimentary rocks other than quaternary gravels outcrop in the area studied by the writer. But at 4 different localities on the floors of the steep canyons leading to the north, small patches of unusually well consolidated gravels are exposed which might easily be mistaken for rocks of an earlier period. At all 4 exposures, the rock is very similar in appearance. It consists of coarse, angular fragments of schist, quartz monzonite, rhyolite and quartz set in a matrix so firm that it is difficult even to break off a specimen. The included fragments average about ½ or ¼ inch in diameter, but at one outcrop a flat slab of amphibole schist about 2 feet in length is included.

Hulin states that he found a small patch of feldspathic sandstone near the tip of the quartz monzonite intrusive which he considered to be a fault block of Rosamond sediments. The writer has failed to find any such outcrop and it is possible that Hulin was referring to the consolidated gravels described above. The possibility of these gravels being Tertiary in age is ruled out by their occurrence as typical recent stream gravels, and by the fact that the conglomerates and sandstones of the Rosamond formation are all poorly consolidated. Their age must therefore be set at quaternary.

****

* STRUCTURE *

The structures of the Rand schist and the Atolia quartz monzonite have been discussed above; there remains now to be mentioned only the general structure of the Rand Mountains.

Perhaps the most striking feature of the Rand Mountains is the great difference in relief between the northern and southern slopes. The abrupt northern face and the gentle southern slopes suggest immediately that uplift of the range has been accomplished by rotational movement along a fault at the northern foot of the mountains. The same result could be attained by either a steep normal fault or by thrusting towards the northwest on a low-angle fault. But in searching for such a fault, a difficulty immediately arises---namely, the character of the rocks involved. It is certain that minor faulting has played a large part in shaping the topography of the northern slopes, yet the faults themselves can never be mapped and hardly even located except in rare instances. The reason is, of course, that all of these faults are in the Rand schist and that faulting in such weak rocks is immediately obscured by slumping and sagging of the adjacent fault-blocks. Structural evidences of faulting can be found in almost any canyon on the north slopes, but the fault itself can never be located accurately and adjacent canyons may have entirely different structures. In a small canyon in the southwest conner of the map for example, it was found that one side of the canyon was formed of green amphibole schist and the other by grey mica-albite schist, the two types having highly discordant dips and apparently butting into one another. In attempting to prolong the fault that probably lay at the bottom of the canyon, it was found that as soom as the canyon was left, the structure became too obscure or too different to permit any correlation. And such a condition is the rule rather than the exception.

Besides faulting and the slumping subsequent to it, it is very probable that simple landsliding has introduced many of these minor structural complications. The Rand schists are rather weak rocks when weathered and sapping in the steep canyons has no doubt caused rotation of small blocks and produced the discordant dips.

Thus it is not difficult to account for the lack of a recognizable fault at the northern foot of the mountains. Yet it is significant to note that many faults are exposed in the mines of the district. Hulin states that the largest of the faults in the Yellow Aster mine is a normal fault dipping about 40 or 50 degrees to the north. This indicates at least that such stresses have been operative in the region as would produce the fault that is suggested so strongly by the topography.

****

* GEOLOGIC HISTORY *

The history of the region around Randsburg began with an Archean sea in which fine clastic sediments from a distant land mass were being deposited. During the earliest period that is recorded in the Rand Mountains, igneous activity in the region was almost continuous and enormous quantities of volcanic tuff settled into the basin of deposition and were mixed with the normal sediments. With the passage of time, the volcanic activity became more sporadic, depositing thin beds of pure tuff and finally dying out altogether. In connection with this activity, numerous small plugs of basic igneous rock were intruded into the sediments. The deposition of shales, sandstones, and limestones now continued until the lower part of the series had been buried to a great depth. Under the pressure of the overlying sediments and in a zone of intense heat, the lower sediments were completely recrystallized to schists---the Rand schists as we now see them.

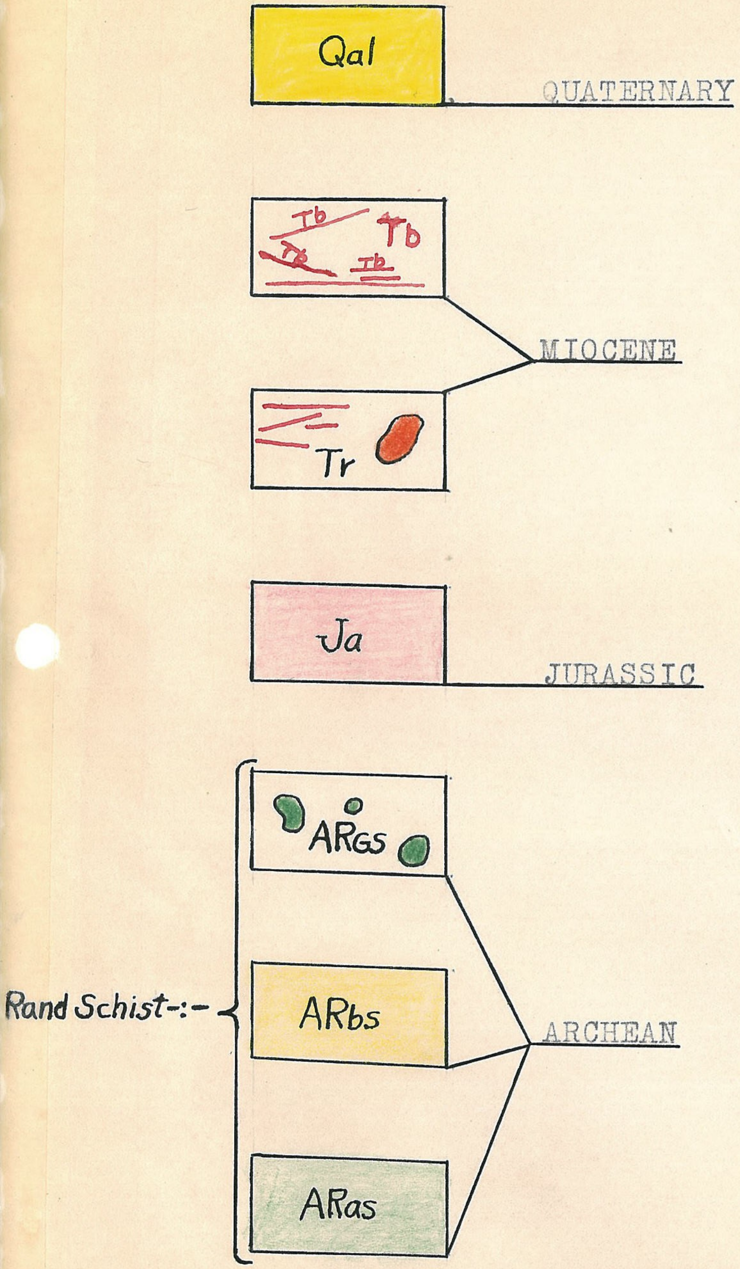
The record is now interrupted until upper Jurassic or early Cretaceous, when a batholith of quartz monzonite was intruded into the schists, emplacement being accomplished by both injection and assimilation. Intrusion was followed by the injection of numerous quartz and quartz-epidote veins in the surrounding schists.

The record is again a blank until Miocene time, when numerous dikes, sills, and plugs of rhyolite and finally of basalt were intruded into the schists and the quartz monzonite.

At a somewhat later time, possibly Pliocene or Pleistocene, the Rand Mountains were uplifted by movement on a steep normal fault or a thrust fault, and erosion gradually shaped them to their present topography. Erosion under arid climatic conditions soom produced a highly irregular and steep topography on the faulted northern face of the mountains, while the southern slopes retained the smooth surface of the pre-uplift erosion period.

* * * * * * *

* MAP LEGEND *



(well-consolidated stream gravels)

(dikes of basalt)

(pipes, dikes, and sills of rhyolite)

(batholith of Atolia Quartz Monzonite)

(metamorphosed intrusive greenstones)

(dominantly mica schists with some limestone, quartzite, and other schists)

(dominantly amphibole schists; largely amphibole-albite and amphibole-epidote schists)

PLATE I

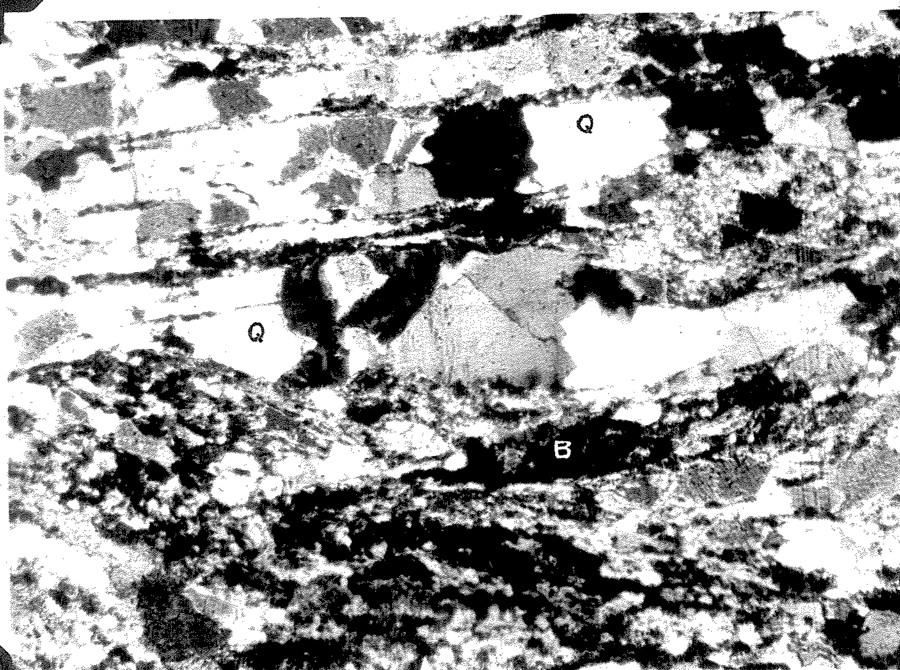
PLATE I

A: Biotite-albite schist; dark streamers of biotite surrounding grains of quartz and albite; plane polarized light, X50.

B: Biotite-albite schist; B, biotite; Q, quartz; X-nicols, X50.

PLATE I

A



B

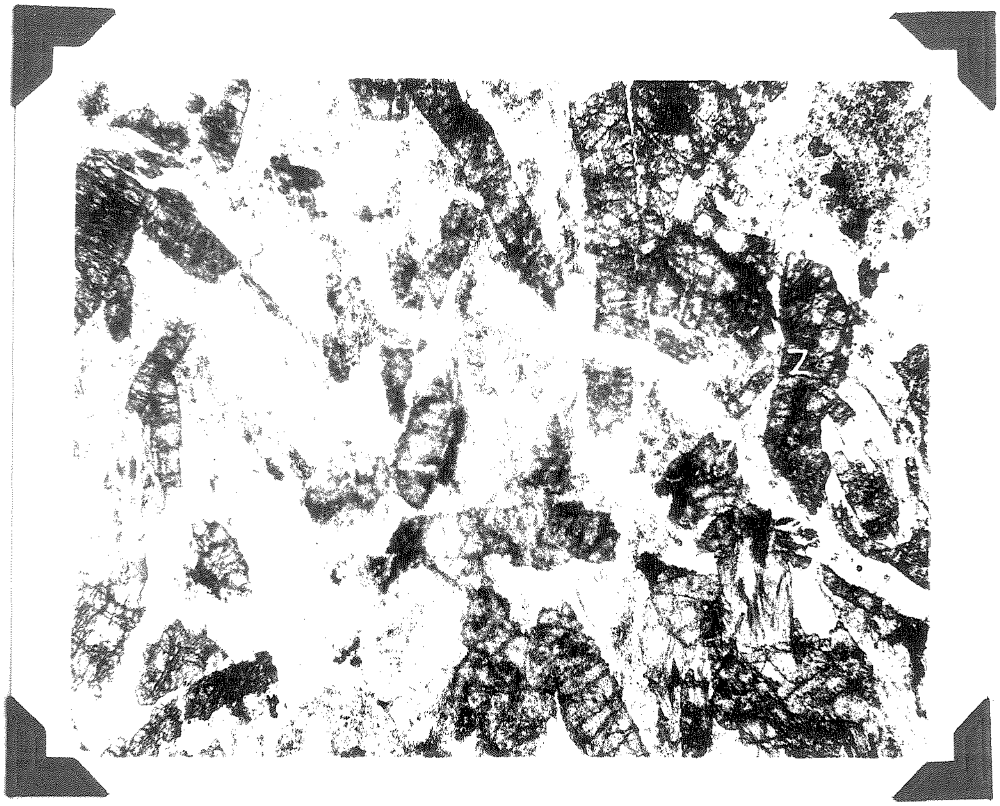
PLATE II

PLATE II

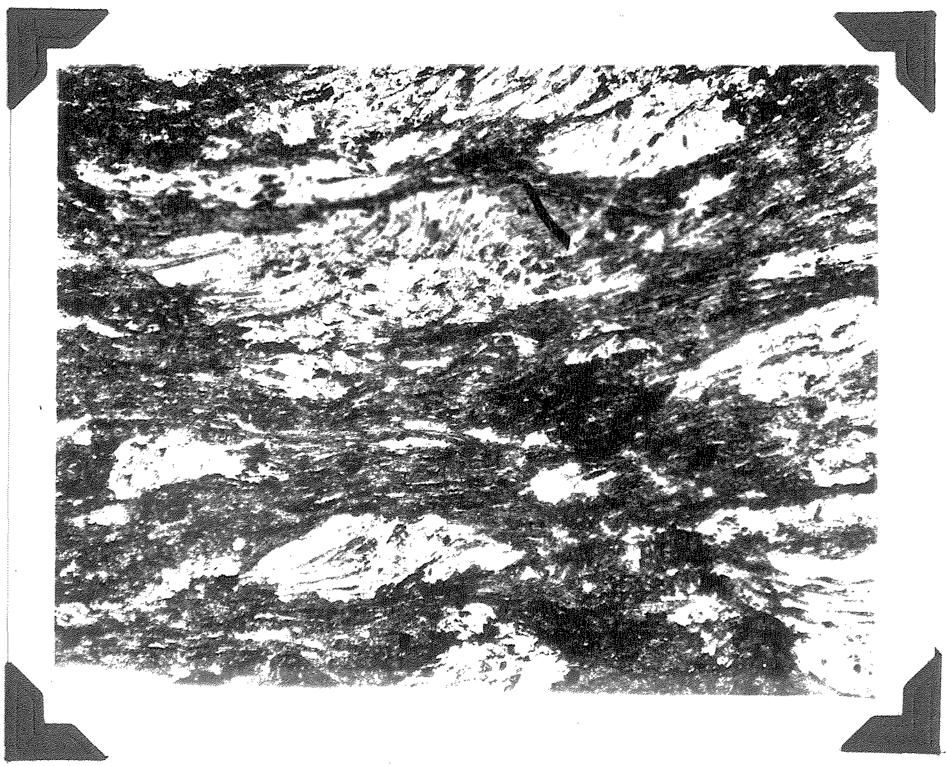
A: Zoisite schist; clouded zoisite crystals in a mica schist; plane polarized light, X30.

B: Amphibole-albite schist; dense aggregates of minute actinolite needles surrounding grains of albite and quartz; plane polarized light, X30.

PLATE II



A



B

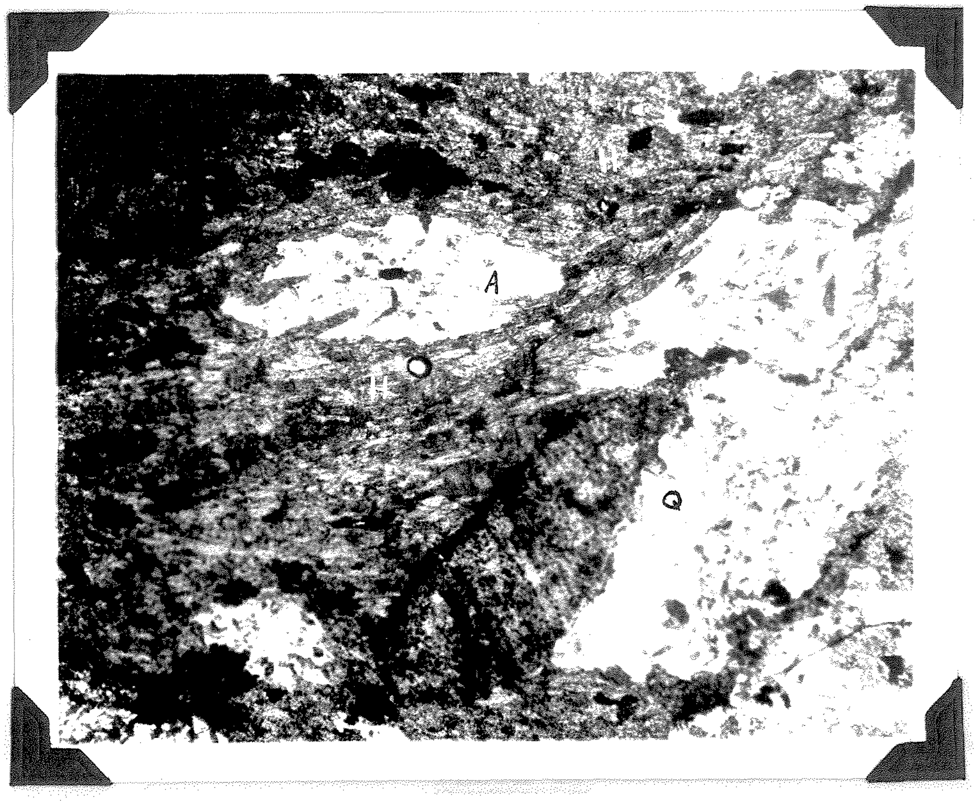
PLATE III

PLATE III

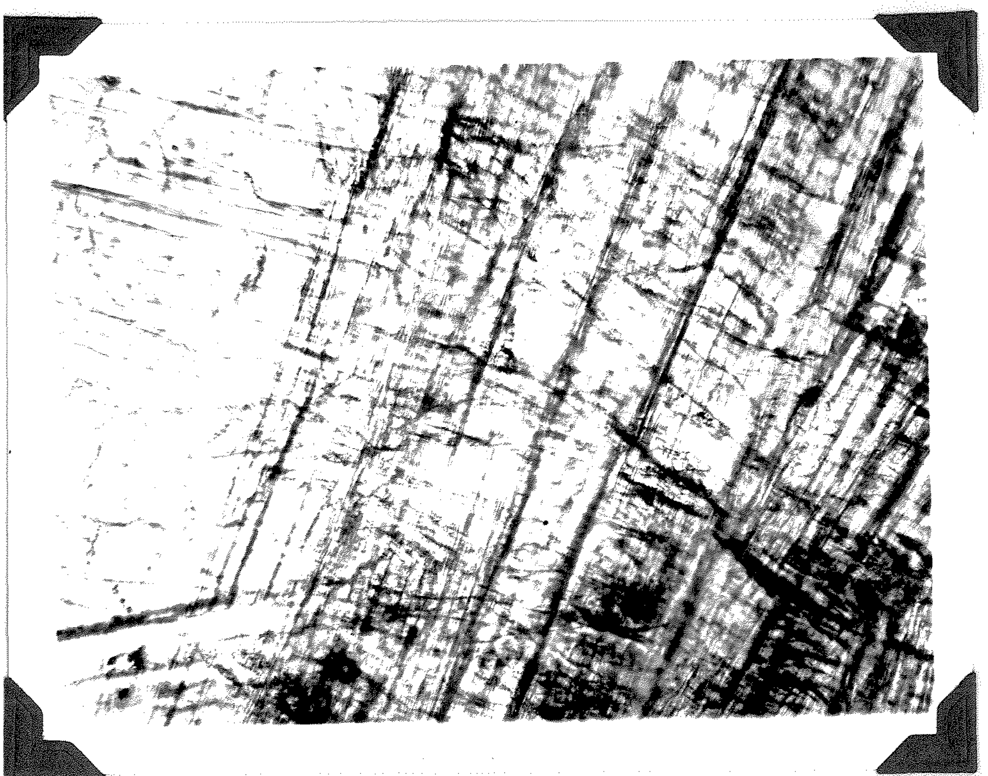
A: Hornblende schist; H, hornblende; A, albite; Q, quartz: dark masses are clouded epidote and zoisite; plane polarized light, X30.

B: Actinolite schist; plane polarized light, X95.

PLATE III



A



B

PLATE IV

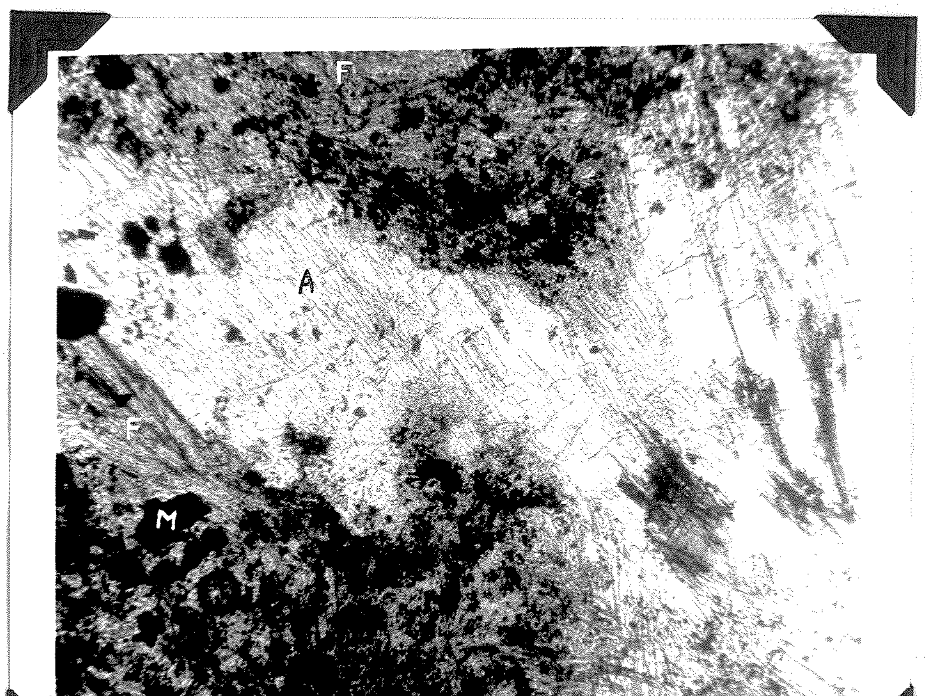
PLATE IV

A: Actinolite-talc schist; A, actinolite; T, talc; plane polarized light, X95.

B: Actinolite schist containing much fuchsite-mariposite (chrome-mica); A, actinolite; F, fuchsite-mariposite; M, magnetite; plane polarized light, X95.

<u>PLATE IV</u>

A



B

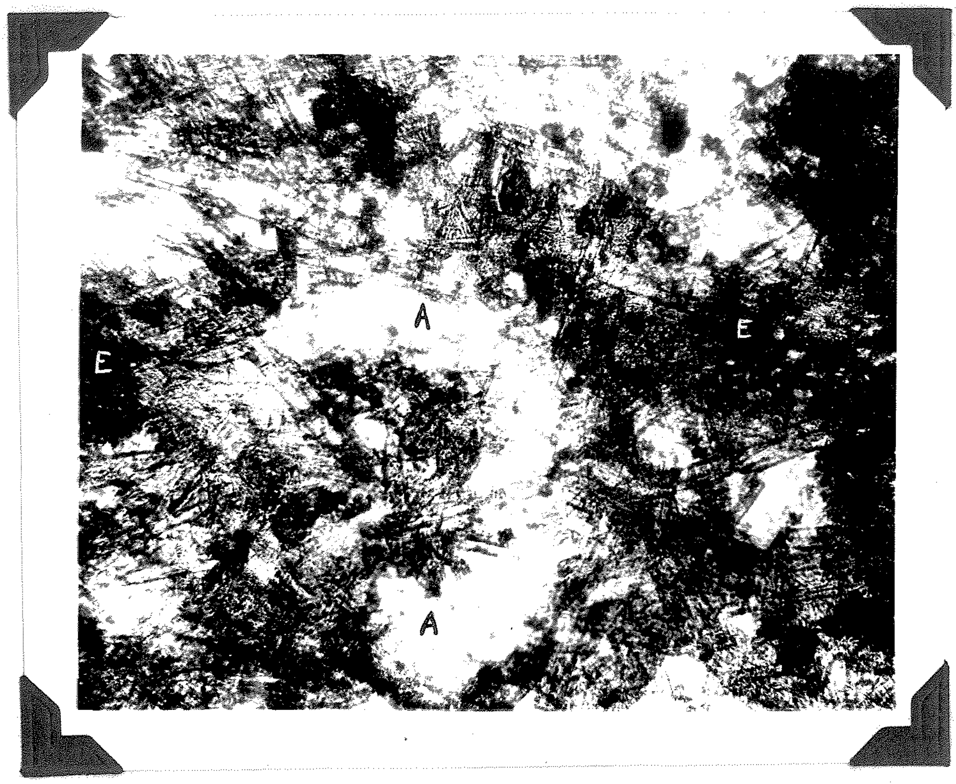
PLATE V

PLATE V

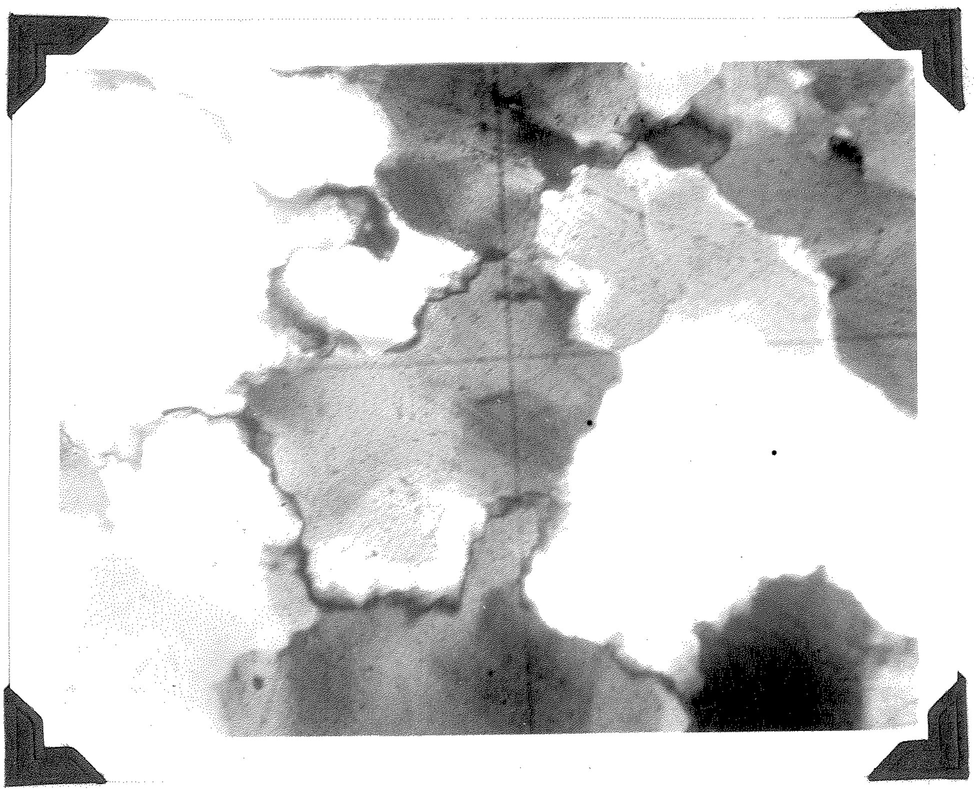
A: Greenstone schist; A, albite; E, clouded epidote; needles are actinolite or hornblende; plane polarized light, X 95.

B: Quartzite; X-nicols, X95.

PLATE V



A



B

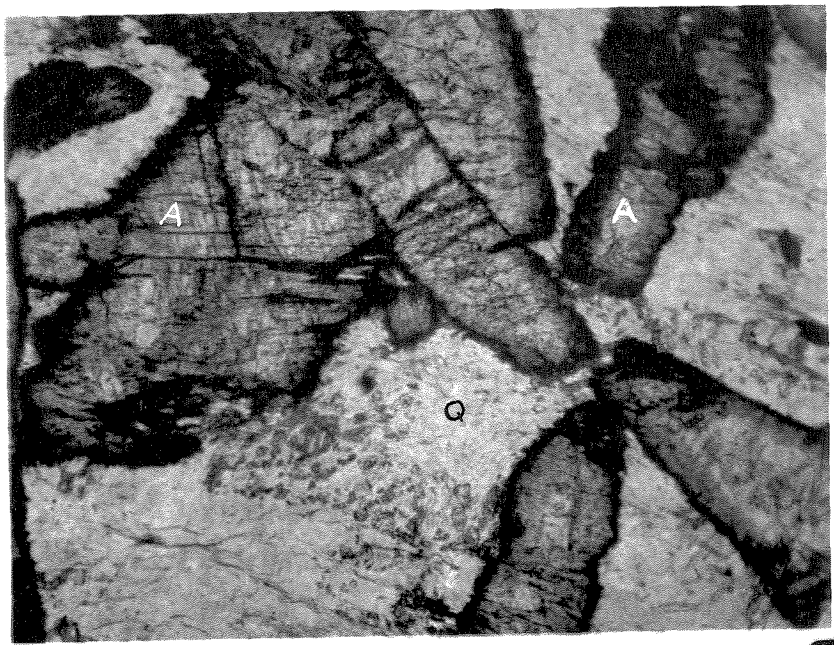
PLATE VI

PLATE VI

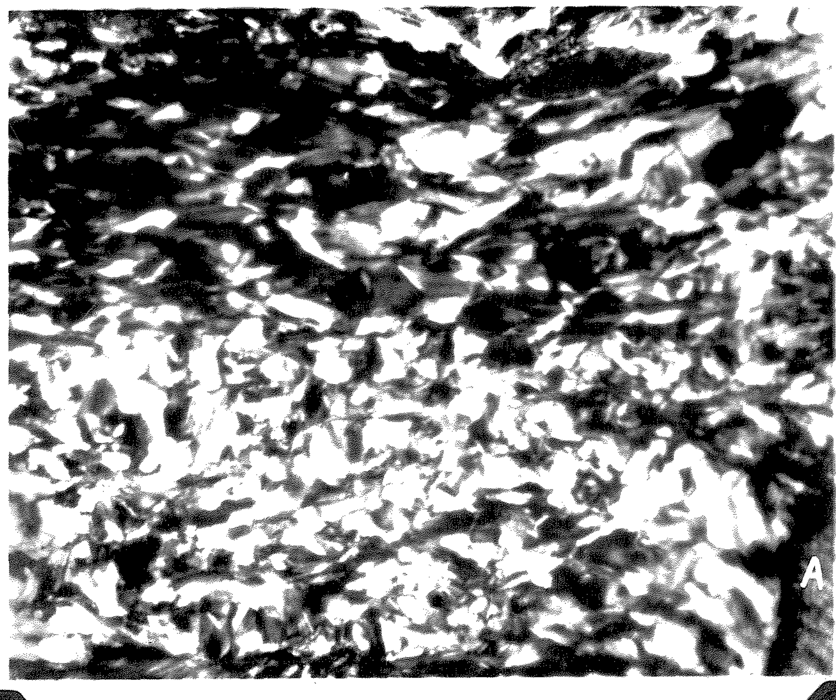
A: Quartz-albite schist; A, albite metacrysts; Q, quartz; plane polarized light, X30.

B: same as A, the groundmass of quartz; X-nicols, X95.

PLATE VI



A



B

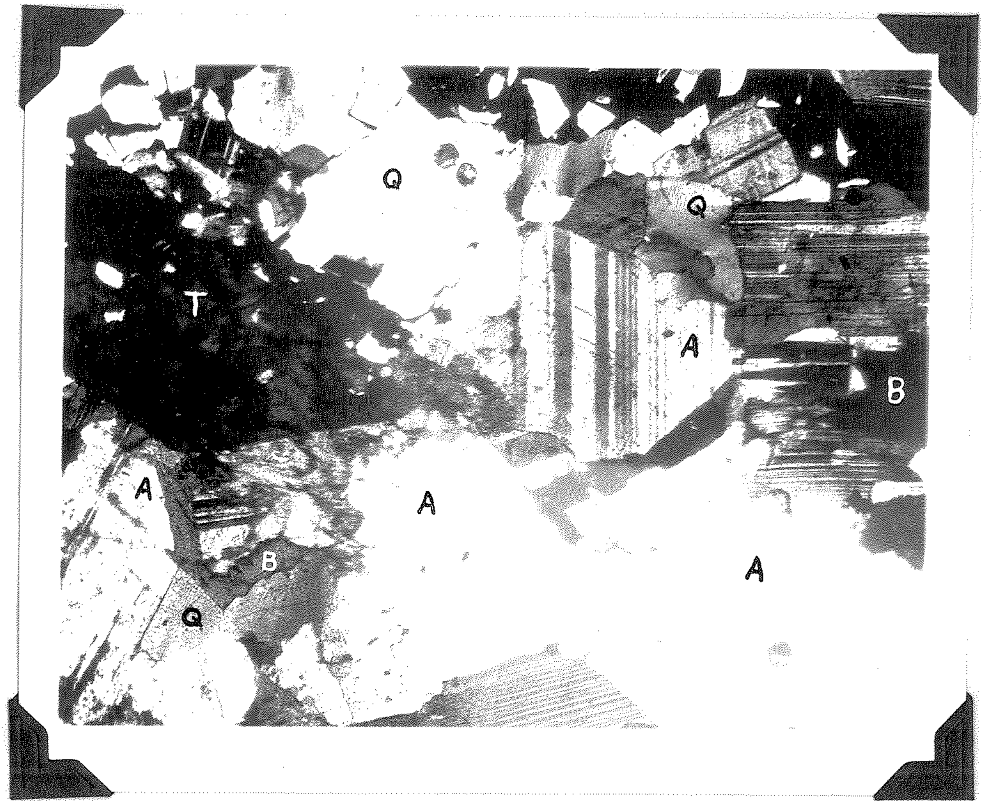
PLATE VII

PLATE VII

A: Quartz monzonite; A, andesine; B, biotite; Q, quartz; T, titanite; X-nicols, X30.

B: Quartz monzonite with completely assimilated schist; A, andesine; B, biotite; Q, quartz; X-nicols, X95.

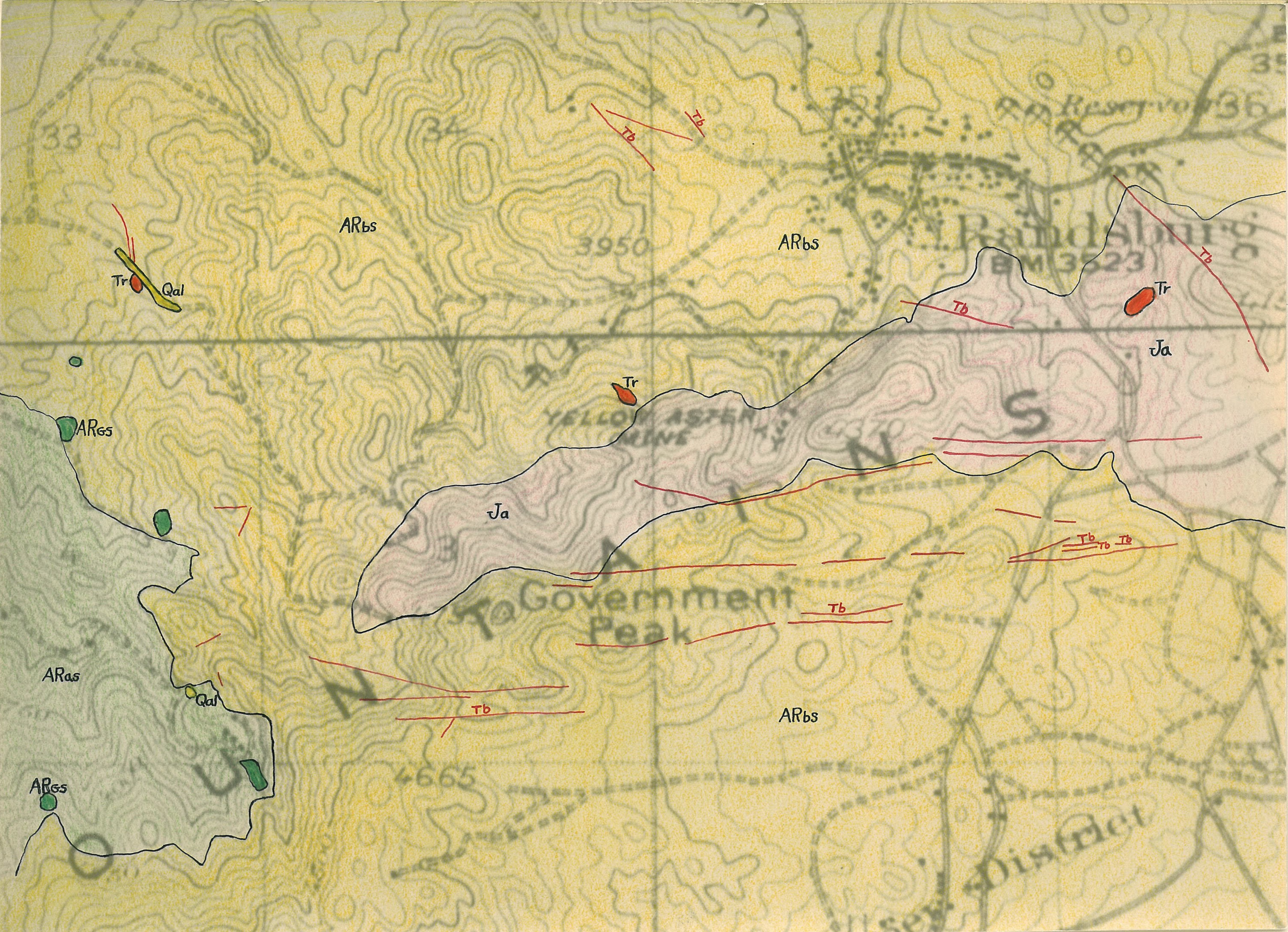
PLATE VII



A

B

Portion of The Rand Notes
M. H. Evans



Randsburg
BM 3523
Reservoir
Tr
Ja
Tb
ARbs
3950
34
33
35
36
Qal
ARGS
ARas
YELLOW ASTER MINE
To Government Peak
4665
District