THE GEOLOGY OF THE HOUSER CANYON PEGMATITE WITH AN X-RAY ANALYSIS OF MONAZITE

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ABSTRACT

A large granitic pegmatite near Campo, in southern San Diego County was found to contain several radioactive biotite-rich inclusions. The pegmatite is irregularly zoned, and in general comprises a well defined graphic-granite border zone, an irregular wall zone of intergrown quartz and perthite, a discontinuous intermediate zone of blocky perthite, and a well developed but somewhat irregular quartz core. The included masses of biotite-rich rock are spatially related to segments of the quartz core and their content of rare-earth minerals may be due in part to this relationship.

The inclusions are composed of interlayered biotite books and feldspar plates which form a series of folded and distorted layers that are randomly oriented throughout the inclusion. Separation and analysis of minerals from the inclusion were accomplished by means of cloud-chamber detection, x-ray powder diffraction analyses, and spectrographic analysis. Thorium-bearing monazite was identified as the source of the radio-activity.

The rare-earth elements and thorium evidently were concentrated in the late residual fluids of the pegmatite. Pendants or inclusions of apatite-bearing schist are believed to have provided a source of phosphorous for the crystallization of monazite. As an additional result of reaction with the pegmatite solutions, the minerals of the schistose pendant were recrystallized and some mineralogic changes were made as well.

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INTRODUCTION

This project was undertaken to determine the nature of radioactive mineralization in a granitic pegmatite in San Diego county and to determine the geochemical significance of this mineralization. Approximately eighteen days of field work was devoted to the project and was supplimented with laboratory study done throughout the three terms of 1950 and 1951 at the Institute. The investigation entailed location of radioactive material in the pegmatite; construction of a geologic map of that part of the pegmatite which contained the radioactive material collection, and separation of this material into its component minerals; and finally, analysis and interpretation of the mineral responsible for the radioactivity.

The pegmatite body that was studied is a large, pod-shaped mass west of Campo and near Morena Lake Village in San Diego County, California. It lies in Sec. 25 T17S R4E SBM. It can be reached from a point approximately one mile south of Morena Lake Village, whence a dirt road extends southward and westward into Houser Canyon.

The extreme northeast part of the mass afforded the best opportunity for study, consequently topographic control was established in a 300 foot square area that encloses this part. A five foot contour interval was used and mapping was done on a scale of 20 feet to the inch using point reoccupation methods.

Previous work done in the area included reconaissance mapping by Mr. B. Brooks (unpublished) and reconaissance study and mapping by Mr. R. H. Jahns in 1948 and 1949.

The writer is indebted to Mr. R. H. Jahns for guidance in all phases of this project, and to Mr. R. Von Huene and Mr. W. Moiser for assistance in technical phases.

GEOLOGIC SETTING

The pegmatite is exposed on the north slope of Houser Canyon where its upper surface forms a dip slope. The dike is enclosed mainly by igneous rock that is a part of the Southern California batholith, a complex group of late Mesozoic intrusive masses. Biotite schist occurs as pendants and inclusions in the intrusives. The pegmatite is in contact with one of these pendants on the east side of the dike and with the igneous rock elsewhere.

PEGMATITE BODY

General Features

The pegmatite body is pod-shaped and is approximately 500 feet in length along the strike, the distance along the dip being slightly greater. The attitude of the pegmatite is such that its top surface forms a dip slope on the side of Houser Canyon, The surface being obscured at its lower part by a covering of country rock and waste material. The pegmatite pod strikes N50W, and its average dip is fifty to sixty degrees SW.

Zones of different texture and mineral composition conform generally to the shape of the pegmatite body. These zones are the result of progressive crystallization inward from the contact with the country rock toward the center of the pegmatite. The zoning is irregular, departing from the usual pattern in zoned granitic pegmatites possibly owing to isolation of individual pockets of residual liquids during crystallization. These pockets are represented by isolated masses of blocky perthite and quartz not concordant with the general zoning pattern.

Internal Structure

In naming the mineral and textural zones, the classification proposed in Monograph 2 of "Economic Geology"(2) has been used.

Border Zone

The border zone, which is four to five feet thick, is mainly a medium to fine-grained graphic intergrowth of quartz and perthite. The fine texture of this graphic intergrowth results in a quartzite-like appearance adjacent to the country rock. The contact of the border zone with the schistose parts of the country rock is emphasized by differences in resistance to erosion. The country rock weathers away from the footwall of the pegmatite body, leaving bulbuous protrusions of graphic granite.

The border zone contains remnants of the country rock which occur in the form of inclusion of books of biotite in coarse graphic texture. The biotite books have an average dimension of ¼ inch thick and five inches in diameter, with random orientation in the outer two to three feet of the border zone. The biotite inclusions become more sparse toward the inside of the border zone, and give way to coarser graphic granite. This characteristic graphic relationship of biotite to the country rock occurs similarly on the edges of the included masses of country rock far within the borders of the pegmatite. This biotite occurrence is probably the result of assimilation of part of the country rock by the pegmatite fluids, involving recrystallization and reorientation of the biotite.

The border zone is well exposed at the southern and eastern edges of the pegmatite body, and quarrying operations have exposed the inner surface of the border zone along the eastern edge of the mapped area.

The contact of the border zone with the wall zone is very sharp, and can be recognized within a fraction of an inch.

Wall Zone

The wall zone is from five to twenty feet thick and is composed of medium to coarse grained perthite and quartz, with traces of fine-grained muscovite and a few larger biotite crystals. The rock is a light dusty color in weathered outcrop. The wall zone occurs as the first textural change in the rock inward from the border zone and is obscured in most parts of the area by talus and dump material. The best outcrop occurs in the southeastern part of the map where a small pod of blocky perthite is contained within it. The outer contact of the wall zone is very sharp, but the inner boundry is extremely irregular. In one location in the east central edge of the pegmatite, the wall zone is absent and a quartz finger occurs adjacent to the border zone. The wall zone is present adjacent to the border zone in all other parts of the mapped area.

Intermediate Zone

The intermediate zone is composed chiefly of coarse blocky perthite. It is light gray in color, with a faint brownish tinge, and shows large prominent cleavage surfaces in outcrops. The zone is very irregular, occurring in the form of isolated masses either within parts of the wall zone or adjacent to massive quartz bodies in the core. The zone is best exposed near the north east edge of the area and its relation to the quartz core can be seen by referring to cross section B.

Core

The core, or central zone in the pegmatite body is well developed but somewhat irregular. The quartz masses are lenticular in shape and conform generally to the shape of the pegmatite body. Several isolated quartz masses are indicated on the map in close relationship to blocky perthite masses. Representation of this relationship can be seen in the lower part of cross section C. The quartz lenses appear to be disconnected, but it is probable that these lenses are extensions of the larger central quartz mass that lies to the west of the area mapped. The relationship between the quartz zone and other zones can be seen on cross sections A and B directly beneath the large biotite-rich inclusions. The quartz is massive and milky with good cleavage in most outcrops.

Inclusions

Two main inclusions, containing radioactive minerals, occur in the area mapped. These are tabular and are roughly concordant with the pegmatite zones. They are closely associated spatially with extensions of the main quartz core. The relationship can be seen on cross section diagrams A and B. The inclusions are composed of thin books of biotite interlayered with plates of feldspar, and have been warped and folded on a small scale so that the layers are distorted and intersecting at all angles. The orientation of the tabular minerals has no relation to the position of the minerals in the inclusion except that layers close to contacts are parallel to the contacts and concordant with the adjacent zone. Alteration of the biotite has yielded iron oxides, which form a red stain on most of the outcrops.

An additional included body, non-radioactive, occurs within the pegmatite body. This inclusion is thin and tabular in shape and has a discordant relationship to the larger concordant inclusions. It is parallel with the pegmatite zoning in strike, but dips in the opposite direction and hence cuts all zones in section. It has been warped and broken in parts, but is fairly continuous across the pegmatite body. This inclusion is a quartz-biotite schist and has been affected only slightly by pegmatite liquids. The slight affect that the pegmatite liquids have had on this zenolith indicates that it was included later in the pegmatite history than were the other inclusions.

Fractures

Fractures occur throughout the pegmatite and show no systematic orientation. Several minor faults also are present within the body; these strike N50W and dip 45 degrees north. The surfaces of these faults are coated with small muscovite flakes.

Microscopic Features

Under the microscope, part of the included rock shows biotite in sigmoid patterns, with microcline plates between the curved biotite sheaves. One cleavage trace of the microcline consistantly parallels the cleavage trace of the surrounding biotite. The microcline, in part, fills the interstices between biotite flakes indicating that biotite was formed first and that microcline was a result of permeation of pegmatite fluids. Monazite crystals were formed last. The proportion of minerals is difficult to determine accurately, owing to the incomplete sampling provided by the few thin sections, but an approximate estimate includes 50% microcline (with some microperthite), 40% biotite, and 10% albite and monazite. The percentage of monazite in thin sections examined was about 2%. Secondary albite occurs replacing microcline around the edges of some biotite flakes.

Euhedral monazite crystal occur in every instance within the microcline plates with at least one face of the monazite crystal adjacent to a biotite cleavage trace. The monazite crystals appear to have exerted a strain effect on the microcline. This strain effect is evidenced by fractures radiating outward into the microcline from the edge of the monazite crystal. As shown in the photomicrograph (Fig. 1), a monazite crystal occurs within the microcline plate and adjacent to biotite on either side. A small segment of biotite protrudes into the crystal at its narrow end. Small feldspar inclusions also occur within the monazite crystals. In a single section cut from the inclusion area, five euhedrons of monazite were observed, four of which were oriented with their b axes parallel to the c axes of associated biotite.

Fig. 1. Photomicrograph of Monazite crystal in biotite-rich radioactive inclusion.

EXPERIMENTAL PROCEDURES

Separation

Material was collected from locations within those inclusions that indicated highest radioactive intensities, and was taken to the laboratory for further processing. The radioactive minerals in the samples could not be located by inspection or other simple techniques, so that a special technique of separation was developed as the work progressed.

The radioactive samples consisted of easily separable mineral components. Biotite was present varying from minute flakes to sheets or books 1/16 to 1/8 inches thick and 5 inches in cross section. The larger sheets were predominant. These biotite books were interlayered with feldspar plates as much as 1/4 inch thick and some quartz also was present. The material was friable and could be broken easily by hand.

Initial separation of the mineral fragments was made in an experimental ore dressing mill. The material was put through a jaw crusher, the fine component screened out, and the remaining crushed mixture passed through rolls. The mixture collected from the rollers was separated by hand into two size grades using a 15 mesh screen. The result of this separation was three size grades with essentially monomineralic fragments consisting predominately of biotite, quartz and feldspar. Some of the fragments contained minor adhering or included minerals.

The next stage of work involved separation of the radioactive particles from the other material in amounts such that chemical and x-ray analyses could be made and positive identification established. Pure crystalline material was needed, and further work was aimed at obtaining such material.

It was decided that radioactive fragments could be detected and isolated using the autoradiograph method. Glass plates were coated with geletin and sprinkled with mineral fragments. These imbedded fragments were placed in contact with a suitably oriented x-ray film. The film was developed at the end of five days, and dark deposits on the film indicated the presence of radioactive minerals. The films, having been oriented by markings corresponding to marks on the glass plate, were then matched with the imbedded fragments on the plate and the spots thereby were superimposed on the fragments that caused the darkening. These fragments then were removed from the plate for further study. This method provided excellent results but yielded limited amounts of material and was time consuming. It did serve to indicate the size grade that contained the highest proportion of radioactive material, and also indicated that the same mineral was active in all size ranges.

The radioactive fragments were examined microscopically, and the possibility of either xenotime or monazite was indicated by their high indices of refraction and other optical properties. The interference figures apparently were uniaxial, or biaxial with a very small optic angle. These observations indicated a definite specific gravity range which facilitated further separation procedures.

The middle size fraction was between the limits of 30 and 15 mesh screen size and was found to contain the highest proportion of radioactive material. This middle fraction was treated on shaker tables (wet). This gave satisfactory separation between a dark and light fraction. A check with a detection instrument indicated a concentration of active minerals in the dark fraction relative to the light fraction. A large proportion of feldspar and quartz was included with the dark fraction, and heavy liquid separation was utilized in taking this out. Bromoform solution was brought up to a specific gravity of 2.75, and standard heavy liquid techniques were employed in obtaining two components from the heavy fraction derived from the shaker table. One-third of this fraction sank, and was composed of highly radioactive material, the other portion was almost entirely feldspar and quartz and showed no measurable activity. The heavy dark component then was examined under a binocular viewer, and was found to contain 15% to 20% of small red to yellow prismatic crystals approximately 3 mm long and 1 mm in cross section. The crystals were flattened parallel to the orthopinacoid with good development of the (101) faces, and appear to be elongated parallel to the c crystallographic axis. The (110), (010), and (100) faces were well developed, and in some samples the (111) faces were apparent. The remainder of the heavy component was mainly biotite, with some feldspar as attached impurities.

It was necessary at this point to devise a system whereby each specific radioactive fragment could be isolated with reasonable speed for further study. As this problem was being considered, information was received concerning an instrument recently devised by Mr. Eugene W. Cowan, Assistant Professor of Physics at the California Institute. This instrument, which was being used to study cosmic ray radiation, is a continuously sensitive diffusion cloud chamber that operates on the same principle as the Wilson cloud chamber but permits continuous observations. Too, the cloud tracks generated by charged particles remain visible for longer periods of time.

A sample obtained from the autoradiograph studies was taken to Mr. Cowan's laboratory and tested in this instrument. The fragment weighed 1.2 mg and had recorded a moderately dense spot on Eastman "no-screen" double emulsion x-ray film in five days. When placed in the continuous cloud chamber, this fragment emitted particles at the rate of approximately 25 per minute. Both alpha and beta particles were observed, and could be differentiated by means of the length and density of the cloud tracks. A simple cloud chamber then was constructed by the writer in the geology laboratory.

The chamber consists of a round glass cylinder on a thick aluminum base. The cylinder was placed on the base and the joint between was sealed with methyl alcohol. A metal top with an absorbent pad on one side was placed on the glass cylinder, and a valve-controlled scource of alcohol was connected with the pad. A small heating element was placed over this metal top, and heated it to 36 degrees centigrade. A spring-loaded platform was used to hold dry ice in contact with the aluminum base. This arrangment produced the proper temperature gradient to supply air saturated with alcohol vapor within the cylinder, and thus a continuous cloud chamber was in operation. Fragments of hand-picked pegmatite material were placed in the cylinder, and within a period of five minutes it was simple to determine which fragments were radioactive and to what degree by watching the electron and alpha-particle tracks leading away from each mineral particle. In this manner fragments from every size fraction were checked, and approximately four ounces of radioactive material was collected.

It was found that the radiation came from a group of small crystals similar to those that had been determined by the autoradiograph method, and that no other significantly radioactive fragments were present. The crystals range in color from deep red to honey yellow, and appear to be monoclinic and of prismatic habit. Microscopic examination indicated that all the crystals were of essentially the same mineral species despite the color differences. The purest crystals then were separated for use in chemical and x-ray examination.

X-ray Examination

The honey-yellow crystalline material was isolated, crushed and halved; one portion was analysed spectrographically by a testing laboratory and the other prepared for x-ray analysis. Another sample was obtained from the deep red material, and also was prepared for x-ray analysis.

Copper radiation was used in the x-ray work. The wave length of the unresolved CuK radiation was taken as 1.5418 Angstrom units, and the United States Geological Survey tables of d spacings were used in computations. A nickel filter was used with a North American Phillips camera having a diameter of 114.6 mm. The computed d spaces are comparable with d spacings obtained from a monazite from southern Korea by Mr. C. W. Chesterman(3) and reported in a paper by Mr. C. Osborne Hutton(3).

The correlation of d spacings between the red and the honey-yellow crystals was perfect, thus demonstrating the identity of the different colored crystals. The d spaces for the three highest intensity lines are given below in Table 1.

TABLE 1

Red Crystal		Yellow Crystal	
Spacing	Intensity	Spacing	Intensity
3.25	7	3.27	7
3.06	10	3.07	10
2.84	8	2.85	8

The correlation of d spacings between the data presented by Hutton and the present experimental data is excellent, and confirms the identification of the mineral as monazite.

Complete comparison of these data is presented in Table 2, and a reproduction of the powder diffraction photograph is shown in Fig. 2.

Chemical Analysis

The spectrographic analysis showed the following chemical constituents: Major constituents (greater than 10%) Lanthanum, Cerium, and Phosphorous. Intermediate (1 to 10%) Neodymium, and Praseodymium. Minor constituents, Silicon 1%, Calcium .5%, Yttrium .5% and Thorium .1%. The chemical composition thereby suggested is essentially (Ce, La, No, Pr) PO_4 with ThO_2, and hence is compatible with identification of the mineral as monazite.

TABLE 2

COMPARISON OF MONAZITE PATTERNS

Monazite from San Diego Co.		Monazite from Southern Korea(7)	
Spacings	Intensities	Spacings	Intensities
5.13	3	---	---
4.70	3	4.72	4
4.15	3	4.17	6
3.48	5	3.52	5
3.27	7	3.31	7
3.07	10	3.09	10
2.96	2	2.99	2
2.85	8	2.88	7
2.59	3	2.61	2
2.44	3	2.45	3
2.18	4	2.19	4
2.130	4	2.139	6
1.957	6	1.969	5
1.928	1	---	---
1.890	2	1.899	2
1.870	6	1.875	6
1.794	3	1.800	2
1.760	1	1.766	4
1.734	4	1.746	6

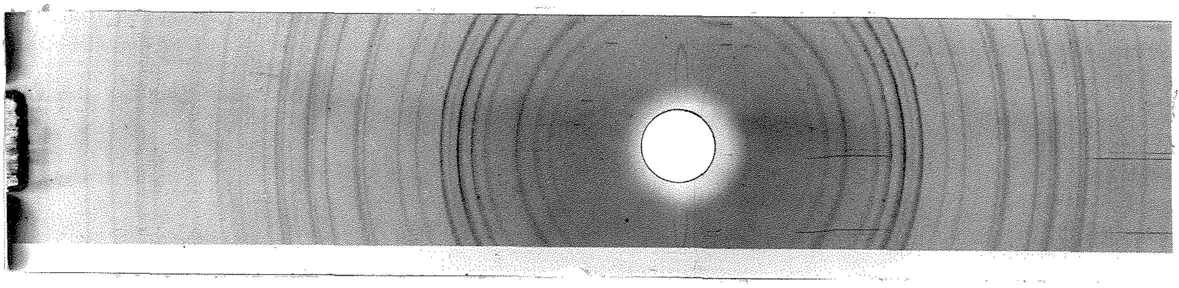

Fig. 2. Powder pattern CuK radiation, Ni filter Camera diameter 114.6 mm. Monazite.

THEORETICAL CONSIDERATIONS

Where the constituent elements in a natural mineral have been established, a general outline of their geochemical behavior may be presented. In describing the geochemical action of the elements that formed the monazite, the presence of the elements Th, La, Ce, Nd, and Pr, as well as the mechanics of their concentration in the late phases of differentiation must be explained. The origin on the phosphorous also is of interest.

According to Rankhama and Sahama(5), the rare-earth elements would be expected to be fixed early in the crystallates from a cooling magma by virtue of their high E values. The E values is a measure of the activation energy of migration of an ion or a measure of the energy required to lift an ion out of its ordered state under specific conditions of coordination and valence(4). These elements however, are usually concentrated in the residual liquors because of their inability to maintain electrical neutrality of the structures when they substitute for the large cations in silicate minerals. The inability to maintain electrical neutrality is due to the high valency of the rare-earth elements which cannot be balanced by a suitable exchange between other parts of the structure. For this reason and from the fact that minerals that can accomodate the rare-earth elements at high temperatures are so rare that concentration of these elements in residual fluids is not impeded, it seems probable that the elements Ce, Pr, Nd, and La, (always found together in mineral occurrence)(6) have been concentrated in the pegmatite under consideration to such an extent that stable equilibrium with the PO_4 in monazite structure was attained.

Thorium also continues to be concentrated after the main stage of crystallization has been completed, despite its high E value. This is explained in the same manner as the concentration of the rare-earth elements(4), and is due to the difficulty of a tetravalent ion of such a large ionic radius in entering the magmatic silicate structures(7).

The scource of the phosphorous in the monazite might be the pegmatite liquid, as some phosphorous might remain as a residuum of material not taken up by formation of apatite during the earlier stages of crystallization of the parent magma. Monazite and other phosphorous-bearing minerals commonly occur in pegmatites having this residuum as their scource of phosphorous(5). In considering the occurrence of monazite within the biotite-rich inclusions, however, the localization of monazite points to a different explanation.

No monazite is present in the pegmatite outside of these inclusions, nor do any other phosphate minerals occur in the pegmatite proper. This leads to two alternate hypotheses: First, the phosphorous could have been the result of a residuum left over from the parent magma, and its subsequent concentration in the inclusion could possibly be the result of a diffusion of phosphorous ions into the inclusion. Diffusion would probably be slow and incomplete at the moderate to low temperatures within the pegmatite; and if this mechanism were responsible for the entrance of the phosphorous into the inclusion, some phosphorous bearing minerals would be expected to appear elsewhere in the pegmatite. The absence of other phosphorous bearing minerals in the pegmatite, and that fact that a valid reason for any such affinity mentioned above is not evident would obviate this hypothesis in favor of another. Secondly: The inclusion itself might have been the scource of the phosphorous. Thin section study of included masses within the pegmatite, but near the border zone, shows small crystals of apatite in limited amounts. These same sections show little or no evidence of monazite formation. Inclusions near the center of the pegmatite, either adjacent to or very near the quartz core, show excellent development of euhedral monazite but do not contain apatite. It is probable that apatite-bearing inclusions, which were in a position near the center of the pegmatite, were under such conditions of pressure and temperature that reaction of the late concentrated rare-earth elements and thorium with the phosphate mineral (Apatite) in the last liquors of the pegmatite was possible to a high degree. The calcium probably was taken up in forming limited amounts of albite. The inclusion was permeated with these late liquids; and minerals were formed in equilibrium under conditions of high pressure, moderate temperature, and high concentrations of volatile constituents. It is thought that this second mechanism is probably the explanation for the scource of phosphorous in the monazite. The determining factor in satisfying the equilibrium of the monazite as opposed to the apatite is thought to be the high concentration of rare-earth elements.

If the phosphorous in the monazite was derived from within the inclusion, a scource of apatite must be postulated for the roof pendants in the late Mesozoic intrusives. The closest correllation to these inclusions is the Julian schist (Triassic?)(1) for which the type section is fifty miles north of the mapped area. These schists are variable in composition and are reported to be predominately metasediments. It is possible that the scource of apatite in the inclusions was the phosphate content of these sediments. Published data(1) indicate little or no apatite content in Julian schist, but data are not available for the biotite schist inclusions present in the area studied. It is quite possible that apatite could have been introduced into the biotite schist at the time of the Mesozoic intrusion and should the metasediments prove to be barren of apatite, this would serve as an alternate hypothesis.

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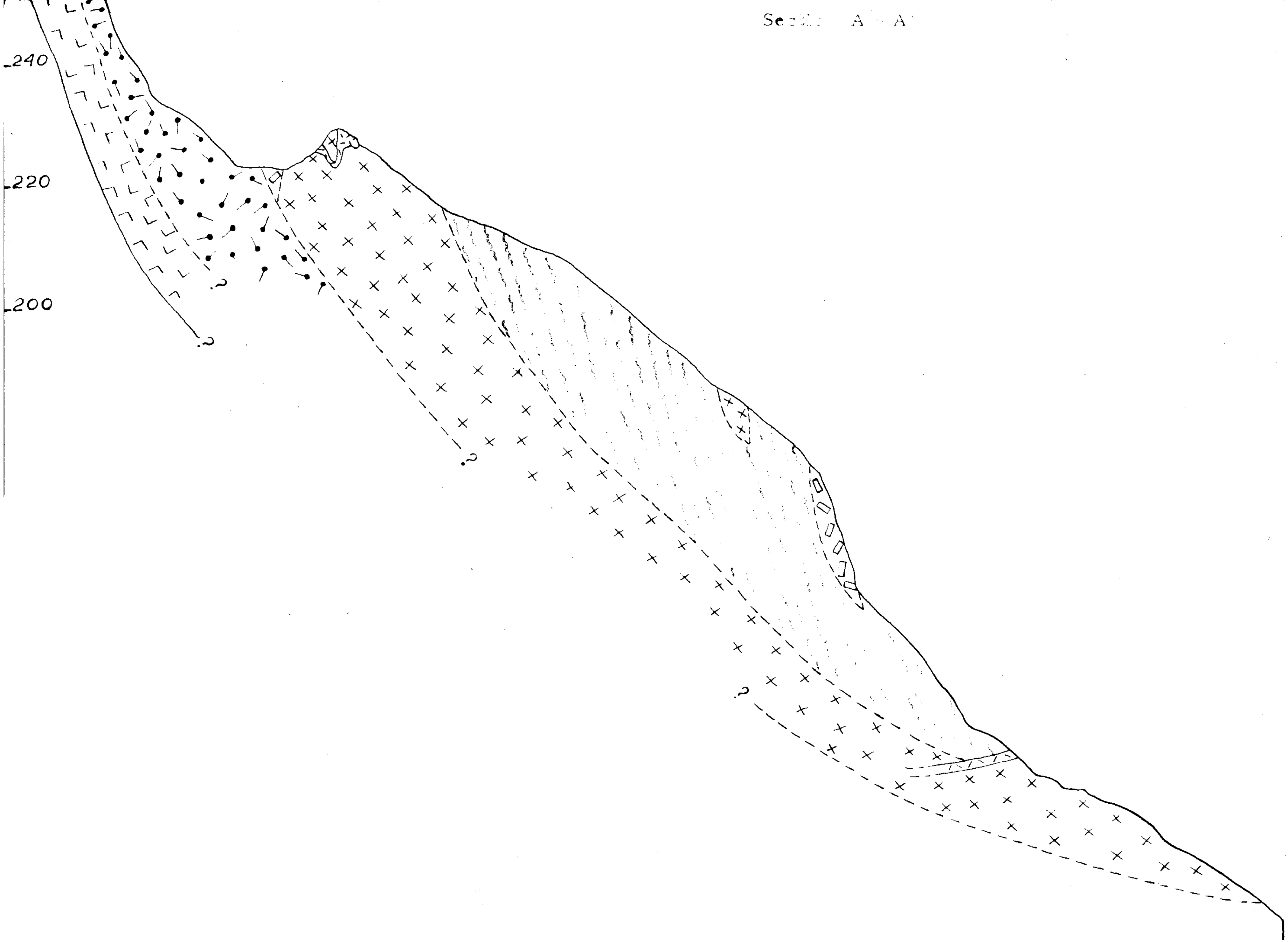
Section A - A'

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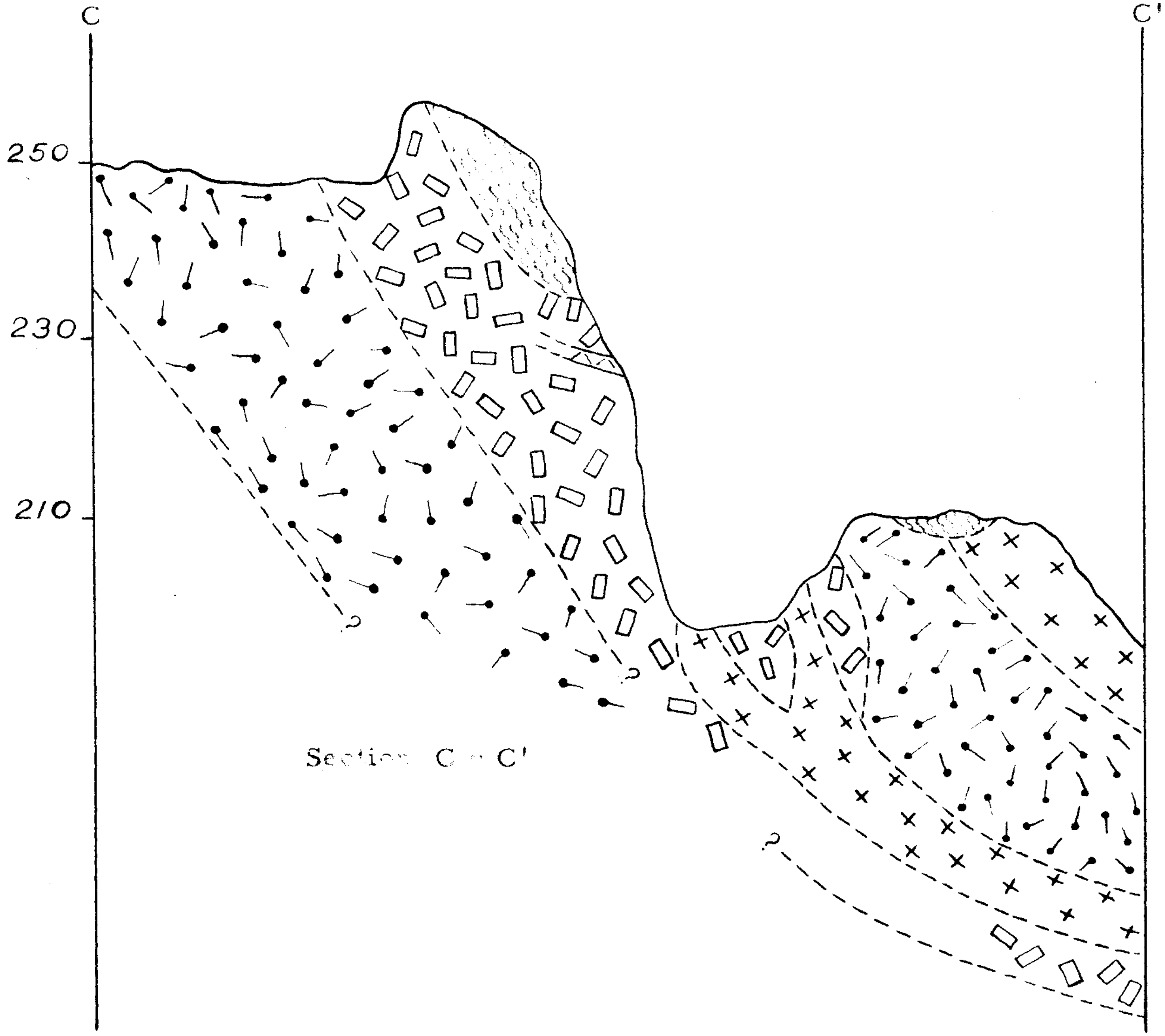

Section C - C'