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THE INTRUSIVE SEQUENCE OF
IGNEOUS ROCKS IN THE
GALLINAS MOUNTAINS, NEW MEXICO

A Thesis
Presented to the Faculty of
New Mexico Institute of Mining and Technology

In Partial Fulfillment
of the Requirements for the Degree of
Master of Science
in Geology

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ABSTRACT

The Gallinas Mountains, located in northwestern Lincoln county, New Mexico, were formed by the intrusion of a rhyolite, a trachyte, and a latite into previously undisturbed Permian sediments. The problem associated with these three intrusives is the determination of the intrusive sequence. None of the bodies are in contact with one another, so the relative ages cannot be determined directly. A study of the thermal states of the feldspars found in these intrusives, along with consideration of hydrothermal action associated with the bodies, is used to arrive at an answer to this problem. It is found that the thermal states of the feldspars from the trachyte and rhyolite are about the same and that they are lower than the thermal states of the feldspars from the latite. The thermal state data, along with other lines of reasoning, is interpreted by this writer to show that the intrusive sequence in the Gallinas Mountains is latite-trachyte-rhyolite.

INTRODUCTION

STATEMENT OF PROBLEM

Igneous intrusives present many problems for study. One of these is the sequence of intrusion. In many cases, this problem can be solved in the field by direct observation; intrusion of one rock by another or metamorphism of one rock by another are generally satisfactory for determining the sequence of intrusion, but such straightforward means of determination do not exist in some instances.

In the Gallinas Mountains, three consanguineous (see GENERAL GEOLOGY) igneous bodies are found completely separate from one another, and the problem is to determine the intrusive sequence by another method.

PROPOSAL FOR SOLUTION

Both orthoclase and plagioclase feldspars are known to exhibit some type of structural change when subjected to different heating or cooling rates (Kuellmer, 1958; Smith and Yoder, 1956). The relation between this structural change and the composition of the feldspar is called the thermal state.

Kuellmer (1958) has shown that thermal states of feldspar phenocrysts in a single intrusive vary systematically with position in the intrusive, and that this variation is related to the particular times of intrusion of the various parts of the body. Generally, phenocrysts from the earlier parts of the intrusion have higher thermal states, reflecting a faster cooling rate.

This relation between thermal state and relative time of intrusion should hold true for several intrusive bodies, on the conditions that the bodies are consanguineous and that no reheating of the rocks has occurred.

This writer will measure and compare the thermal states of feldspar phenocrysts from the Gallinas Mountains in an effort to determine the intrusive sequence there.

ACKNOWLEDGEMENTS

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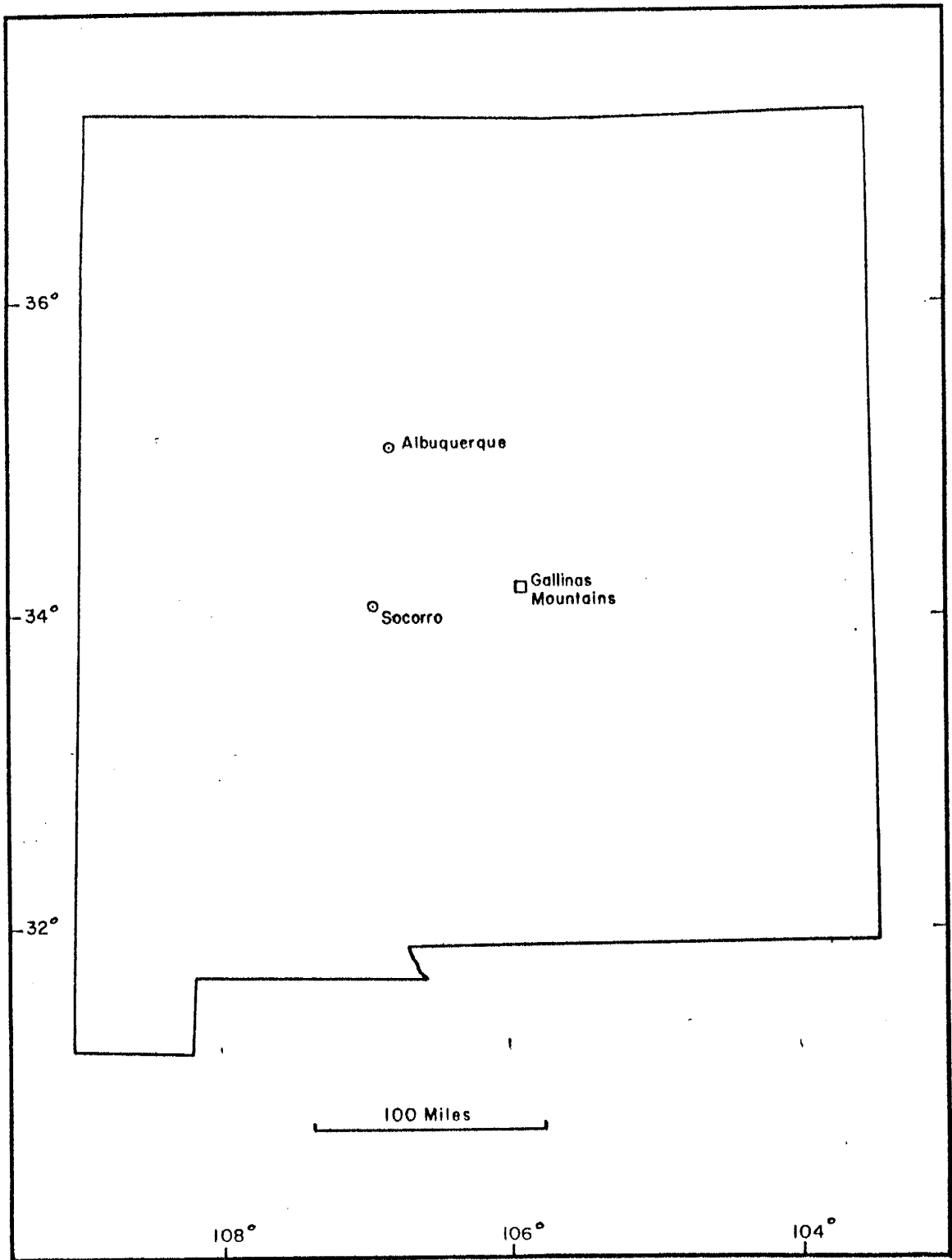


Fig. 1. Index Map

GENERAL GEOLOGY

LOCATION

The Gallinas Mountains are located in northwestern Lincoln county, New Mexico, about 75 miles east of Socorro, New Mexico, (Fig. 1). The mountains are easily accessible by dirt roads leading to nearby highways.

PREVIOUS WORK

The geology has been described and mapped by Perhac (1960), and Kelly (1946). Descriptions of the mines and mineral deposits are included in other reports by Griswold (1959), Kelly (1949) and Rothrock and others (1946).

STRATIGRAPHY

Descriptions of rocks present in the area, other than the three intrusions, are taken largely from Perhac. Data on the intrusion are primarily the responsibility of this writer.

Precambrian Rocks

Granite occurs in three small areas. All three are the result of exposure by erosion of raised fault blocks. Only one outcrop is shown in Fig. 2, because the others are too small to show on this scale.

In the Gallinas Mountains, the granite can only be dated as pre-Abo, or, pre-Early Permian. However, no Early Paleozoic intrusions occur nearby, so the rock is most likely Precambrian (Perhac, p. 18).

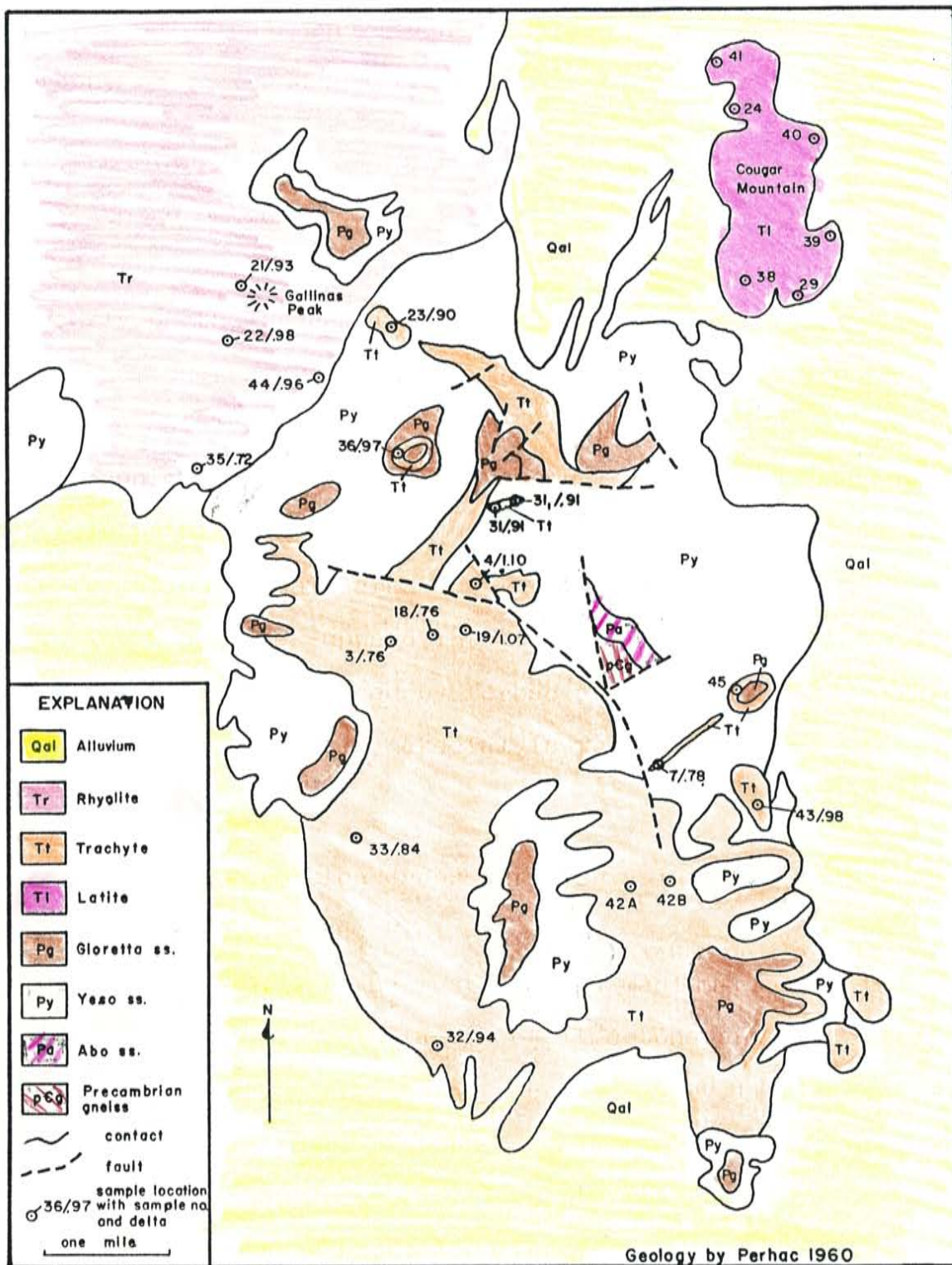


Fig. 2. Geologic and sample location map of the Gallinas Mountains

The granite is light grey, massive, medium- to fine-grained, and equigranular. Quartz, microcline, and oligoclase are the principal constituents with minor amounts of magnetite, zircon, sphene, and apatite.

PERMIAN ROCKS

Abo Formation

In the Gallinas Mountains, the Abo formation rests directly on the Precambrian granite.

The lower section of the formation is a basal conglomerate, composed mainly of pieces of granite with some fragments of metamorphic material. Above the conglomerate is a sequence of feldspathic sandstones and siltstones. The thickness of the formation in this area is probably about 175 feet.

The Abo grades upward into the overlying Yeso formation, and the contact is placed by Perhac above the highest strata in which coarse arkosic material is found.

Yeso Formation

The Yeso formation crops out over a large area in the Gallinas Mountains (see Fig. 2).

The rock is, for the most part, a medium-grained feldspathic sandstone. Thin layers of limestone and shale are found at various levels in the section. Very little gypsum is found in this area. Gypsum is characteristic of this formation in other areas. The average thickness of the Yeso in this area is about 1600 feet.

The upper contact with the Glorieta formation is quite sharp.

Glorieta Formation

The Glorieta formation is the youngest sedimentary rock in the area and is found capping many of the higher portions of the mountains. It is a white to light grey, medium-grained orthoquartzite. A complete section does not exist in the Gallinas Mountains so the total thickness is not known, although 250 feet of section is exposed.

TERTIARY IGNEOUS ROCKS

In the Gallinas Mountains, three igneous rocks occur that are younger than the Permian sediments. These rocks are a porphyritic latite, a porphyritic trachyte, and a porphyritic rhyolite. These intrusions are dated as Tertiary by analogy to intrusions to the south in the Capitan-Nogal districts in southern Lincoln county, which cut Late Cretaceous and Early Tertiary rocks (Griswold, Pl. 1). The Gallinas intrusives are considered by Griswold (p. 13) to belong to this same group of igneous bodies.

Porphyritic Latite

Porphyritic latite occurs in Cougar Mountain, in the northeast part of the region (Fig. 2). The outcrop area is elongate, the long axis of which lies along a north-south line. Quaternary alluvium surrounds the body entirely, and no remnants of pre-intrusive rock are found in contact with the body. Consequently, the shape of the mass cannot be determined. Perhac (p. 61) believes it to be a small cross-cutting stock, because of undisturbed Yeso beds nearby (Fig. 2).

The rock is massive, with no noticeable flow structure,

either macroscopic or microscopic. Many prominent east-west trending, vertical joints exist in the central part of the body. These joints are clearly seen on aerial photographs. They may be part of some primary fracture pattern in the rock.

In hand sample, the rock is holocrystalline-porphyritic, with a medium-grained groundmass. Fresh surface color is light grey, but the weathered surface is medium grey with limonite stain. Phenocrysts are euhedral, equidimensional, white plagioclase crystals, about 1 cm long. Euhedral crystals of hornblende, occurring both as phenocrysts and as poikilitic intergrowths in the plagioclase phenocrysts are common. A few small mafic clots of about equal amounts of orthoclase and hornblende are scattered throughout the intrusion.

Microscopically, the groundmass is orthoclase and hornblende with minor amounts of plagioclase, sphene, apatite and magnetite. A few grains of quartz are also present. Groundmass grain size is about 0.5 to 2.0 mm. The average mineral content, as estimated visually in thin section is:

Plagioclase	
Phenocrysts (An ₁₂₋₁₄)	35-40%
Groundmass	1%
Orthoclase	20-25%
Hornblende	25-30%
Sphene	} 5%
Apatite	
Magnetite	
Quartz	

Minor deuteric alteration occurs as narrow sericite rims around the plagioclase phenocrysts, and has converted hornblende and magnetite to limonite.

Porphyritic Trachyte

A large body of porphyritic trachyte forms the southern and eastern part of the Gallinas Mountains (Fig. 2). That the intrusive is a laccolith is suggested by the fact that the upper and lower contacts of the intrusive are conformable with the sediments and the central part of the intrusive is much thicker than the edges (500 feet as compared to 30 feet, Perhac, p. 43).

A northwest trending fault divides the laccolith into two parts. The northeast part is still largely covered by Permian sediments, and many small sills and dikes occur in this area.

The rock is generally massive, although pronounced flow structures are found near contacts and in the smaller dikes and sills.

Hand samples show a holocrystalline-porphyritic texture. Colors are variable; purple groundmass with white phenocrysts, yellowish-tan groundmass with grey phenocrysts (most common) and grey to brown groundmass with pink phenocrysts are typical. Both lath- and rhomb-shaped phenocrysts of orthoclase occur, generally 4-10 mm long. Some samples contain almost all plagioclase phenocrysts, causing the mineralogic composition of the rock to grade into a latite.

Microscopically, the groundmass is orthoclase, plagioclase, and remnants of a mafic mineral, probably hornblende. Quartz, magnetite, apatite, and sphene are found in minor amounts. The average mineral content is:

Trachyte

Orthoclase	
Phenocrysts	30-40%
Groundmass	30-35%
Plagioclase (An ₆₋₈)	10-15%
Quartz	1-5%
Hornblende remnants	1-5%
Magnetite	} 5%
Apatite	
Sphene	

Latitic Phase

Plagioclase	
Phenocrysts (An ₆₋₈)	30-40%
Groundmass	10-20%
Orthoclase	25-30%
Quartz	1-5%
Hornblende remnants	1-5%
Magnetite	} 5%
Apatite	
Sphene	

Hydrothermal alteration occurs throughout the intrusive. The feldspar phenocrysts are commonly altered to sericite and kaolinite on their borders. In some of the small dikes and sills, the groundmass grains are almost completely replaced by sericite, and the phenocrysts are largely altered to kaolinite. The mafic mineral, hornblende (?), has been altered to chlorite and then to limonite. Magnetite is replaced by limonite. Post-crystallization hydrothermal deposits of fluorite and copper ores are found associated with the trachyte throughout the area.

Porphyritic Rhyolite

A rhyolite intrusive body occurs in the northwestern part of the Gallinas Mountains. This intrusive is also a laccolith, with conformable contacts and a thick central section that thins rapidly in all directions. Small rhyolite dikes and sills extending into the country rock are associated with this laccolith but are much less numerous than those associated with the trachyte.

The rock is quite massive with no flow structures observed either macroscopically or microscopically. Several sets of joints are present in the rock. Joint planes are curved rather than straight, giving the appearance of conchoidal fractures.

In hand sample, the rock is light yellowish-tan, and has a holocrystalline-porphyritic texture with a fine-grained to aphanitic groundmass. Mirolitic cavities that have been filled with quartz give the appearance of quartz phenocrysts. Other partially filled cavities are lined with feldspar crystals. Phenocrysts of feldspar also occur. The quartz grains average about 1-3 mm, and the feldspar phenocrysts, 1-2 mm.

Microscopic examination shows the groundmass grain size to be about 0.1 mm or less. Minerals present in the groundmass are orthoclase, plagioclase, quartz, magnetite, biotite, apatite and sphene. The average mineral content is:

Orthoclase	
Phenocrysts	5-10%
Groundmass	45-50%
Plagioclase (An ₆₋₈)	10-15%
Quartz	
Phenocrysts	1-5%
Groundmass	10-15%
Magnetite	} 5%
Biotite	
Apatite	
Sphene	

Hydrothermal alteration of the rhyolite is comparable to that of the trachyte, but developed to a lesser degree. Sericite and kaolinite replace parts of the groundmass feldspars and the feldspar phenocrysts respectively. Magnetite and biotite are altered to limonite. No hydrothermal deposits occur in association with the rhyolite.

Petrologic Relations

The latite, trachyte, and rhyolite are similar in several ways. The rhyolite and trachyte contain about the same percentage of orthoclase and plagioclase, and the plagioclase of these two rocks is the same composition. The latitic phase of the trachyte and the latite from Cougar Mountain also contain about the same percentage of orthoclase and plagioclase. The accessory mineral content is practically the same, except for the mafic minerals. In addition, Perhac has calculated the amount of $K_2O + Na_2O$ present, and found it to be about 13 percent for each of the three rocks.

The rocks differ in quartz content and mafic mineral content, the rhyolite containing the most quartz and the latite containing the most mafic minerals.

The similarities mentioned above suggest that the three rocks are consanguineous.

STRUCTURE

Doming of the Permian rocks by intrusion of the two laccoliths, and normal faulting are the principal structural features.

The doming is gentle, averaging about 15° (Perhac, p. 88). Foliation, when found in the trachyte, parallels the dip of the overlying strata.

The major faults strike northwest and northeast. Perhac believes that the faulting is a result of the doming.

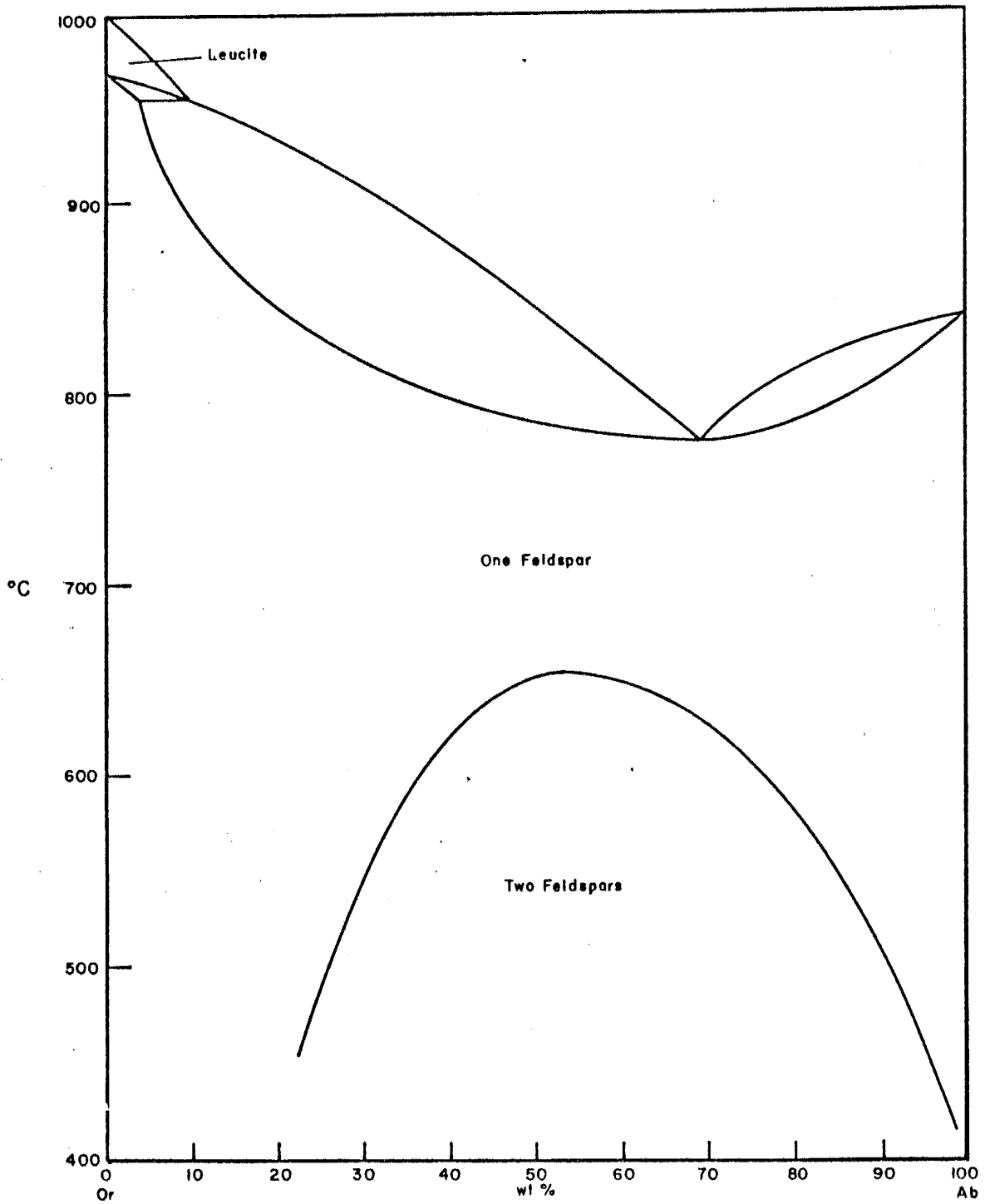


Fig. 3. The system Or-Ab vs. temperature at 2000 kg/cm² pressure H₂O

(Bowen and Tuttle 1950)

METHOD OF INVESTIGATION

The purpose of this section is to explain the theory of the thermal states of the feldspars.

THEORY OF THERMAL STATES

Orthoclase

Orthoclase is, in general, an intermediate member of a solid solution series ranging from pure KAlSi_3O_8 to pure $\text{NaAlSi}_3\text{O}_8$. Chemically, this series is continuous, but crystallographically, it is discontinuous, because there is a change from monoclinic symmetry in the potash-rich members to triclinic symmetry in the soda-rich members. Fortunately, this symmetry change does not affect any measurements made by the methods to be described.

The system Or-Ab is characterized by a solvus, or unmixing curve, as shown in Fig. 3 (Bowen and Tuttle, 1950). Water pressure variations in the system will change the solidus and liquidus significantly, but will not appreciably affect the position of the solvus, because water is not involved in the equilibria of the unmixing (Bowen and Tuttle, p. 499).

Several names used for different feldspars in this paper should be defined. A true sanidine is a feldspar in which the two phases have been completely mixed, or homogenized. A pseudo-sanidine is a feldspar in which the K and Na ions are mixed, but the Al and Si ions retain much of the crystallographic ordering characteristic of the sodic

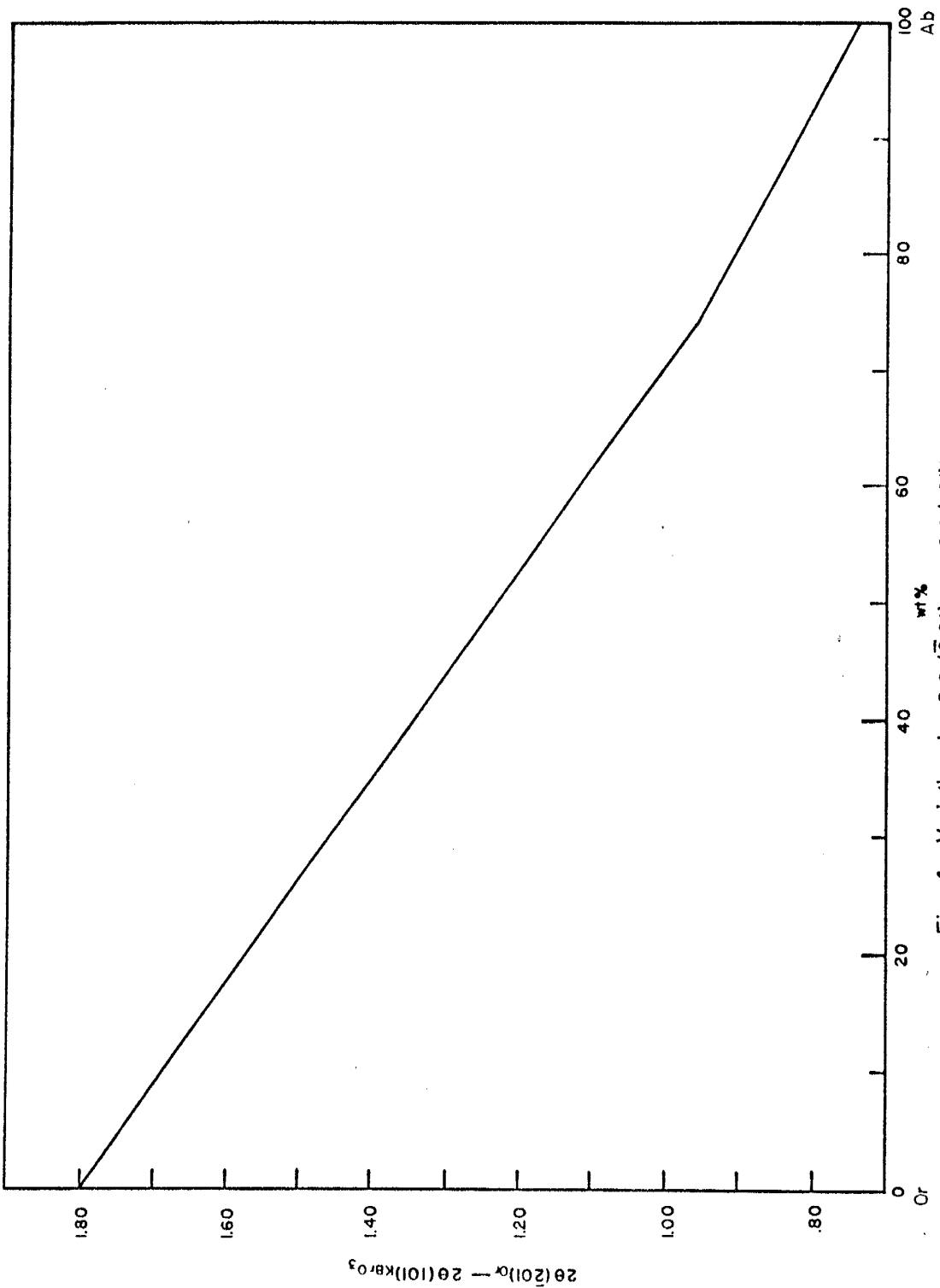


Fig. 4 Variation in 2θ ($\bar{2}01$) or -2θ ($10\bar{1}$) KBrO_3 with percent Or in feldspar

(Orville 1963)

and potassic phases. A pseudo-sanidine and a true sanidine have almost identical X-ray diffraction patterns, except for slight changes in the 2θ positions of some of the peaks. A perthite is a feldspar in which exsolution or unmixing of the two phases has taken place to such a degree that on an X-ray diffraction pattern, each phase is represented by its own particular set of peaks. Perthites can exist with any degree of unmixing present.

The process of unmixing and mixing of feldspars can be carried out in the laboratory. Ideally, the process should take place immediately when the proper temperature is reached for a given feldspar composition. The process is slow, however (Laves, 1952, p. 567), as is the situation for many reactions in silicate systems. Complete homogenization of a perthite can be hastened considerably, as can unmixing of a sanidine, by the addition of water to the system for, although water does not enter directly into the reaction, it acts as a catalyst (Bowen and Tuttle, 1950).

Because of the slowness of the remixing, pseudosanidines can be made by heating perthites to some temperature above the solvus for a short time with no water present.

Compositions of sanidines can be determined by measuring the difference in 2θ position of the $(\bar{2}01)$ peak of the sanidine and the (101) peak of KBrO_3 . A relation exists between this difference and the weight percent orthoclase (Orville, 1963), and is shown on the graph in Fig. 4. As mentioned above, the diffraction peaks of pseudo-sanidines have slightly different 2θ values than true sanidine peaks.

In the case of the ($\bar{2}01$) peaks, the 2θ value for the pseudo-sanidine is always larger than that for the true sanidine. This greater value will give an apparently higher weight percent orthoclase for a pseudo-sanidine than for a true sanidine of the same composition. (see Fig. 4) This apparent difference in composition is a measure of the amount of homogenization induced into a perthite by heating dry, at a temperature between the solvus and solidus.

A convenient method of relating the apparent composition of the pseudo-sanidine to the true composition of the feldspar has been devised by Kuellmer (1958). This method defines a number, δ , as $\frac{1 - Or_a}{1 - Or_t}$, where Or_a is the apparent composition of the pseudo-sanidine, and Or_t is the true composition of the feldspar sample.

Now, if several feldspar samples in various states of unmixing are heated for the same length of time at the same temperature above the solvus, and the true composition and pseudo-sanidine composition for each sample is converted to a δ value, the samples that were initially more unmixed will have lower δ values than the more homogeneous samples. Because the initial unmixing of the sample is dependent only on the cooling rate of the sample, δ is thus a measure of the thermal state of the sample, as defined earlier. High δ values correspond to a high thermal state, and low δ values to a low thermal state.

A second method of determining thermal states of alkali feldspars was also devised by Kuellmer (1959). In this paper, Kuellmer (1959) has shown that X-ray line broadening in each

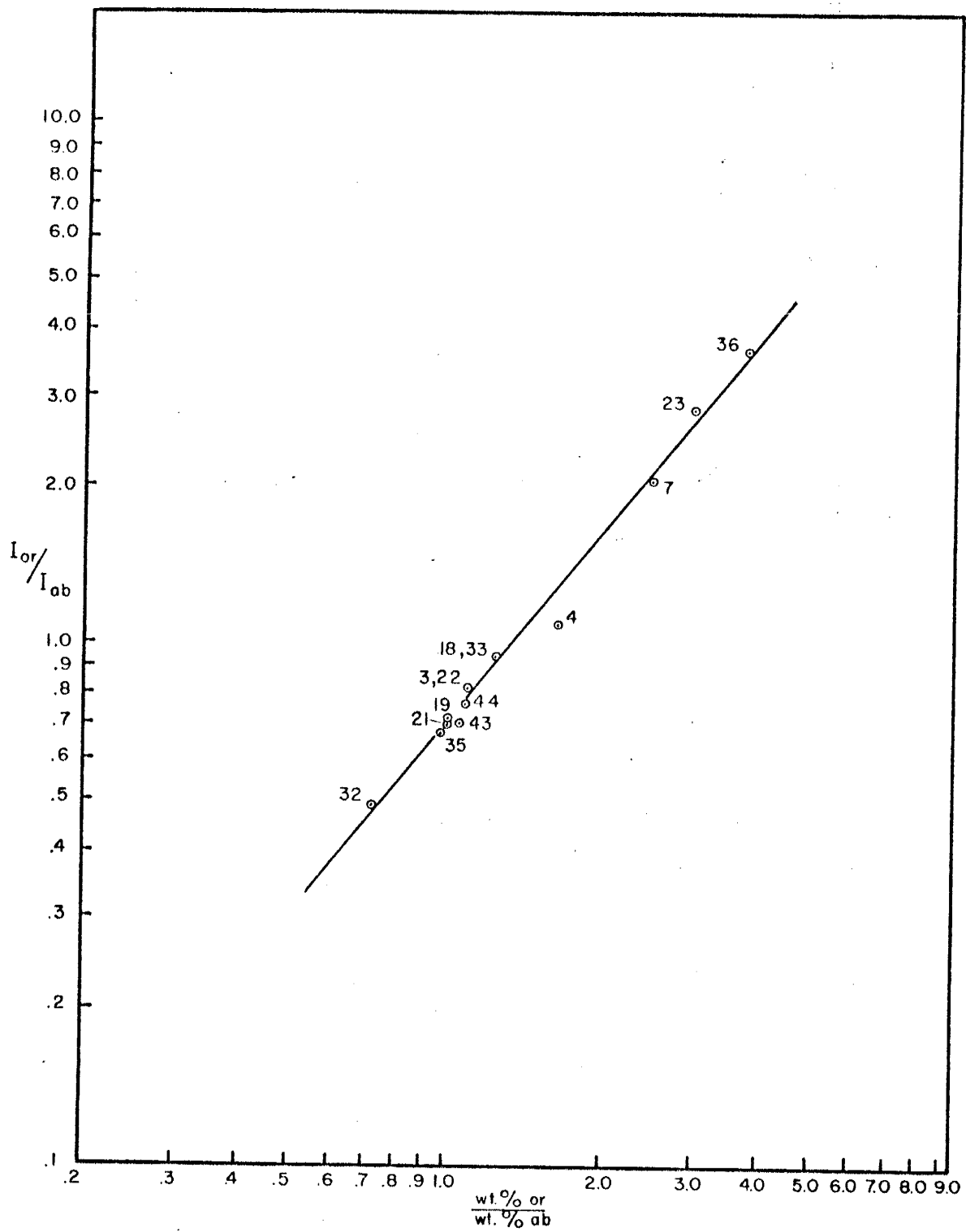


Fig. 5 Variation of $(\bar{2}01)$ peak intensity ratios with compositional ratio

phase of a perthite is dependent on the thermal state of the feldspar. Specifically, the three causes of line broadening that are dependent on the thermal state are; particle size differences of the two phases due to different amounts of unmixing, particle distortion of one phase by another during unmixing, and lattice mistakes in the crystal structure.

Kueller derived the relation, $\frac{I_{or}\beta_{or}}{I_{ab}\beta_{ab}} = k\frac{X_{or}}{X_{ab}}$, where I is the intensity of the phase abbreviated in the subscript, X is the weight percent of each phase, and β is the integral breadth, which is proportional to the line broadening.

A plot, on a logarithmic scale, of weight percent ratios vs. intensity ratios of feldspars of different thermal states, should be a series of straight lines (Kueller, 1959), each line representing the broadening ratio for the feldspars of that particular thermal state. Thus, all feldspars that fall on a straight line when plotted on a graph such as the one in Fig. 5, are at the same thermal state.

Plagioclase

The plagioclase series is a complete solid solution series, with no solvus present. Consequently, a method based on something other than unmixing relations must be used to determine the thermal states of plagioclase samples. Two variations of such a method exist (Goodyear and Duffin, 1954; Smith and Yoder, 1956). The method given by Smith and Yoder is used in this paper.

Smith and Yoder have shown that significant angular separation changes occur in two pairs of diffraction peaks of plagioclase. The pairs are; (131) and ($1\bar{3}1$), and (220) and ($2\bar{2}0$).

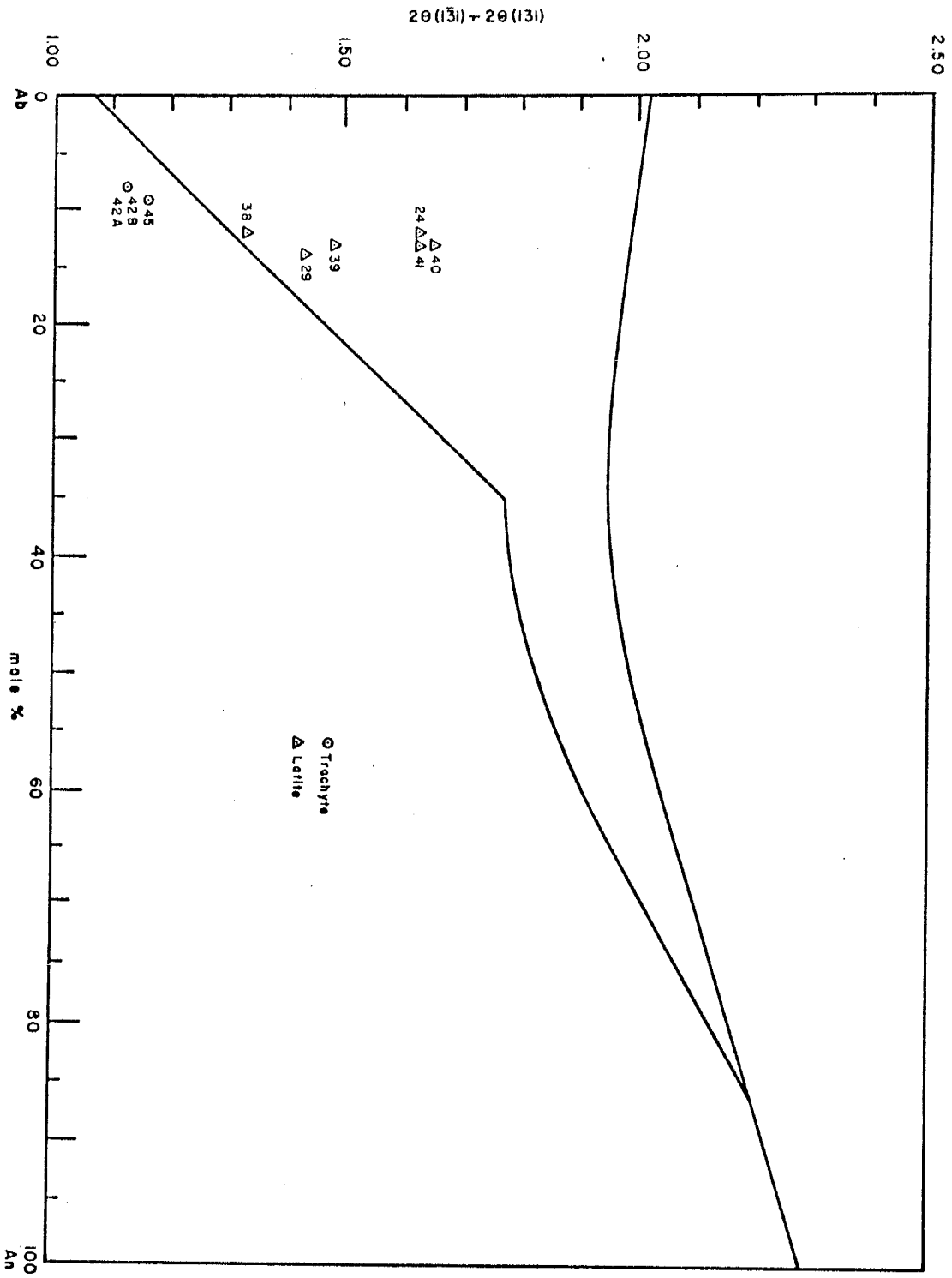


Fig. 6 Variation of $2\theta(1\bar{3}1) - 2\theta(131)$ with composition in plagioclase (Smith and Yoder 1956)

and $(1\bar{3}1)$. In general, plagioclases that have cooled rapidly after crystallization will have a different angular separation of diffraction peaks, than plagioclases of the same composition that have cooled slowly. For the pair of peaks used in this paper, the (131) and $(1\bar{3}1)$ peaks, the separation is greater for rapidly cooled samples than for slowly cooled samples.

Smith and Yoder have found that maximum and minimum values exist for these separations. The upper line in Fig. 6 represents the upper limit of separation as determined from data of plagioclase samples synthesized dry. The curved section of the lower line represents the lower limit of separation as determined by measurements on plagioclase samples from the Skaergaard, Great Dyke, Bushveld, and Stillwater igneous complexes. These latter samples are considered to have cooled more slowly than any other samples. The straight section of the lower curve is determined from plagioclase samples from granites. The exact shape and position of this section is listed as uncertain (Smith and Yoder, p. 640) because doubts exist about the homogeneity of plagioclase in this range of composition.

Examinations of (131) - $(1\bar{3}1)$ peak separations of plagioclase samples from various types of igneous rocks were made by Smith and Yoder, and the results plotted on a graph like that shown in Fig. 6. Generally, plagioclase from pegmatites, granites, and metamorphic rocks plotted along the lower curve. Plagioclase from volcanic rocks fell about halfway between the upper and lower limits for more sodic

compositions, and slightly higher for more calcic compositions. Only the natural samples that had been heated to temperatures near their melting points, and the synthetically prepared samples plotted along the upper curve in the more sodic compositions.

The change in separation is due to changes in lattice parameters, such as those found in work done by Laves and Chaisson (1950). Laves and Chaisson state (p. 589) that high albite is more triclinic than low albite. High and low, in this case refer to a structural state that is dependent on thermal history. More triclinic means that the crystal structure of the high state is less similar to monoclinic symmetry than is the symmetry of the low state. This explanation agrees with the peak separation data of Smith and Yoder. The more monoclinic a crystal becomes, (from a triclinic direction) the more nearly the 2θ values for the (131) and ($\bar{1}$ 31) peaks should approach each other.

EXPERIMENTAL PROCEDURE

SAMPLE COLLECTION

Twenty-five samples were collected from the Gallinas Mountains; four from the rhyolite, fifteen from the trachyte (including three samples of the latitic phase), and six latites from Cougar Mountain.

The rhyolite samples are located as follows: 21, top of Gallinas Peak; 22, a canyon south of Gallinas Peak; 35, near the southern edge of the laccolith; 44, at the southeast edge of the laccolith. All samples were uniform in appearance.

Trachyte sample locations are: 3, 18, northwest part of the main intrusive mass; 19, 42A, 42B, central part of the main intrusive mass (42A and 42B are latites); 32, 33, near the southern and western edge of the laccolith; 7, 31, 31₁, dikes in the eastern part; 23, 36, 43, 45, sills in the eastern part (45 is a latite); 4, small fault block, this sample is very coarse grained.

Because the form of the latite intrusive is not known, locations of samples can not be related to intrusive contacts. The six samples were collected from reasonably fresh rock.

SAMPLE PREPARATION

Orthoclase

Whole rock samples of rhyolite and trachyte were crushed to minus 14 mesh and fragments of the phenocrysts picked out under a binocular microscope. Fragments were selected for

freshness of appearance; only fragments with shiny cleavage faces were taken, since dull faces suggest a large amount of kaolinite alteration. Despite the care taken in picking grains, probably up to 3 percent of each sample is kaolinite. The few plagioclase grains were visually separated from orthoclase on a color basis, the plagioclase grains present were much whiter than the orthoclase.

The picked samples were cleaned in concentrated HCl to remove the limonitic material that was present in almost all samples. Samples were then ground under acetone in an automatic mortar and pestle to minus 325 mesh.

Plagioclase

Whole rock samples of the Cougar Mountain latite were crushed to minus 14 mesh and the freshest appearing plagioclase phenocryst fragments picked out under a binocular microscope. These samples were crushed to minus 20 mesh, put into tetrabromoethane to separate the poikilitic amphiboles present, and then washed with acetone to remove the heavy liquid. The plagioclase was then ground under acetone in an automatic mortar and pestle to minus 325 mesh.

Plagioclase phenocrysts from the latitic phase of the trachyte were prepared the same as the orthoclase.

TREATMENT OF PREPARED SAMPLES

X-ray diffraction patterns were made using a Norelco high-angle goniometer with Ni filtered Cu radiation. Scanning speed was $\frac{1}{4}^{\circ}$ 2 θ per minute; chart speed was $\frac{1}{4}$ inch per minute. Samples were mounted in aluminum sample holders.

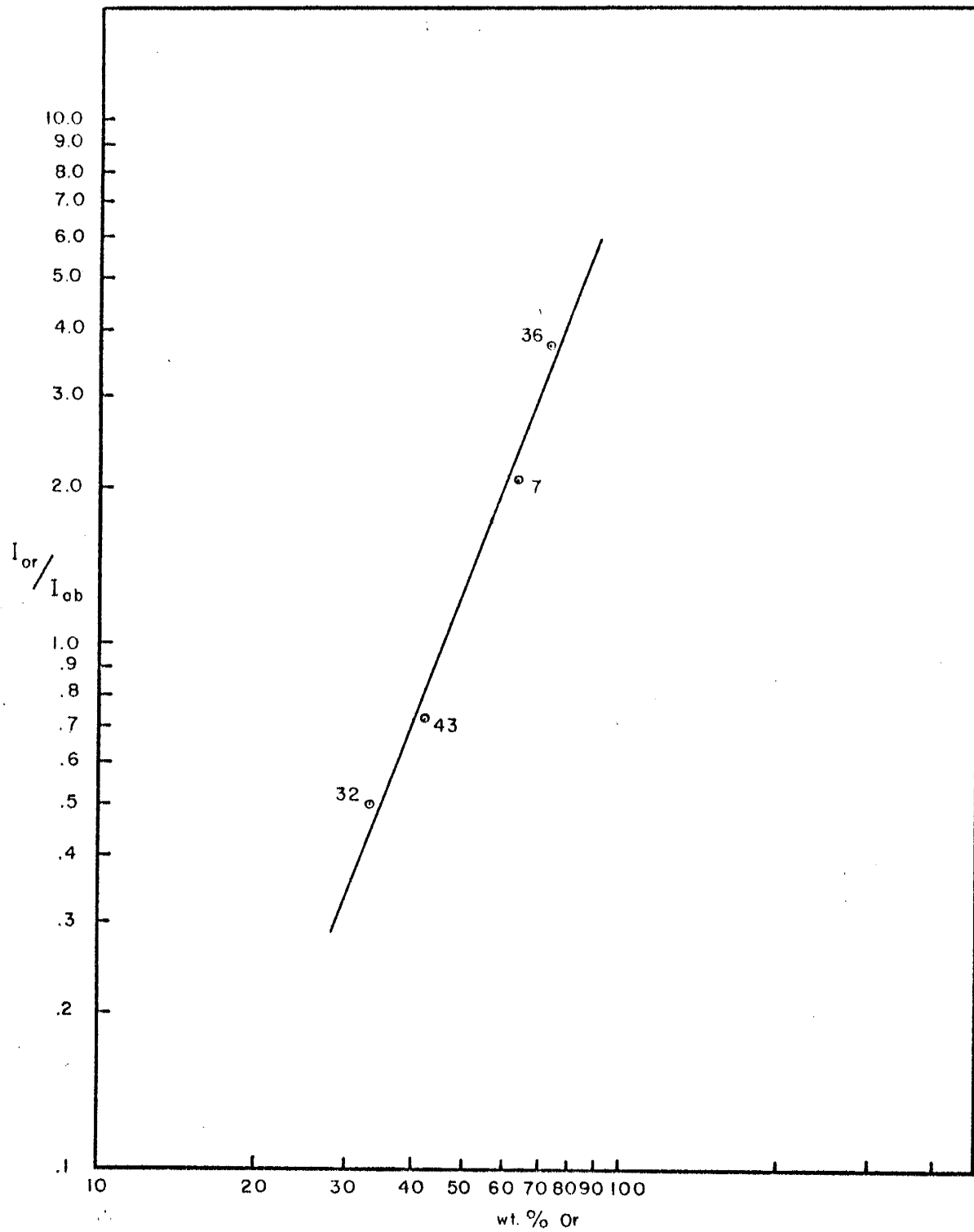


Fig. 7 Variation of $(\bar{2}01)$ peak Intensity ratios with composition

Integrated intensities of diffraction peaks were determined by polar planimeter measurements on the charts.

Peak separation measurements were made to the nearest $0.01^\circ 2\theta$ using an engineer's scale.

Orthoclase

All samples were divided into two parts, and diffraction patterns were made of the (201) peaks of the two phases of the perthites. Integrated intensities were measured from these charts, and from these data, five samples were selected to represent the complete range of intensity ratios. These samples were heated in a high pressure, high temperature vessel at 750°C and 500 bars water vapor for 4 hours to sanidize them completely. After quenching, the samples were removed from the vessel and again ground under acetone to minus 325 mesh. About 0.5 weight percent KBrO_3 , used as an internal standard, was mixed into each sample and a diffraction pattern made of the (101) KBrO_3 peak and the ($\bar{2}$ 01) sanidine peak. The true composition of these samples was obtained by comparing the angular separation of these two peaks to a graph (Fig. 4) by Orville (1963). A graph of true weight percent orthoclase vs. the integrated intensity ratio was constructed from these figures (Fig. 7). It was found later that one of these samples (4) was unsatisfactory (see RESULTS) so only four samples were used to determine the straight line in Fig. 7. This line was fitted to the points by eye. The true composition of all other orthoclase samples was obtained by comparing their intensity ratios with Fig. 7.

The other portion of the samples was heated dry in an

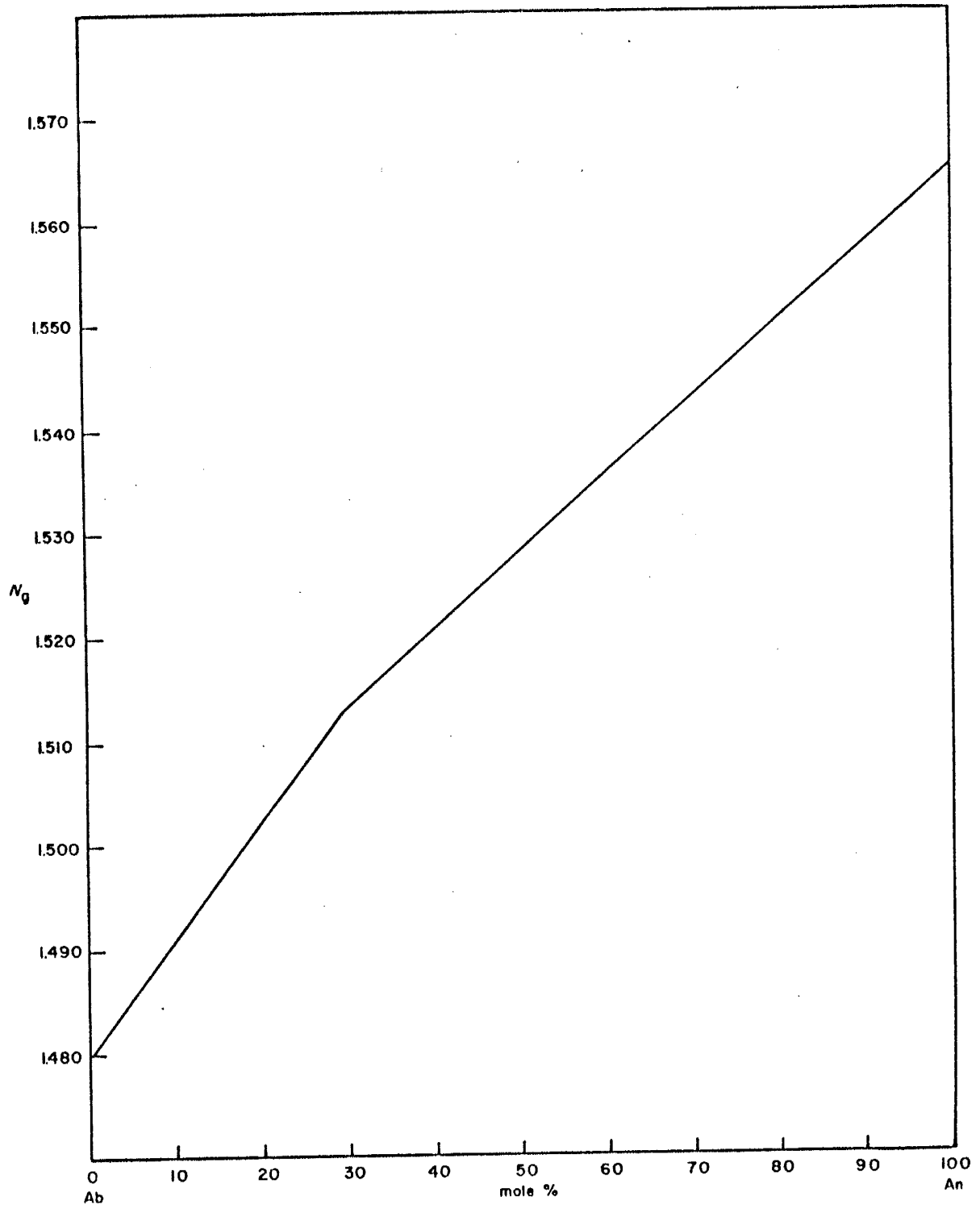


Fig. 8. Indices of refraction of plagioclase glass (Foster 1955)

electric furnace at 1040°C for 48 hours. The purpose of this operation was to partially remix the samples and form pseudo-sanidines. The apparent compositions of these pseudo-sanidines were measured in the same manner as were the compositions of the true sanidines.

From the foregoing procedure, two compositions were obtained for each sample, one for the true sanidine, and one for the pseudo-sanidine. These two compositions are used to calculate a value of δ for each sample. These δ values are summarized in Table I.

Part of the data obtained above can also be used to make a graph showing the line broadening ratio of the samples (Fig. 5). The weight percent Ab was calculated by subtracting the weight percent Or from 100.

Plagioclase

To use the graph of Smith and Yoder, as shown in Fig. 6, it is necessary to find both the mole percent An and the angular separation between the (131) and ($\bar{1}\bar{3}1$) peaks for each sample.

To determine the composition of the plagioclase, part of each plagioclase separation was fused at about 1250°C in an electric resistance furnace and the index of refraction of the resulting glass measured by immersion in suitable oils. This index of refraction was then compared to the curve given by Foster (1955) of mole percent An vs. the index of refraction of plagioclase glass (Fig. 8).

A diffraction pattern for each sample was made in the 2 θ range of the (131) and ($\bar{1}\bar{3}1$) peaks and the angular separation

TABLE I ORTHOCLASE FELDSPAR DATA

Sample	%Ort	%Ora	Delta	Rock Type	Occurrence
3	43	58	.74	trachyte	main intrusive mass
18	46	61	.72	"	"
19	41	38	1.05	"	"
32	33	37	.94	"	"
33	46	57	.80	"	"
4	49	48	1.02	"	near fault zone
7	63	71	.78	"	dike
31	89	90	.91	"	"
31 ₁	89	90	.91	"	"
23	68	72	.88	"	sill
36	72	73	.97	"	"
43	42	43	.98	"	"
21	41	46	.91	ryholite	main intrusive mass
22	42	45	.95	"	"
35	40	58	.70	"	"
44	42	46	.93	"	"

This range of error is also covered by the symbol size in Fig. 6.

RESULTS

Values of δ of the Or samples are given in Table I, along with notes on rock type and sample location.

Two of the δ values, samples 4 and 19, exceed unity. According to the theory underlying the measurement of δ , this is impossible if the true composition is known.

Both true and pseudo-sanidine compositions for sample 4 were measured by the same method, peak separation, so both values should be equally reliable. A possible explanation for δ being greater than unity is that a true sanidine was not produced by the method used, hydrothermal remixing. Errors in this method include failure to add enough water to the sample to facilitate remixing. At the temperature used (750°C) and the time heated (4 hours), the resulting product would be a pseudo-sanidine that is even less remixed than the pseudo-sanidine produced by the dry heating at 1040°C for 48 hours. Lack of enough water added to the sample when prepared for sanidination results in the discrepancy of the δ value in sample 4.

The true composition of sample 19 was obtained from intensity ratio measurements. This method is not too precise. Maximum error produced by intensity ratio measurements is shown to be about 5 weight percent. This error, when applied to the true composition of sample 19, is sufficient to explain the abnormal value of δ .

Data from measurements made on plagioclase samples is plotted on Fig. 6, and include plagioclases from the latitic phase of the trachyte.

The average δ for the trachyte, except for the two that exceed unity, is 0.86; the average for the rhyolite is 0.89. The second figure of these numbers is probably not justified because of inaccuracies in intensity measurements, therefore, averages of both trachyte and rhyolite δ values can be considered to be the same. This means that the rhyolite and the trachyte orthoclases are, for all practical purposes, at the same thermal state. Confirmation of this observation is given in Fig. 5, where all points but one, sample 4, are seen to lie approximately on a single straight line, therefore showing a similar thermal state. As has already been mentioned, sample 4 is probably in error as to its true composition.

The three latite samples from the trachyte laccolith are seen to be at a lower thermal state than samples from the Cougar Mountain intrusive (Fig. 6). This means that the rhyolite samples are also at a lower thermal state than the Cougar Mountain latite.

SUMMARY AND CONCLUSIONS

Field relations have not permitted the determination of the sequence of igneous intrusion of the three igneous rocks in the Gallinas Mountains. In an attempt to solve this problem of intrusive sequence determination, a study of feldspar phenocrysts, both orthoclase and plagioclase, from the igneous rocks was made in an effort to determine the thermal states of the feldspars. Evidence of hydrothermal action is also taken into account in the solution of this problem.

Data presented in this paper show that the feldspars from the latite of Cougar Mountain are at a higher thermal state than are the feldspars from the trachyte and rhyolite. Phenocrysts from the trachyte and rhyolite appear to be at about the same thermal state.

The trachyte appears to be much more affected by hydrothermal action than the rhyolite. No hydrothermal mineral deposits exist in the rhyolite, and overall alteration of the rhyolite is less than that of the trachyte.

The conclusion drawn from these data is that the intrusive sequence is latite-trachyte-rhyolite.

The latite feldspars are at a higher thermal state than feldspars from either the trachyte or rhyolite. According to the theory of thermal states, the latite would be the earliest of the three intrusives.

No age relation between the trachyte and rhyolite can be determined directly from the thermal state data, but

consideration of the hydrothermal activity in the area indicates that the trachyte is older than the rhyolite. If the two bodies were intruded at about the same time, as the thermal state data indicate, hydrothermal alteration and mineral deposits should be equally developed in both intrusives, but this is not so. Also, if, by some means, both were intruded at the same time, but only the trachyte was intensely affected by hydrothermal fluids, the thermal states of the trachyte feldspars would be lower than those of the rhyolite because the hydrothermal action would tend to unmix the trachyte feldspars.

It is suggested by this writer that the trachyte was intruded at some time before the rhyolite, and that the trachyte underwent extensive hydrothermal alteration, which ceased or was greatly diminished by the time the rhyolite intrusion occurred.

BIBLIOGRAPHY

- Bowen, N. L., and Tuttle, O. F., (1950), The system $\text{NaAlSi}_3\text{O}_8\text{-KAlSi}_3\text{O}_8\text{-H}_2\text{O}$: Jour. Geol., v. 58, p. 489-511
- Foster, W. R., (1955), Simple method for the determination of the plagioclase feldspars: American Min., v. 40, p. 179-185
- Goodyear, J., and Duffin, W. J., (1955), The determination and thermal history of plagioclase by the X-ray powder method: Mineral Mag., v. 30, p. 648-656
- Griswold, G. B., (1959), Mineral Deposits of Lincoln County New Mexico: N. Mex. Inst. Min. and Technology, State Bur. Mines and Mineral Res. Bull. 67, 117 p.
- Kelly, V. C., (1946), Stratigraphy and structure of the Gallinas Mountains, New Mexico: Geol. Soc. America Bull., v. 57, p. 1254, (Abstract)
- _____, (1949), Geology and Economics of New Mexico Iron-Ore Deposits: Univ. N. Mex. Pub. no. 2, 246 p.
- Kuellmer, F. J., (1958), Alkali feldspars in a Tertiary porphyry near Hillsboro, New Mexico: Jour. Geol. v. 66, p. 151-162
- _____, (1959), X-ray intensity measurements on perthitic materials, I. Theoretical considerations: Jour. Geol., v. 67, p. 648-660
- Laves, F., (1952), Phase relations of the alkali feldspars: Jour. Geol., v. 60, p. 549-574
- Laves, F., and Chaisson, U., (1950), An X-ray investigation of the "high"- "low" albite relations: Jour. Geol., v. 58, p. 584-592
- Orville, P. M., (1963), Ion exchange between vapor and feldspar phases: American Jour. Sci., v. 261, p. 201-237
- Perhac, R. M., (1960), Geology and Mineral deposits of the Gallinas Mountains, New Mexico: Unpublished dissertation, Univ. Michigan, 225 p.

Rothrock, H. E., Johnson, C. H., and Hahn, A. D., (1946),
Fluorspar Resources of New Mexico: N. Mex School of
Mines, State Bur. Mines and Mineral Res., Bull 21

Smith, J. R., and Yoder, H. S., (1956), Variations in X-ray
diffraction patterns of plagioclase feldspars: American
Min., v. 41, p. 632-647

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