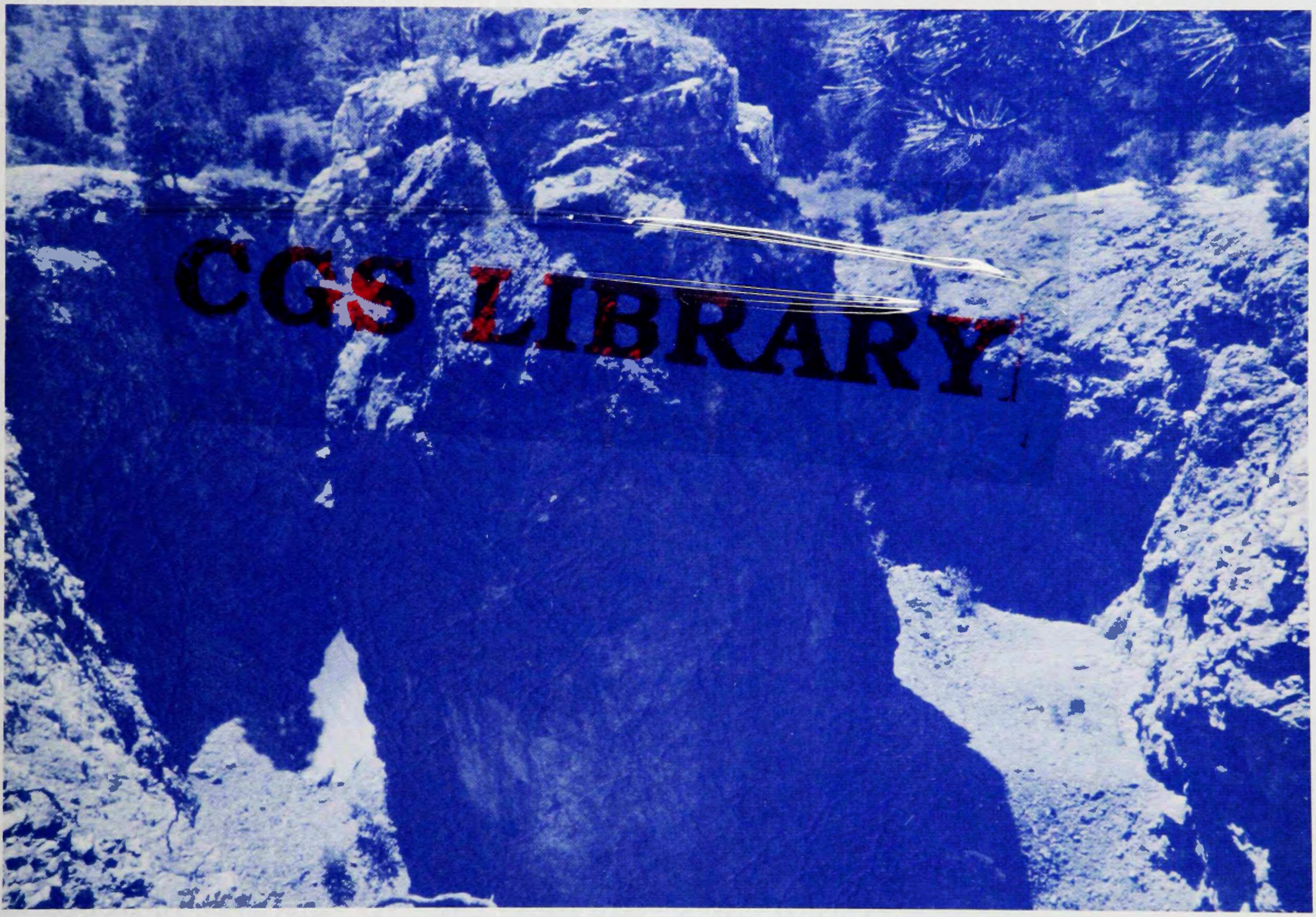
Resource Series 11

Rare-Earth Pegmatites of the South Platte District, Colorado

by Wm. B. Simmons
and E. Wm. Heinrich



Colorado Geological Survey
Department of Natural Resources
Denver, Colorado / 1980

Front cover: Wide Angle photograph of the Oregon No. 2½ pegmatite, South Platte pegmatite district, Colorado. This striking example graphically illustrates the exceptionally well-developed internal structural zonation of the pegmatites of this district. A fifty foot high column (40 feet across at the base) of nearly-pure quartz projects above the water at the bottom of the pit. The quartz core of the pegmatite was left standing in relief as the enveloping, nearly-pure feldspar of the intermediate zone was mined away. The top of the core is corroded and replaced by a hematite-biotite replacement unit. Plate 3 is a geologic map of this pegmatite.

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RARE-EARTH PEGMATITES
OF THE
SOUTH PLATTE DISTRICT, COLORADO

by

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ABSTRACT

The South Platte district, Jefferson County, Colorado, consists of a distinctive cluster of well-zoned, complex, rare-earth-, fluorine-, iron-rich pegmatites underlain chiefly by consanguineous granitic rocks of the Pikes Peak batholith. The district lies within the northern end of the Pikes Peak batholith near its contact with Precambrian gneisses and schists. The major petrologic units are: 1) schists and gneisses of the Idaho Springs Formation, 2) Pikes Peak granite, 3) Pikes Peak quartz monzonite, 4) aplite dikes, 5) xenolithic inclusions of biotite gneiss, granitic gneiss, and associated aplite, 6) pegmatites, 7) quartzite dikes, and 8) high-level Tertiary gravel.

Normative analysis indicates that the granite and quartz monzonite formed from liquids of essentially similar composition. Plots of Ab/An and Ab/Q ratios for water-saturated melts indicate that the granite crystallized under lower PH_2O conditions than the quartz monzonite. Loss of water vapor at the margin of the batholith is believed to have resulted in marginal crystallization of a one-feldspar, hypersolvus granite whose early solidification acted as an armor to confine water in the interior part of the pluton. Hence the remaining interior magma, with its higher water vapor content, crystallized at lower temperatures as a subsolvus two-feldspar quartz monzonite.

The district is characterized by over 50 large, complex, concentrically zoned, nearly vertical pegmatites, which all occur within the pluton rather than marginal or exterior to it. In shape and external structure, two end-member types are distinguishable: 1) vertical pipe-like bodies with essentially circular plans, and 2) vertical to steeply dipping, thick ellipsoidal lenses. Pegmatites of the central group are restricted to elevations between 6800 and 7800 feet within the granite, forming a clearly defined level or niveau of pegmatites. The concentric internal zonation consists of the following generalized, idealized sequence: 1) very poorly developed border zone (usually absent), 2) wall zone of biotite graphic granite, 3) outer-intermediate zone of giant biotite crystals (rarely present), 4) intermediate zone of microcline-perthite, 5) core-margin zone of green

fluorite, 6) large core massive quartz or quartz-microline, 7) secondary replacement units superimposed on the primary zonal sequence and containing albite, fluorite, rare-earth minerals, and hematite. The core-margin green fluorite is believed to be primary. The bulk composition of an average South Platte pegmatite consists of 42 percent microcline, 10 percent quartz, and 2 percent biotite. Fractional crystallization of the Pikes Peak magma resulted in water-enriched liquid segregates of residual fluids which became the parent fluid from which the pegmatites crystallized.

Whole-rock neutron activation analysis of the granitic rocks reveals that the parental magma was anomalously rare-earth rich. Calculations show that volumetrically the pegmatites are enriched in rare earths as compared with the grantic rocks. The wall and intermediate zones of the pegmatites are strongly depleted in rare earths indicating that within the pegmatites these elements were partitioned into the residual pegmatitic fluids, from which the replacement units formed. The original chemical nature of the magma appears to have been the most important factor in the formation of the rare earth-rich deposits. The bulk of the granitic magma apparently retained most of its original rare-earth content. The large concentrations of these elements found in the pegmatites are due chiefly to original concentration with fractionation becoming an effective agent only in the volatile-rich, residual pegmatitic fluids.

The district has been a major source of feldspar in the past and recently has become a major supplier of terrazzo-stone quartz. In addition, small amounts of fluorite and rare-earth minerals (chiefly Y-group-rich) have been obtained.

INTRODUCTION

The rare earth- and fluorine- rich pegmatites of the South Platte district, Jefferson County, Colorado constitute a distinctive and well-defined province. The district, which contains a group of centrally clustered pegmatites and additional outlying deposits, is underlain chiefly by granitic rocks of the Pikes Peak batholith. The central area comprises about 30 square miles in Jefferson County and contains over 50 pegmatites which have been excavated to various degrees, as well as numerous virgin deposits. Access to the district is over State Highway 126 between Pine and Deckers, Colorado. The thirteen outlying deposits, which are mineralogically and structurally similar, are found as far as 12 miles from the central group in Jefferson and Park Counties and are also in Pikes Peak granitoid rocks.

The northern and eastern margins of the central district are bounded by the North Fork of the South Platte River and the South Platte River, respectively, which join at the site of the former town of South Platte. The area is characterized by mountainous topography with elevations ranging from 6000 to 8900 feet, but the southwestern part is relatively undissected in comparison with the steep, V-shaped valleys and prominent ridges to the east. This flatter portion typically is mantled with well-developed grus and probably represents a remnant of an originally more extensive, probable Eocene erosional surface.

The South Platte pegmatites have been known at least since the early 1920s when they were first prospected for feldspar. It is probable that earlier they also were prospected for gold, because of their large "bull quartz" cores.

Reports of rare minerals in these pegmatites first attracted the attention of mineralogists during the 1940s (Hanley and others, 1950). Heinrich (1958a) and Haynes (1958, 1959) have reported rare-earth mineralization in the South Platte and Lake George areas. The structure and petrology of the northernmost end of the Pikes Peak batholith have been investigated by Hutchinson (1960), and Peterson (1964) has mapped the geology of the Platte Canyon Quadrangle. Haynes (1965) reported on three of these pegmatites as part of a master's thesis.

The South Platte pegmatites are the only pegmatites in Colorado presently being quarried systematically, principally for quartz for terrazo stone from their large, nearly monomineralic cores. Feldspar, rare-earth minerals, and fluorite have been produced in the past from these exceptionally well-zoned pegmatites. Unlike many other pegmatite districts in Colorado that are genetically affiliated with granite plutons, the South Platte pegmatites occur well within the pluton rather than marginal or exterior to it. Also unique is the geochemical nature of this group as compared with that of other districts. Many Colorado pegmatites, particularly those related to Boulder Creek granitoids, are noted for their contents of boron and beryllium species. The South Platte province is unusual in having essentially no tourmaline or beryl but very high contents of rare-earth and iron minerals. The high iron content is reflected in the fact that essentially all the mica is biotite, rather than muscovite, so characteristic of other districts.

The geological field work and plane-table and alidade mapping of the pegmatites were done during the summers of 1969 and 1970. The writers express their thanks to their associates at the University of Michigan for research assistance, discussions, and critical reviews of the mansucript: Professors E. J. Essene, D. R. Peacor, W. C. Kelly, A. A. Gordus, and Mr. J. Jones. Field and laboratory assistance was provided, at various times, by Linda Simmons, C. A. Salotti, J. R. Shappirio, and E. B. Gross.

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GEOLOGY OF THE DISTRICT

GENERAL

The South Platte district lies within the Precambrian core of the Rocky Mountain Front Range (Figure 1). The district is within the northern end of the Pikes Peak batholith near its contact with the Precambrian gneisses and schists, generally referred to as the Idaho Springs Formation (Lovering and Goddard, 1950), to the east and northeast (Figure 2). The area mapped in this study near South Platte, Colorado, which is restricted to the Pikes Peak granite surrounding the central cluster of pegmatites, comprises approximately 30 square miles. It includes parts of the U.S. Geological Survey Platte Canyon, Pine, Deckers, and Green Mountain Quadrangles. The Platte Canyon Quadrangle was mapped by Peterson (1964), and the geology of that part of the quadrangle shown on the map of this study, with few modifications, was taken from his map. The remaining area in the Pine, Deckers, and Green Mountain Quadrangles was mapped by Simmons.

The geological-petrological units are:

1. Pre-batholithic rocks: various para- and ortho-schists and gneisses (Idaho Springs Formation). The metamorphism is pre - 1,700 m.y.

2. Batholithic rocks: Pikes Peak batholith - 1000 m.y.
   a. Granite
   b. Quartz monzonite
   c. Aplite dikes
   d. Xenoliths and associated aplite (termed alaskite by Peterson, 1964)
   e. Pegmatites

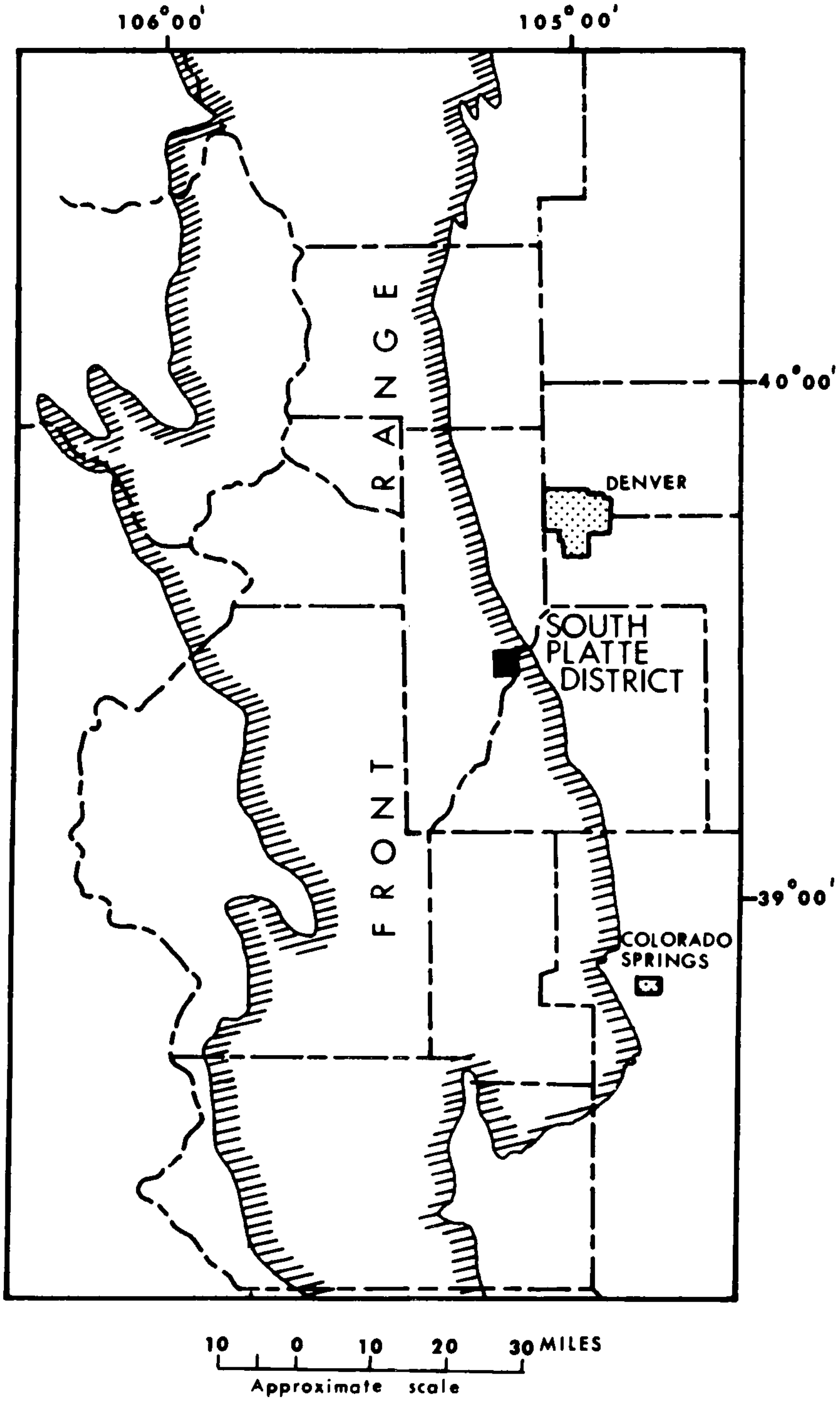

Figure 1. Map showing location of the South Platte pegmatite district within the central Colorado Front Range (modified from Sims, 1960).

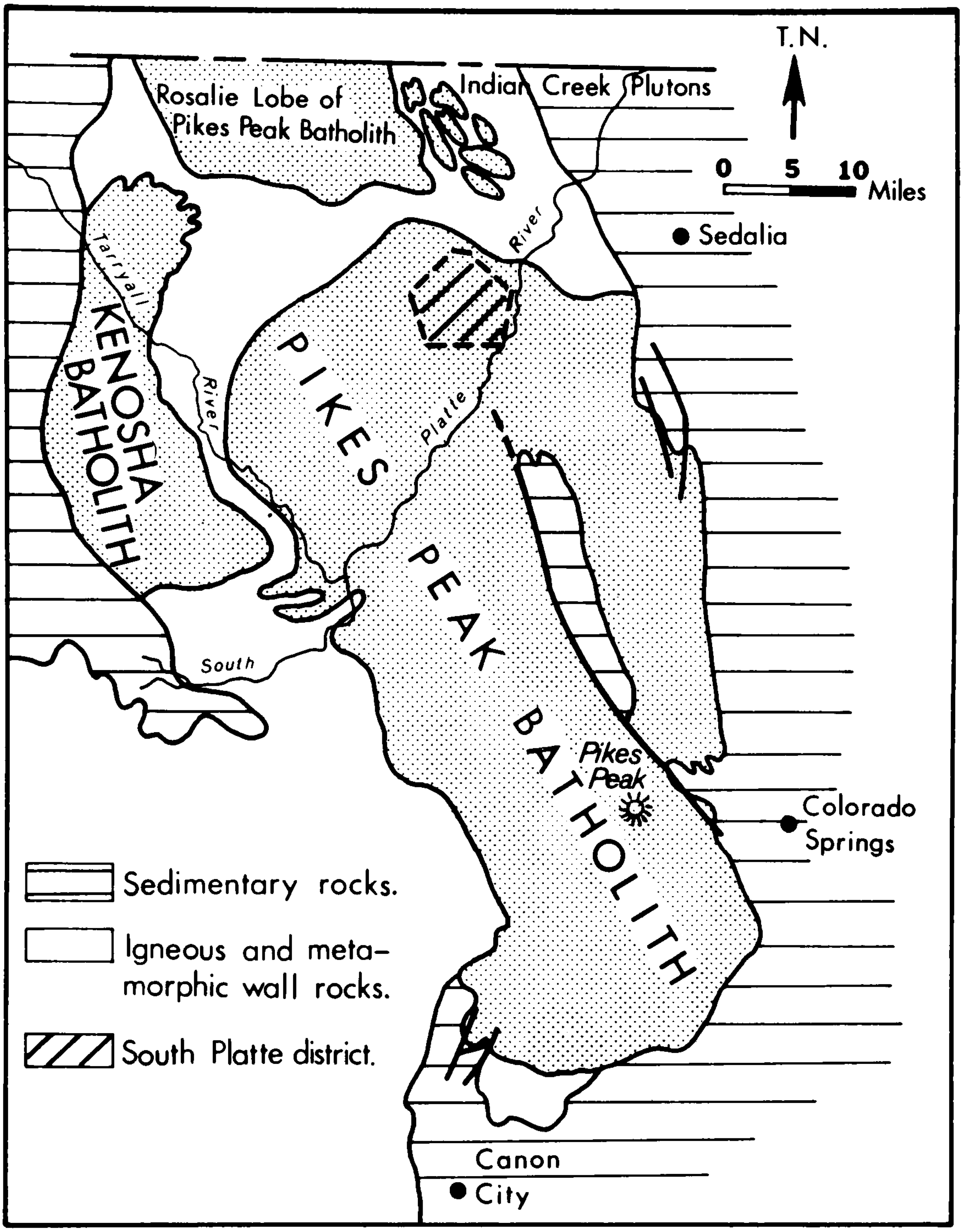

Figure 2. Generalized geologic map showing location of the South Platte district within the Pikes Peak batholith (modified from Hutchinson, 1960).

3. Post-batholithic rocks
   a. Quartzite dikes
   b. Fluorite veins
   c. Grus
   d. High-level Tertiary gravel

PIKES PEAK GRANITE PLUTON

General

The Pikes Peak granite pluton is exposed over about 1,700 square miles in the southern Colorado Front Range (Figure 2). The entire batholith extends about 60 miles northward from the Canon City Front Range embayment into southern Jefferson County, Colorado and extends about 30 miles westward from its eastern faulted contact with Paleozoic sediments between Denver and Colorado Springs to its contact with older gneisses and schists on the west. One large block of down-faulted Paleozoic sediments overlies the granite north of Pikes Peak. Within the batholith there are widely scattered bodies of younger igneous rocks, of both younger Precambrian and Laramide ages, small caps of Paleozoic sediments, and xenoliths and roof pendants of older metamorphic rocks such as those in the South Platte area.

Structure

The South Platte district lies within the northernmost end of the Pikes Peak batholith near its contact with the metamorphic rocks. The primarily structural features within this part of the batholith described by Hutchinson (1960) are: 1) concentrically curved, approximately vertical, linear and planar flow structures paralleling the trend of the contact of the batholith and the wall rocks, 2) inward-dipping marginal fissures filled with pegmatite and aplite, 3) radial dikes of pegmatite and aplite subnormal to the plan flow structures, 4) aplite-filled shears, 5) hydrothermally altered primary tension joints in radial arrangement near the contact, and 6) near-concordance of the igneous and metamorphic foliation within the batholith.

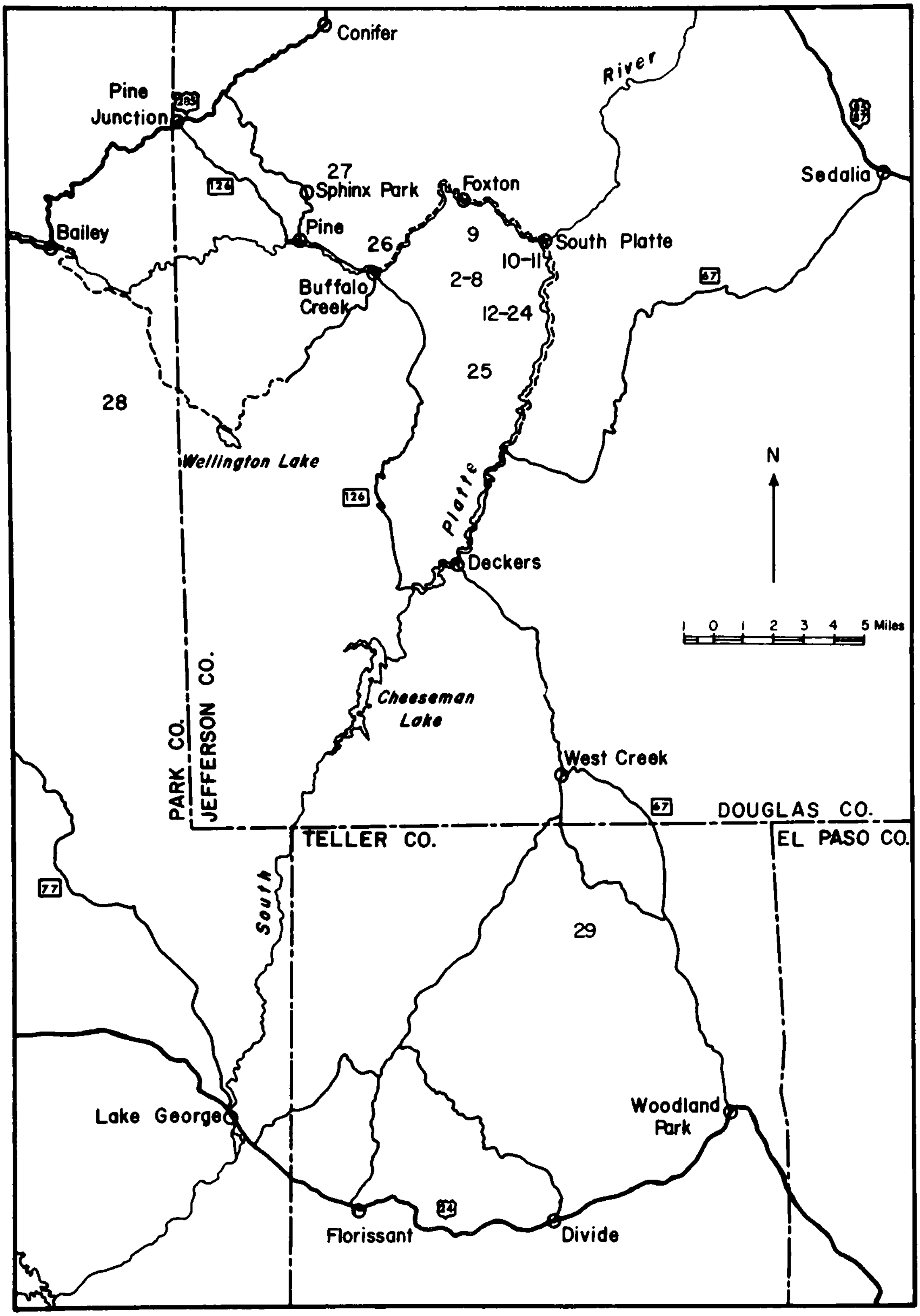

Figure 3. Map showing location of pegmatites in the South Platte district and related peripheral pegmatites. Numbers correspond to plate numbers of individual pegmatite maps.

In areas around the South Platte district, the Pikes Peak granite typically displays a poorly developed flow layering formed by the alignment of tabular microcline crystals and subparallel biotite flakes; but within the district foliation is indistinct and, in general, megascopic internal structures are absent.

Jointing is conspicuous throughout the district within both of the granitoids. One joint set parallels the granite-metamorphic rock contact, whereas the other is normal to it. Hutchinson believes that the distribution, quantity, and types or primary fracture systems indicate that the outer-zone granite crystallized before the granodiorite, quartz monzonite, and granite of the interior parts of the pluton.

Generally the contacts of the granite with the wall rocks to the north and east are sharp and dip steeply away from the batholith. However, Hutchinson (1960) reports contact migmatization in a few places and also scattered zones of partial granitization and alkali feldspar enrichment. The wall rocks are migmatite, quartz-biotite gneisses, granitic gneisses, biotite schists, and amphibolites.

The granite contains numerous xenoliths of gneissic metamorphic rock and migmatite which closely resemble rocks of the enclosing metamorphic complex. Typically the gneissic inclusions are enveloped and penetrated by an aplitic material. This associated leuco-granite is typically an even- or sugar-textured pale pink rock, fine-grained and composed predominantly of microcline-perthite, plagioclase, quartz, and accessory biotite. The xenoliths range in size from bodies less than an inch in diameter to about one-third of a mile long. The aplitic material may have originated from remobilized granitic fractions derived from the trapped metamorphic inclusions. It is more likely, however, that a combination of such partial melting plus igneous injection provides a better explanation for this association. Magmatic reactions of grantic magma with fragments of gneisses produced a hybrid hydrous granitic liquid from a combination of fractionally melted metasedimentary material and additions of molten igneous material. This highly mobile hybrid liquid then enveloped and intruded the residual more mafic constituents of the inclusions.

Biotite schlieren trailing from smaller inclusions probably represent remnant resistant material from almost completely digested metamorphic fragments.

The presence of these inclusions with associated aplite and biotite schlieren is believed to indicate that the present level of exposure of the batholith is only slightly below its original "roof."

Petrology and Composition

The northern part of the Pikes Peak batholith contains two main types of granitic rocks: granite and quartz monzonite. The granite forms an outer zone of the batholith, whose contact is generally conformable to the regional foliation of the metamorphic rocks. For the batholith as a whole Hutchinson (1960) has recognized a border zone of leucogranite, an outer zone of coarse granite, an intermediate zone of predominantly quartz monzonite to granodiorite, and a central zone of quartz monzonite to granite. In the area mapped for this study only granite and quartz monzonite are found. They appear to correspond to Hutchinson's outer and intermediate zones, respectively.

The granite of the Pikes Peak batholith underlies the northern and eastern two-thirds of the area. It is predominantly medium-grained but coarsens slightly westward toward the gradational quartz monzonite contact. Hutchinson has described the texture as seriate inequigranular. Where fresh, outcrops are reddish orange to reddish pink; they weather to a reddish brown. The rock is homogeneous, and outcrops are typically uniform in appearance. The principal minerals are microcline-perthite, quartz, orthoclase, biotite, and hornblende. Common accessory minerals, generally clustered, are fluorite, magnetite, allanite, apatite, and zircon. Both thin sections and stained slabs have been used for modal analyses (Table 1).

Microcline-perthite, the most abundant constituent, is replaced to varying degrees by irregular patches of oligoclase and finely dispersed sericite. Hematite dust included in the perthite accounts for the typical reddish color of the rock.

Table 1. Modal Compositions of Pikes Peak Granitoid Rocks[1]

	GRANITE			QUARTZ MONZONITE			APLITE
	SER-106	SPG-5	SPG-1	TWM-1	SPG-15	TWG-1	SPG-32
Microcline-perthite	68	56	61	41	30	32	34
Plagioclase	3.0	6.9	8.9	23	26	27	27
Quartz	21	32	25	26	31	22	36
Biotite	7.7	4.9	3.6	6.5	7.6	15	1.9
Hornblende	-	-	0.3	0.6	1.1	2.3	Tr.
Magnetite	0.2	Tr.	1.1	1.3	1.0	0.7	0.5
Apatite	0.1	0.1	-	0.9	1.5	0.8	0.1
Sphene	-	-	-	0.7	1.8	0.1	-
Zircon	Tr.	0.1	0.1	0.1	Tr.	Tr.	-
Hematite	-	Tr.	-	Tr.	-	-	Tr.
Fluorite	-	Tr.	-	-	-	Tr.	0.6
Or/Ab	22.7	8.1	6.9	1.8	1.2	1.2	1.3

Sample Locations:

SER-106	Eleven feet from contact of Seerie pegmatite.
SPG-5	Quarry 2.2 miles northeast of Buffalo Creek.
SPG-2	Bossie quarry 1/2 mile northwest of Foxton.
TWM-1	Monzonite 3 miles southeast of Buffalo Creek.
TWG-1	Monzonite 2 1/2 miles southeast of Buffalo Creek.
SPG-15	Quarry just northwest of Buffalo Creek.
SPG-32	Dike on west flank of Raleigh Peak.

[1] Modes were computed both from thin section point counts of about 1500 points at 0.1 mm and from one mm graduated scale measurements on stained slabs of about 300 points.

Rare subhedral fluorite, closely associated with biotite and other minor accessory minerals, appears to be primary. Two types of zircon are present: 1) clear or zoned blocky crystals with rectangular outlines and 2) minute rounded radioactive crystals which have produced halos in the biotite. Very rare minute yellow-brown grains of radioactive allanite are also present in biotite. In addition, bastanaesite, (La,Ce) FCO_3, has been reported as an extremely rare mineral associated with allanite (Adams and Young, 1961). They believe the bastanaesite was formed from allanite by late fluorine- and carbon dioxide-bearing magmatic solutions. No bastnaesite was observed by the writers.

Plagioclase (An_{17} to An_{34}) occurs as small (one to four mm) anhedral crystals interstitial to the larger quartz and microcline-perthite grains. In some crystals zoning is indicated by strongly sericitized cores.

The quartz monzonite variant crops out in the western part, underlying the remaining third of the area. Westward across the gradational contact with the granite, microcline gradually increases in grain size, becomes subhedral to euhedral, thus assuming the nature of megacrysts. The rock color changes subtly from dominantly pink to dominantly gray owing to a gradual increase in plagioclase, biotite, and hornblende. In contrast to the granite, the quartz monzonite is distinctly porphyritic. Scattered large pink microcline megacrysts stand out against the background of medium-grained clear quartz and grayish plagioclase. The microcline crystals, up to two inches long, constitute about ten percent of the rock.

Whereas fresh outcrops are mottled light gray to light pinkish gray, weathered outcrops are a tan-gray. Weathered surfaces are crumbly and characterized by a topography of protruding megacrysts of more resistant feldspar. The principal minerals are oligoclase, microcline-perthite, quartz, biotite, and hornblende. Common accessory minerals are sphene, apatite, magnetite, and zircon (Table 1).

The microcline-perthite displays all stages of replacement by plagioclase; in many specimens only small remnants of microcline remain. Also, irregular patches of hematite dust occur within microcline crystals.

The plagioclase occurs both as small anhedra interstitial to quartz and biotite of the groundmass and as somewhat rarer large euhedra. The smaller crystals range from oligoclase to sodic andesine. Many of the larger ones display conspicuous zoning, with strongly sericitized cores and untwinned rims. The cores, ranging from calcic to sodic andesine, are rimmed by oligoclase. A few crystals appear to have an outer rim of albite.

Chemical compositions of Pikes Peak granitoids (Hutchinson, 1960) together with their mesonorms calculated from the analyses according to the method of Barth (1962a) are given in Table 2. Samples SPG-1, SPG-5, and SPG-15 were collected from the same quarries from which Hutchinson's corresponding samples P-3, P-4, and P-5 were obtained and their modes were determined (Table 1). The SPG samples are considered representative of the rocks at these places and equivalent to the analyzed specimens.

The norms are essentially Barth mesonorms (Barth, 1962a, 1962b) with the following exceptions: 1) TiO_2 is calculated as sphene, 2) F in excess of that used for apatite is calculated as fluorite, and 3) Rb, Ba, rare earths (REE), Mn, CO_2, S, Cl, and H_2O are omitted from the calculations.

Although the modal analyses (Table 1) show a distinct difference in the mineralogy between the granite and quartz monzonite, there is but a relatively small difference in their chemical analyses (Table 2). Whereas normative Or/Ab ratios are somewhat larger for the granite (Table 2), they do not begin to approach the modal Or/Ab ratios (Table 1). Their chemical similarity is further indicated by ternary plots of the normative compositions, shown in Figures 4 through 7.

A comparison of the modal versus normative composition of the granitoids is shown in Figure 4. Addition of anorthite to the norm produces little change in the position of the points and further indicates the close similarity of the original magmas from which these rocks crystallized. The difference in modal and normative Or/Ab ratios reflects the fact that the granite K-feldspar contains most of the plagioclase component as exsolution lamellae, whereas in the quartz monzonite plagioclase occurs as distinct grains. This implies that

Table 2. Chemical Analyses and Barth Mesonorms of Granitoid Rocks of the Pikes Peak Batholith.[1]

	GRANITE		QUARTZ MONZONITE
	P-3	P-4	P-5
SiO_2	73.64	71.34	67.29
TiO_2	0.27	0.32	0.90
Al_2O_3	12.71	13.40	13.53
Fe_2O_3	0.38	0.57	1.77
FeO	2.20	2.60	3.30
MnO	0.08	0.09	0.11
MgO	0.03	0.05	0.89
CaO	0.94	1.10	2.71
Na_2O	3.28	3.35	3.08
K_2O	5.55	5.89	4.91
P_2O_5	0.04	0.12	0.50
H_2O+	0.21	0.21	0.23
H_2O-	0.00	0.00	0.04
Rb_2O	0.01	0.01	0.02
BaO	0.07	0.08	0.16
R.E.E.[2]	0.05	0.09	0.10
CO_2	0.05	0.22	0.13
F	0.25	0.37	0.29
Cl	n.d.	0.03	0.03
S	0.01	0.01	0.04
(3)	-0.11	-0.16	-0.14
TOTAL	99.66	99.65	99.89

Table 2 - Continued

NORMS[4]			
	P-3	P-4	P-5
Q	28.5	25.1	23.2
Or	33.5	35.1	29.6
Ab	30.0	30.6	28.1
An	2.0	1.2	5.5
Fe	3.1	3.6	4.0
En	0.1	0.1	2.4
Mt	0.5	0.6	1.8
Ap	0.2	0.3	1.4
Ti	0.6	0.6	1.8
F	1.0	1.5	0.9
C	0.5	1.2	1.3
Or/Ab	1.12	1.15	1.05

[1] Analyses from Hutchinson (1960); Sample locations of P-3, P-4, and P-5 approximately the same as samples SPG-1, SPG-5, and SPG-15 of this study (see Table 1); Analyst, C. O. Ingamells.

[2] R.E.E. = rare-earth elements.

[3] Less O for F, Cl, S.

[4] Rb, Ba, R.E.E., Mn, Co_2, S, Cl, and H_2O omitted from the norm calculations.

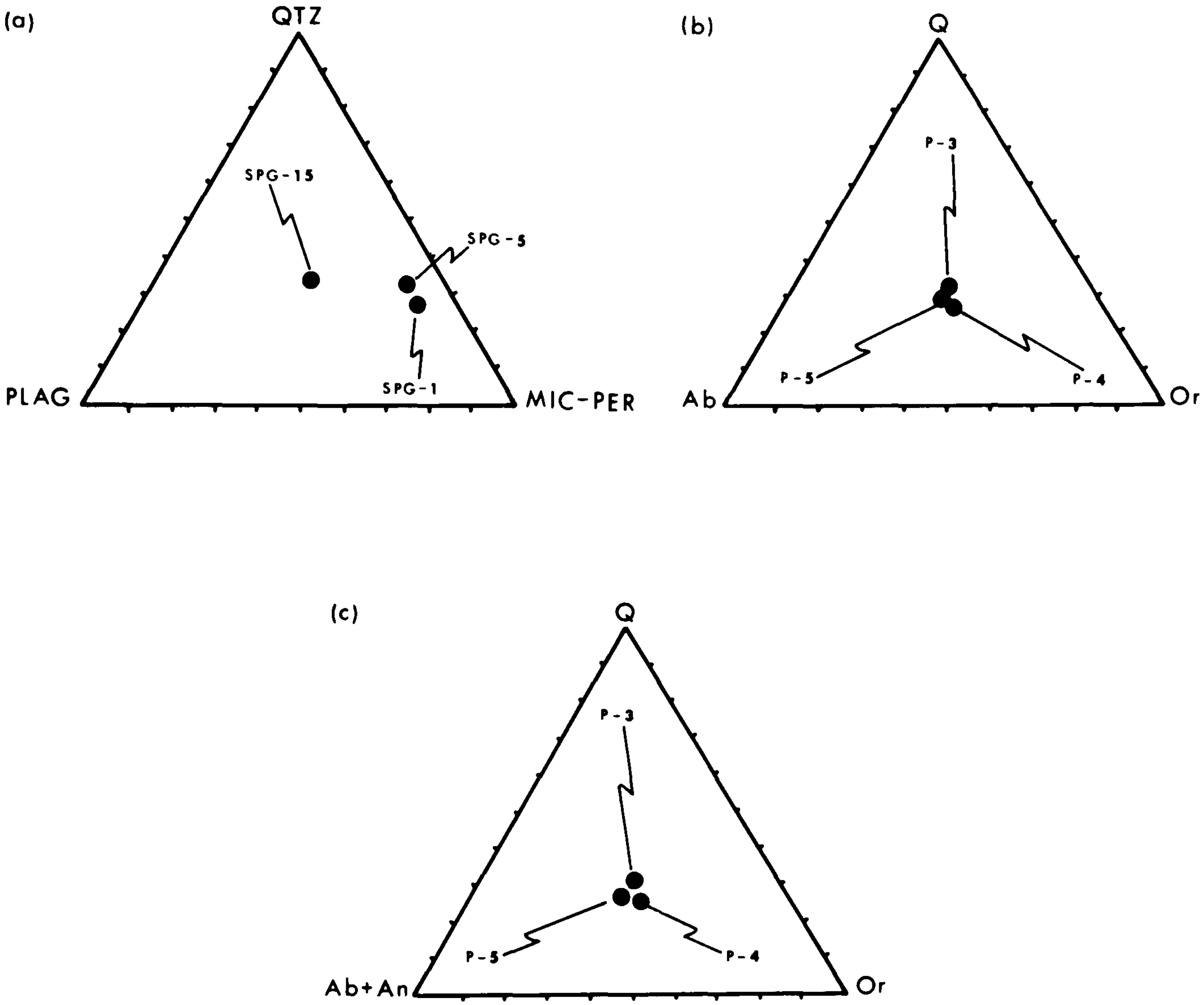

Figure 4. Ternary composition plots of South Platte granitoids. (a) Plot showing the modal quartz, microcline-perthite, and plagioclase compositions from SPG-1, SPG-5, and SPG-15. (b) Plot of the corresponding normative Q-Or-Ab composition (calculated from Hutchinson's, 1960, data). (c) Plot showing the small effect of adding the An component to the normative composition shown in (b).

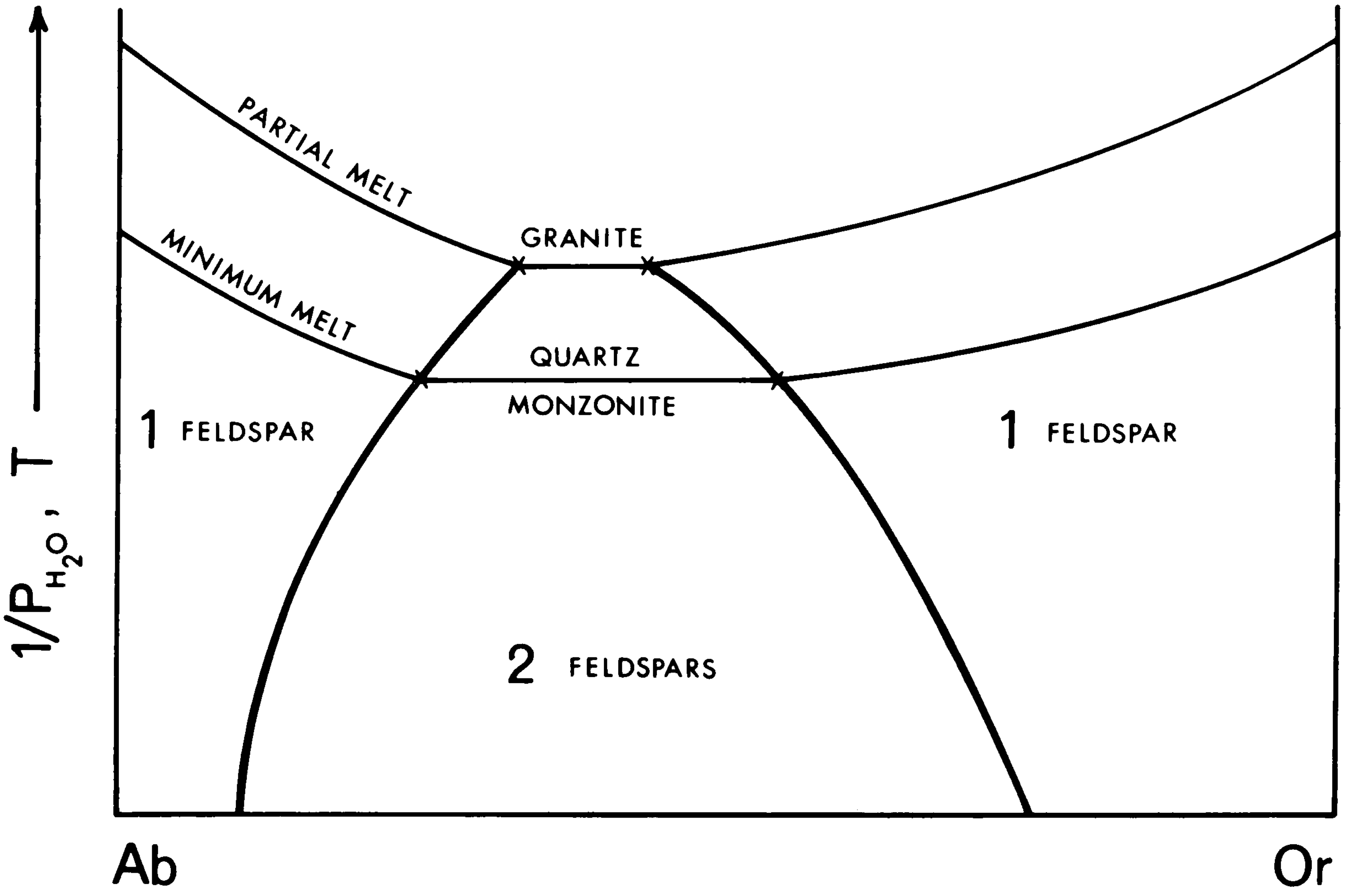

Figure 5. Schematic representation of the alkali feldspar two-phase solvus, showing the effect of temperature and PH_2O on the system.

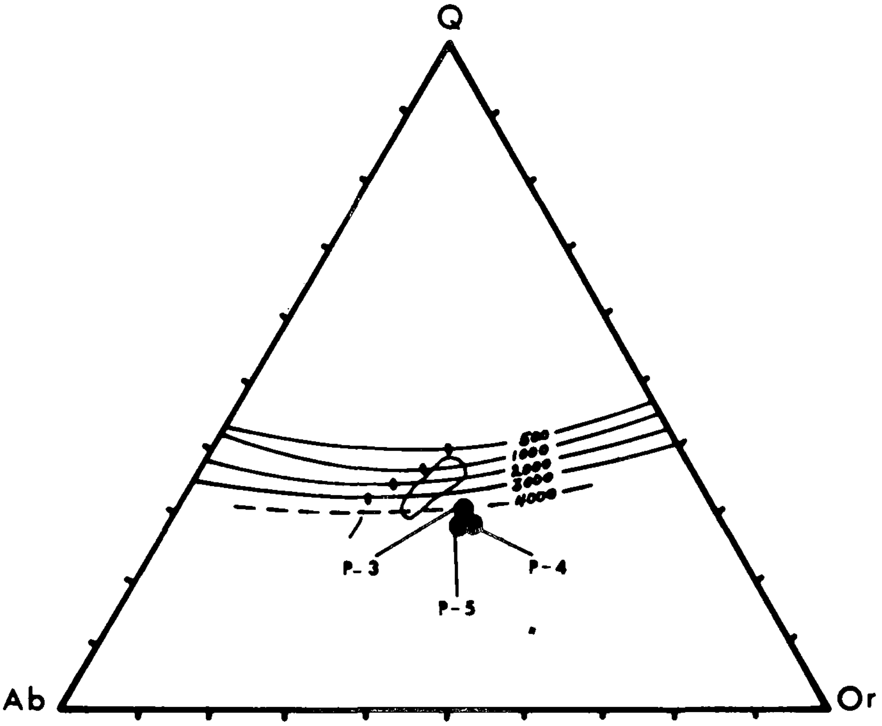

Figure 6. Relation of the South Platte granitoids to the synthetic granite system of Tuttle and Bowen (1958). Normative percentages of Q-Or-Ab are shown for granitoids P-3, P-4, and P-5. Curves are the quartz-feldspar field boundaries at 500, 1000, 2000, 3000, and 4000 bars water-vapor pressure. Closed curve is the low-temperature trough for analyzed granitic rocks.

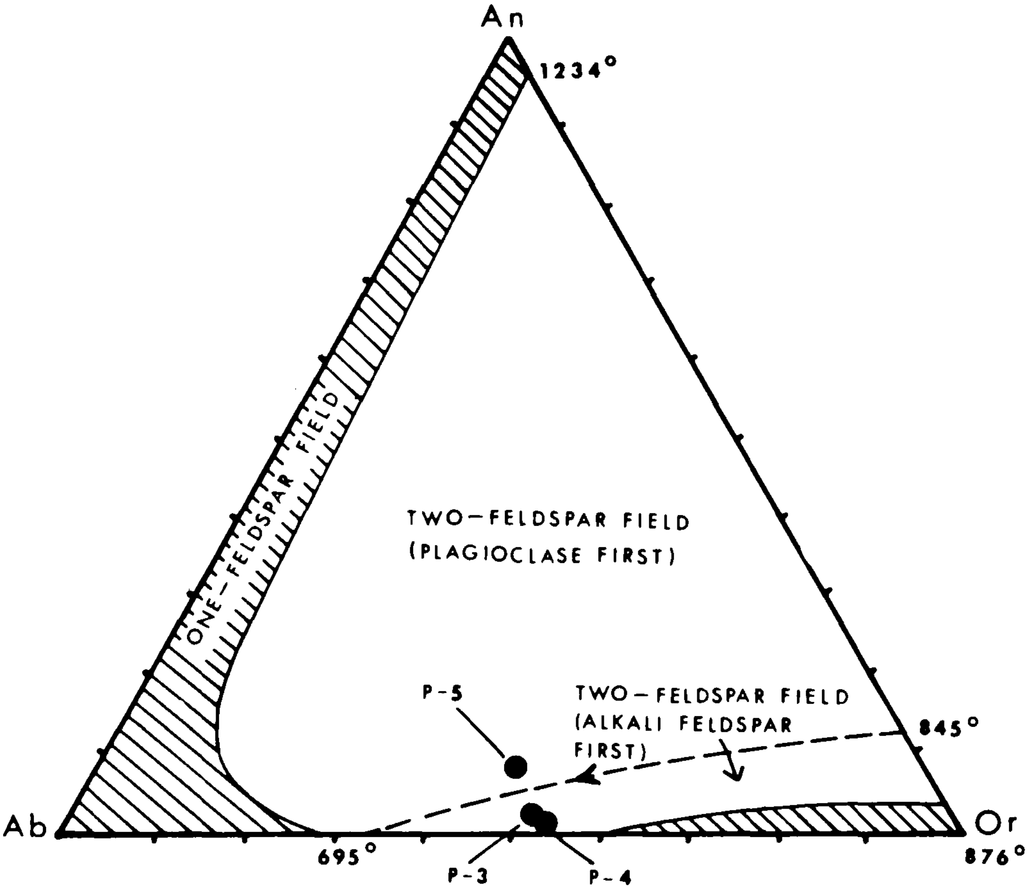

Figure 7. A diagram illustrating the positions of South Platte granitoids on the qualitative An-Or-Ab-(SiO_2) system at 5000 bars water pressure. Solid curves represent feldspar field boundaries. Dashed line shows the position of the low-temperature trough in this system. Diagram modified from Turner and Verhoogen, 1960.

the granite crystallized at higher temperatures and/or lower water vapor pressure than the compositionally similar quartz monzonite, so that the feldspar of the granite originally was closer to a one-phase material (see Figure 5).

The significance of the very high rare earth content in these rocks will be discussed later. The relatively high fluorite, in excess of that typically required for apatite and biotite, occurs as fluorite.

Petrogenesis

A^{40}/K^{40} ages on biotite from the granitoids are 1.08 b.y. for the granite and 1.05 b.y. for the quartz monzonite (Hutchinson, 1960). He gives no error values for these ages but states that the error is approximately equal to the apparent age difference. He also cites structural features which he believes indicate that the outer zone granite is older and crystallized before the quartz monzonite. However, since the error in the constants for K - A is of the same order of magnitude as the apparent age difference of the dates and no unequivocal corroborative structural evidence was observed in the area studied, there is some uncertainty as to the relative ages of these two granitoids. Furthermore, it is doubtful that Hutchinson's suggestions that unmixing of the feldspar toward the interior of the batholith adequately accounts for the textural and mineralogical differences between the two rocks.

The normative Ab-Or-Q plots shown in Figure 6 fall close to the ternary minimum of Tuttle and Bowen (1958). The relation of these plots to the synthetic granite system is indicated by the superimposed quartz-feldspar field boundaries at 500, 1500, 3000, and 4000 bars water vapor pressure. The points coincide with the area of the low-temperature trough determined by Tuttle and Bowen at approximately 4000 bars water vapor pressure in the system $NaAlSi_3 08-KAlSi_3O_8-SiO_2-H_2O$.

For a more quantitative analysis of the system it is essential to consider the effect of the anorthite component. Normative plots on the Ab-Or-An(SiO_2) system of Yoder and others (1957) are shown in Figure 7. These points also fall close to the low-temperature trough for this system at 5000 bars water vapor pressure. Significantly, all the points plot well within the two-feldspar field at this PH_2O, and thus the quartz monzonite would crystallize plagioclase first, whereas the granite would first precipitate K-feldspar.

More recent investigations by von Platen (1965), von Platen and Holler, (1966) in the five-component A-Ab-An-Or-H_2O system have shown that, at constant H_2O pressure, the composition of the minimum-temperature melt shifts along the quartz-plagioclase-orthoclase cotectic line and becomes enriched in Or and Q and depleted in Ab as the Ab/An ratio of the rock is decreased. He has shown that the quartz content of the minimum increases by about one percent for every one percent increase in anorthite. P-T curves for granitic "minimum melts" containing different amounts of anorthite component are shown in Figure 8. These curves were constructed from von Platen's P-T data (1965, 1966) for various Ab/An ratios which he obtained from experimental studies of the melting conditions for obsidian to which different amounts of anorthite compoenent were added. The chemical composition of the obsidian is similar to those of the rocks under consideration here, and its weight per cent normative mineral content is:

Q -- 30.5　　An -- 4　　Mafics -- 4
Ab -- 31.5　　Or -- 30

Superimposed on the Ab/An curves in Figure 8 is another set of curves contoured from the Ab/Q ratios of the same points from which the Ab/An curves were constructed. Thus, if the Ab-An-Or-Q-composition of a "minimum granitic melt" saturated with water is known, the corresponding P-T conditions can be estimated. The validity of conclusions based on this plot is somewhat restricted, however, owing to the small number of data and the uncertainty in constructing the curves. Notwithstanding, with certain qualifying assumptions, extrapolations to natural systems may be attempted, and the appropriate conditions of formation can be estimated.

The following assumptions were made in plotting the compositions of the South Platte granitoids shown in Figure 8: 1) that the variants are comogmatic,

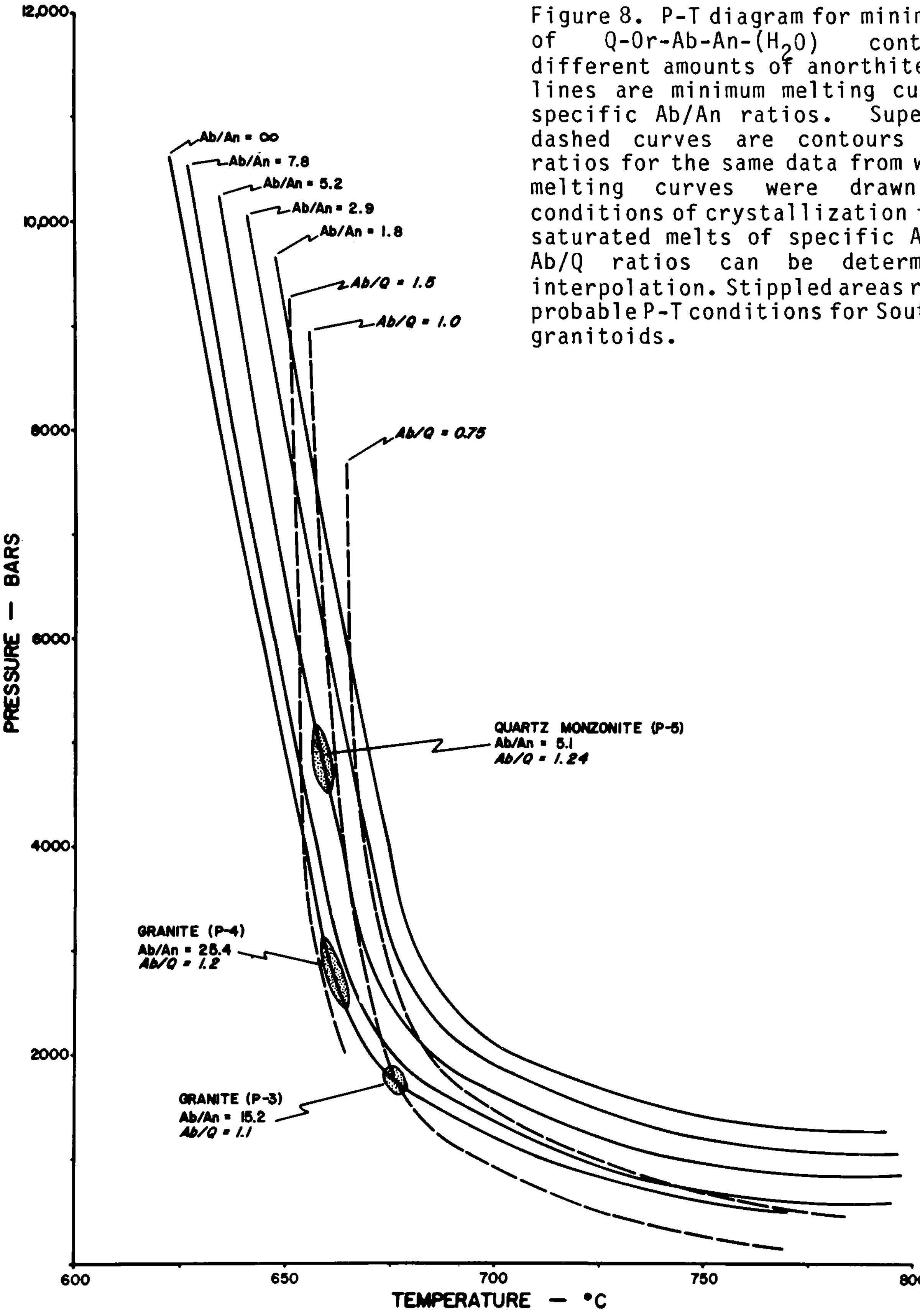

Figure 8. P-T diagram for minimum melts of Q-Or-Ab-An-(H_2O) containing different amounts of anorthite. Solid lines are minimum melting curves for specific Ab/An ratios. Superimposed dashed curves are contours of Ab/Q ratios for the same data from which the melting curves were drawn. P-T conditions of crystallization for water saturated melts of specific Ab/An and Ab/Q ratios can be determined by interpolation. Stippled areas represent probable P-T conditions for South Platte granitoids.

2) that their compositions lie near the minimum on the solidus curve (that at least some plagioclase in the granite is primary), 3) that the pressure of the solids equals the water vapor pressure, and 4) that the effects of the mafic minerals are negligible. The uncertainty in locating the interpolated compositions and the acute nature of the intersections of the curves are indicated by plotting areas instead of points. The quartz monzonite (P-5) with Ab/An ratio of 5.1 and an Ab/Q ratio of 1.24 plots at about 660°C and 4800 bars PH_2O, granite (P-4) with Ab/An = 15.2 and Ab/Q = 1.06 at about 660°C and 2800 bars PH_2O, and granite (P-3) with Ab/An = 25.4 and Ab/Q = 1.21 at about 675° and 1800 bars PH_2O. Thus there were apparently differences in the environments of crystallization.

Only one of the above assumptions is likely to be in serious error. Although the compositions of the variants probably do not correspond exactly to "minimum melts", the quartz monzonite probably falls close; the granites undoubtedly do not correspond but fall somewhere along the quartz-orthoclase cotectic line, but still they appear to be in the low-temperature trough. The addition of mafics is known to change the slope of the curves, but since there is a good correspondence between the composition of these rocks and those from which the experimental data were collected, their effect can be assumed to be small. For the third assumption, however, the differences in pressure indicated on the diagram are significant. Obviously, if the rocks crystallized nearly contemporaneously from consanguineous magmas, they would have consolidated under approximately the same total pressure, which is not the case indicated in Figure 8. The explanation for this discrepancy appears to be that the granite crystallized under lower water vapor pressure than the quartz monzonite. It should be noted that granite P-3 is the closest to the contact of the batholith and gives the lowest pressure. This may indicate a water pressure gradient, with PH_2O decreasing toward the contact.

The gradational contact between the two variants plus the compositional information in Figures 4-7 strongly suggest that here both phases of the Pikes Peak batholith crystallized from liquids of essentially the same composition. Physical, not chemical, variations played the dominant role in the formation of the variants and account for the modal differences between these two rock types.

The outer zone granite seems to have formed at higher temperatures and lower water vapor pressures. These conditions account for the fact that the solidus did not intersect the feldspar solvus, resulting in the formation of only one feldspar which later exsolved to form the microcline-perthite. In contrast, the inner zone melt appears to have saturated with water, causing the depression of the solidus to intersect the solvus and resulting in the concomitant crystallization of two primary feldspars to produce the quartz monzonite. This raises the question as to the reasons for such variations. It appears probable that in this area the escape of vapor near the margins of the batholith in addition to the chilling effect of the surrounding rocks produced both a temperature and a pressure gradient from the central to the outer portions of the batholith. Retention and concentration of water in the interior melt were augmented by the resulting earlier crystallization of an outer shell of granite which effectively imprisoned the remaining water vapor within the inner zone melt. This initial loss of vapor may also account for the alkali enrichment which has been noted in some of the contact rocks.

In summary, our model and the calculations on which it is based, agree with Hutchinson's suggestion that the granite crystallized somewhat before the quartz monzonite but does not support his idea that feldspar unmixing in the more central parts of the batholith can account for the differences between the two rocks.

APLITE DIKES

Many scattered aplite dikes are exposed within the South Platte area. One set of sub-parallel dikes that crop out near Buffalo Creek, striking generally N 60° W and dipping about 10° NE, can be traced for over three miles. The dikes range from less than an inch to as much as twenty feet in width but average about two feet. Individually they are uniform in width, and most are exposed continuously only for several hundred feet. Their dips range from nearly vertical to about 10°. No systematic strike orientation is apparent. They dip both into and away from the contact of the batholith. Contacts with the granite are sharp, and chilled borders are absent. Some dikes show transitions into pegmatitic material of similar composition which may contain miarolitic cavities lined with crystals of smoky quartz and microcline coated with hematite. More rarely, fluorite may also be present. The dikes are more resistant to weathering than their enclosing coarser grained granitic rocks and tend to stand out as prominent walls or ledges. Locally associated with the larger dikes are numerous smaller inosculated dikelets, some less than an inch wide, which appear to be branches from the main dike. Only rarely can these smaller dikelets be traced for more than a few feet.

The fine-grained aplite has a typical saccharoidal texture. Dark minerals form less than five percent and average less than one percent. Fresh outcrops are a light grayish pink, whereas weathered material may be a more brownish pink. The dominant minerals are microcline, quartz, and plagioclase. Accessories include biotite, magnetite, muscovite, fluorite, and zircon.

The aplites are believed to be genetically related to the later stages of emplacement and crystallization of the Pikes Peak batholith with which they are spatially and compositionally affiliated. They occupy fractures most of which cut quartz monzonite; in a few cases they transect granite. One example of an aplite cut by pegmatite is known (see Plate 28). Probably the dikes resulted from the rapid crystallization of residual water-rich silicate fluids injected into fractures formed late in the consolidation of the batholith. Such fractures may have developed from the increase in vapor pressure as crystallization neared completion. The rapid release of vapor pressure and thermal quenching by the wall rocks probably accounts for the relatively finer grain size of these dikes.

FAULTS AND QUARTZITE DIKES

Faults and associated fractures, which are widespread in the district, are characterized by iron-staining, brecciation, silicification, and may stand out in topographic relief as conspicuous ridges. The most conspicuous feature of the zones is deep red staining produced by iron_oxides cementing brecciated feldspar and quartz. Biotite is chloritized to varying degrees, and slickensides may be present locally. Usually, intensely fractured, deep red stained rocks pass gradually into unaltered rock within a few tens of feet, but in some areas altered rock extends over widths of thousands of feet. Calcite, fluorite, hematite, galena, pyrite, malachite, and barite are minor scattered accessories in a few of the fault zones, as well as small veinlets of fluorite and barite.

Many of these faults are approximately normal to the contact of the batholith and essentially vertical. The more extensive faults have a persistent north-northwest trend. Hutchinson (1960) has shown that smaller fractures of a similar nature, which he terms primary jonts, form a radial pattern normal to the contact. Many contain quartz-rich zones or quartz veins near their centers. Both Hutchinson (1960) and Haynes (1965) consider these features primary tension joints with accompanying hydrothermal or deuteric wall rock alteration. Many may indeed have originated as tension fractures related to the cooling of the batholith, but the presence of breccia and gouge, also noted by Peterson (1964), indicates that these zones have undergone post-fracture-filling lateral movement, and some show evidence of repeated faulting. Hence these features also have been mapped as faults.

Outcrops and float of mottled reddish-brown quartzite occur along some of the more extensive faults. The outcrops form vertical or nearly vertical dikelike bodies parallel to the fault zone. The dikes range in width from a few inches to more than ten feet. One dike just south of Buffalo Creek crops out continuously for several hundred feet, but most are smaller or only exposed discontinuously. In a few places a complex of minor dikes and dikelets is associated with the main dike.

The dikes, which have been described by Vitanage (1954), Scott (1963), and Peterson (1964), are composed of up to 99 percent fine-grained quartz fragments of granite. A faint foliation similar to flow structures in igneous dikes is parallel to and near the walls in a few places.

The detrital quartz sand grains are uniform in size ranging from about 0.1 to 3 mm and averaging about 0.5 mm. The grains are rounded and fairly well sorted. Small veinlets of secondary silica are parallel with the granite contact in places. The larger subangular feldspar and rock grains appear to be fragments from the wall rocks incorporated during the injection of the dikes.

Vitanage (1954) suggests that the Cambrian Sawatch Quartzite was the source of detrital sand. Apparently while the Sawatch was still unconsolidated, faulting opened up fissures in the underlying Pikes Peak granitoids and metamorphic rocks which were then filled by the downward filtering or injection of detrital sand. Brecciation and iron-staining as well as the extent over a vertical range of several thousand feet indicate that following the period of sand filling younger movements refractured and displaced the original surface. Thus, the faults are believed to extend in age from late Precambrian or earliest Cambrian to Laramide or even younger.

PEGMATITES

Geology

The South Platte area is characterized by numerous large, complex, concentrically zoned, nearly vertical pegmatites. The main cluster of pegmatites is located just west of the former town of South Platte, after which the district is named. Typically their large "bull quartz" cores stand up as resistant knobs above the surrounding granite. Early feldspar mining, chiefly by hand, also left the much harder quartz cores standing in bold relief as the enveloping microcline was removed. The pegmatite bodies are roughly circular to elliptical in plan with well-developed concentric zoning. The major axes of elongation of the few elliptical bodies show no systematic alignment nor parallelism with flow structure, joints, aplite dikes, or faults within the batholith. Their diameters or long axes range from a few to several hundred feet in length. Most of these bodies contain very large crystals of feldspar, quartz, and biotite, some over six feet in length.

Pegmatites occur throughout the area, but the larger ones are centrally clustered just west and to the south of Raleigh Peak. More than fifty pegmatites crop out in this relatively small area of only about four square miles. All but one of the pegmatites within the mapped area occur in the granite unit of the batholith.

About 13 outlying pegmatites, which are believed genetically related to the central group on the basis of structural and mineralogical characteristics, have been found. These bodies occur at different distances, up to 12 miles, from the main group and show no similar vertical control. Of these, eight have been mapped and included in this study for comparative purposes (see Figure 3).

Several other types of mineralogically simple "mini-pegmatites" also crop out. Some aplite dikes contain pegmatitic zones, generally small and compositionally similar to the aplite. Typically these bodies are never more than a few feet in maximum dimension. The larger of these may contain miarolitic cavities. Pegmatitic material also is locally present along fractures, fissures, or tensional joints, but these are small and limited in extent.

The larger pegmatites are both zoned and complex. In shape and external structure, two end-member types are distinguishable: (1) vertical pipe-like bodies with essentially circular plans, and (2) vertical to steeply dipping, thick, ellipsoidal lenses. Their dimensions range from 20 to nearly 2000 feet in length and from ten to about 500 feet in thickness. Although numerous smaller pegmatites also are present, only the larger complex bodies are considered here.

Granite-pegmatite contacts are characteristically sharp, showing an abrupt transition from the medium- to course-grained (0.5 to 2 cm), seriate hypidiomorphic granular granite to the much finer-grained (0.5 mm) graphic wall-zone rock of the pegmatites. The finder-grained wall-zone rock is typically more resistant to weathering, and contacts along more deeply weathered outcrops commonly show some relief. In a few places the contact is gradational over distances ranging from a few inches to several feet. Megascopically the granite shows no crystal orientation, radial fractures, distortion, or change in texture adjacent to wall zones except for the rare gradational contacts. Hence the pegmatites appear to have had little or no effect on the surrounding granite, suggesting that the pegmatites crystallized penecontemporaneously with the granite under essentially the same conditions of temperature and pressure, which is consistent with a liquid segregate mode of origin.

Unlike some other pegmatite districts in Colorado affiliated with granite plutons, all of the South Platte pegmatites occur within the pluton rather than marginal or exterior to it. In other districts pegmatites occurring within the interior parts of the igneous mass possess only a crude internal zonal structure and no hydrothermal or secondary alteration units. The South Platte pegmatites are extraordinarily well zoned and in most cases have been extensively altered by secondary hydrothermal replacement. This combination of interior district position and well-developed internal zoning with superimposed secondary replacement features is also a peculiarity of the district.

The pegmatites of the central group are restricted to elevations between 6800 and 7800 feet within the granite, forming a clearly defined pegmatite niveau (Simmons and Heinrich, 1971). No similar vertical zonation has been described in other districts, and this represents another unusual feature of the South Platte district.

INTERNAL STRUCTURE

Concentric internal zonation is conspicuously developed, particularly in pegmatites with nearly circular horizontal cross sections. Their structure, from the outer margin to the center, consists of the following generalized, idealized sequence:

1) very poorly developed thin border zone, usually absent;

2) wall zone of biotite graphic granite;

3) outer-intermediate zone of giant biotite crystals, rarely present;

4) intermediate zone of microcline-perthite;

5) core-margin zone of green fluorite;

6) large core of massive quartz or quartz-microcline;

7) secondary replacement units superimposed on the primary zonal sequence and containing albite, fluorite, RE minerals, and hematite.

Two types of internal development are distinguishable. The first is the quartz-core type which commonly is more nearly circular in plan and contains four or more well-developed, mappable zones (Figure 9). This type is characterized by: 1) wall zone, 2) intermediate zone of microcline-perthite; 3) core-margin zone of green fluorite, 4) large core of nearly pure, monomineralic quartz. Usually this type is more extensively replaced by secondary mineralization that is more complex and variable than that of the other zonal type.

The second type, although it also is distinctly zoned, generally displays only two zones: a core and a wall zone (Figure 10). These are classified as composite-core pegmatites and typically never show an intermediate zone. Instead of segregating into two zones, their cores developed as a single unit composed of microcline enclosing large pods of quartz.

Composite-core pegmatites tend to be more ireggular in their external shapes and commonly have elliptical horizontal cross sections. Also, the cores in this type are characteristically larger in proportion to the rest of the pegmatite than the simple quartz cores. Each type tends to cluster into geographical groups; pegmatites north of Spring Creek are commonly the quartz-core type, whereas those to the south are typically the composite-core type.

Both core-types show considerable variability in their core-size to pegmatite-size ratio. Core size seems to be related to the size of the pegmatite in which it occurs; generally the larger the outcrop area of the pegmatite, the larger the core. There are some notable exceptions however in which the cores are anomalously large or small. Such exceptions are probably due to vertical asymmetry of the pegmatites rather than to a large

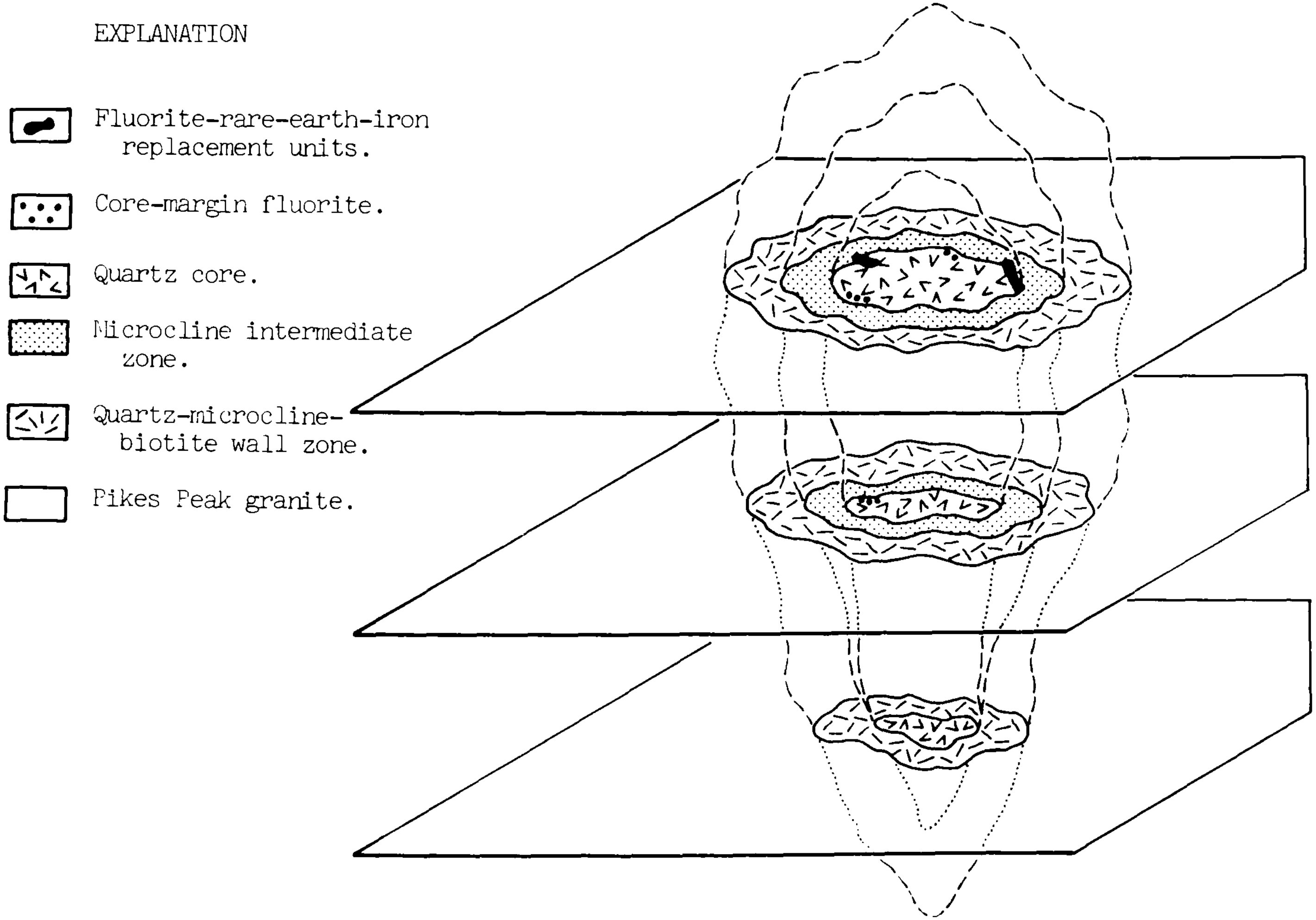

Figure 9. Idealized block diagram of quartz-core pegmatite showing vertical assymmetry and outcrop pattern resulting from different levels of exposure.

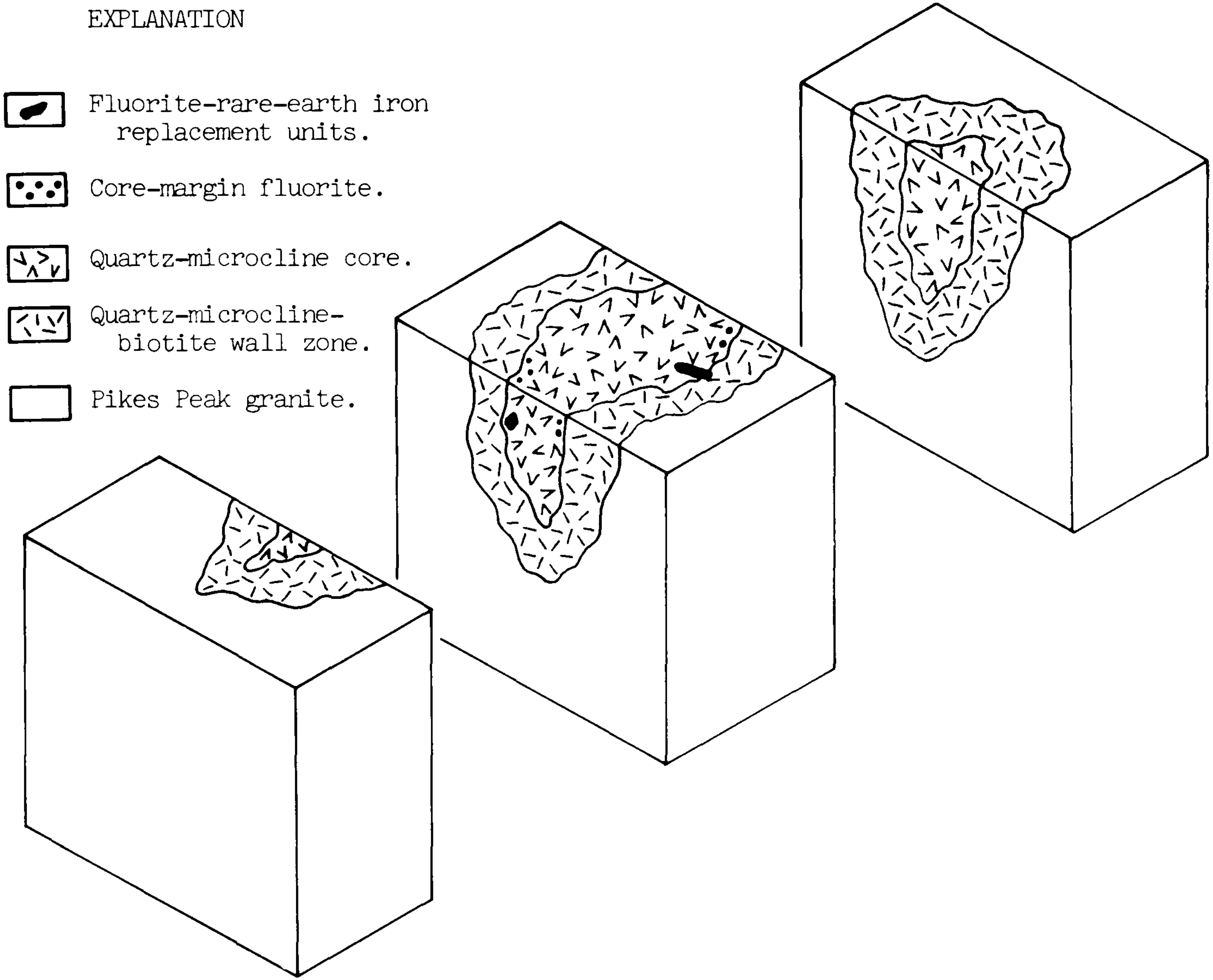

Figure 10. Idealized block diagram showing internal structure and shape of ellipsoidal composite-core pegmatites.

compositional different for a particular pegmatite. Individual pegmatites are rarely sufficiently well exposed vertically to display their three dimensional symmetry; and certain specific cases may not be strongly asymmetric in three dimensions. Nevertheless, a general review of the internal dips of pegmatite units indicates a tendency toward vertical asymmetry for most pegmatites. In idealized section, the average pegmatite body is narrow at the bottom flaring upward to a maximum diameter in approximately the upper 1/4 or 1/3 of the pegmatite body. At the point of maximum diamter, the dips of the pegmatite units are theoretically vertical; below this point of maximum diameter and size, the dips are generally steeply dipping inward toward the center of the pegmatite body; above this zone of maximum diamter, the dips as one moves upward are initially steep and outward from the center of the pegmatite body and rapidly flattens as one nears the top of the pegmatite body. Intermdiate zone microcline-perthite, core margin fluorite, and replacement units are larger near the top of the pegmatite body where their dips are shallow and inclined away from the pegmatite body. These same units are smaller where they are steeply dipping or inclined toward the center of the pegmatite, perhaps indicating that these units are displaced toward the top of the pegmatite.

Hence, the extent of areal exposure for the interior zones for any given pegmatite is strongly dependent upon its degree of asymmetry and the vertical level of its exposure. This relationship is illustrated schematically in Figure 9, which shows that the level or erosion of a pegmatite and its general three dimensional shape may be inferred from the dips and relative thicknesses of the zones.

MINERALOGY AND PETROLOGY

Border Zone

Border zones are rarely well developed in these pegmatites. Generally this zone is indistinguishable; but a few deposits (most notably the Seerie) show a minor development of a one- or two-inch thick, discontinuous selvage composed of a graphic to granular intergrowth of quartz and microcline-perthite. The variable grain size typically ranges from less than

0.1 mm to about 0.4 mm. A slightly lighter color, resulting from a paucity of biotite and iron oxide alterations, and a slightly finer granular texture are characteristics distinguishing this zone from the adjacent wall zone. The rock has an aplitic or sub-graphic texture which is commonly gradational into the distinctly graphic wall-zone rock.

Wall Zone

Volumetrically, graphic granite of the wall zone forms the largest unit of a pegmatite, typically comprising over 50 per cent of the entire body. A fine-grained texture of graphically intergrown quartz and microcline-perthite grains about 0.5 mm across with much larger two- to three-inch laths of biotite characterizes this zone.

Microcline-perthite predominates, making up between 60 and 70 per cent of the rock. The remainder is chiefly quartz and accessory biotite. The abundance of randomly scattered biotite varies greatly from pegmatite to pegmatite, with some containing as much as 12 to 15 per cent and others only a few per cent. Modal compositions of the wall zone are difficult to determine owing mainly to the large difference in grain size of the biotite and the the quartz-feldspar aggregate; but three modes from large slabs average slightly less than nine per cent biotite. Modal compositions range from:

Microcline	43 - 66%
Albite	3 - 21%
Quartz	27 - 31%
Biotite	0 - 9%

However, on outcrops, all wall zones were observed to contain some biotite thus the lower figure merely shows the difficulty of obtaining accurate modes from thin sections or even slabs of such a relatively coarse-grained rock.

The cuneiform quartz grains are small, averaging about 0.3 mm across, whereas the microcline crystals are about twice as large, averaging 0.6 mm. A few sparse grains of microcline may exceed several millimeters in their longest dimension. Small perthitic blebs of albite are scattered irregularly throughout the microcline. The biotite forms long black blades, typically two to three inches in length and about 1/4 to 1/2 inch across, which contrast sharply with the lighter quartz-feldspar matrix. In wall zones with abundant biotite, these characteristic blades commonly are arranged in subradial patterns.

Minor patches of replacement albite are sparsely distributed in most wall-zone rock, principally as interstitial grains of clear albite replacing perthite; but less commonly in some examples as bodies as much as several feet across.

Outer-Intermediate Zone

The outer-intermediate zone is only rarely present. Typically it is discontinuous and incompletely developed around the inner-margin of the wall zone and is characterized by the presence of giant biotite crystals, which in a few places exceed five feet in length. These crystals usually measure about two feet across and range from slightly over an inch to more than six inches in thickness. Subradial clusters of these slabs are randomly distributed in a matrix of microcline-perthite and minor quartz. Generally, the perthite of this zone grades into that of the subsequent intermediate zone, and the abrupt disappearance of biotite is all that marks the boundary between these two zones. The thickness of the outer-intermediate is variable but commonly is less than five feet. Giant biotite is atypically developed at the Little Patsy pegmatite where not only are large biotites concentrated into a separate outer-intermediate zone; but they also occur in lesser quantities scattered throughout the intermediate zone.

Crystal aggregates of cyrtolite (rare earth-rich zircon) occur with the biotite. Exceptionally large radial groups of cyrtolite, weighing up to ten pounds, have been found in masses of biotite. Commonly these aggregates are less than an inch in diameter and have unusual step-sided pyramidal surfaces on the side that was embedded in the biotite. Aggregates that have terminations not in contact with the biotite show the typical curved tetragonal habit of cyrtolite. Haynes (1959) has termed these step-sided surfaces "compromise surfaces." Thorite aggregates and fergusonite which also occur in the biotite are less common than cyrtolite.

Intermediate Zone

A sharp contact between blocky microcline-perthite and the graphic microcline-quartz wall-zone rocks marks the beginning of the intermediate zone. With the exception of the Seerie pegmatite, intermediate zones are restricted to the quartz-core type pegmatites, and, although they are typical of this type of pegmatite, not all of these have a mappable or exposed intermediate microcline zone. Initial mining interest in the South Platte district focused on pegmatites containing these nearly monomineralic microcline zones. Sporadically, over a period of almost 30 years, pegmatites containing well-developed intermediate zones were sought and exploited for their feldspar. Consequently, in most deposits this zone is conspicuous only by its absence. Annular open cuts are all that remain to attest to the former presence of this zone in many deposits. Fortunately, the early mining methods, even into the late fifties, were not highly mechanized; most deposits were worked by two or three men. Hence the mining was highly selective and the borders of annular trenches, in most cases, accurately mark the original extent of this zone. The cuts, ranging from ten to 30 feet wide, average about 15 feet in width and are generally less than 50 feet deep, with access typically by a down-slope cut through the wall zone. The contacts generally are smooth and nearly circular, paralleling that of the wall zone with the granite.

The intermediate zone is composed of virtually pure microcline-perthite. Point counts on stained slabs and thin sections demonstrate that this zone is over 99 percent feldspar; a few examples have up to one percent quartz. Although modes were calculated only from remnants and no large volumes of this rock could be examined, all indications suggest that on the whole this zone was essentially quartz-free, as is the case in most other pegmatite districts whose deposits characteristically have this unit. Perthitic, white albite, ranging from stringers 1.0 mm across to small belbs less than 0.1 mm, comprises from 10 to 20 percent of the rock; the remainder is pink microcline. A very coarse texture characterizes this zone, with single crystals measurable in feet not uncommon.

Core Margin Zone

A discontinuous zone of green to blue-green fluorite characteristically occurs between the intermediate microcline-perthite zone and the core in the quartz-core type pegmatites. Even though the volume of this type of fluorite is small and varies from deposit to deposit, it occurs in a sufficient number of examples, consistently in the same zonal position, that it may be properly considered as a primary zonal species. In a few occurrences the fluorite unit reaches thicknesses of up to ten inches where it may be traceable for several feet as it "wraps around" the core. More typically, however, the mineral occurs as scatterend anhedral pods along the margin of the core, ranging in size from nodules about an inch in diameter to masses several feet long. These pods of fluorite may be completely enclosed by quartz, feldspar, or both. There is a tendency in a few deposits, most notably the Oregon No. 3 and the Luster, for some of the fluorite to occur in crudely formed polygonal crystals. Well-formed crystals are uncommon, and, because of the prominant cleavage, it is even more difficult to obtain fragments of the better developed crystals with more than a few crystal faces. Casts of crystals in quartz and feldspar are malformed and deeply striated, or grooved, as are remnants of original crystals, making their morphology difficult to interpret. Some of the casts, however, tend to show hexagonal symmetry which could result from a distorted dodecahedral form elongated in the direction of the three-fold axis. Haynes (1959, p. 1089) also noted this type of deeply striated or grooved fluorite which he refers to as having "step-sided, pyramidal 'roots'". It is possible that in some places simultaneous crystallization of primary fluorite and quartz did occur, but whether this caused the steps on the surfaces of euhedral fluorite is questionable. However, for the district as a whole, idiomorphic fluorite is exceptional, and deeply striated pyramidal crystals and casts ("roots") are not characteristic of this zone. Instead, irregular or anhedral masses and lenses are more typical.

A few examples or irregular fluorite units appear to be definitely fracture controlled. Brecciated feldspar fragments occur along and adjacent to the feldspar-fluorite contact, and in some instances angular feldspar fragments are completely encased by fluorite. In addition, fluorite fills numerous small fractures which extend as much as several inches from the contact into intermediate-zone feldspar. The abundance of obvious fracture-related green fluorite is small and apparently characterized only a minor amount of this type of fluorite. But a complicating factor in determining its abundance and relationship to non-fracture-related fluorite is its extensive replacement by at least two, and possibly more, generations of secondary fluorite, which further obscure the primary relationships. The secondary fluorites will be discussed later.

Topaz also occurs in the core-margin zones of a few pegmatites, the most notable of which are the Seerie and the McGuire deposits which contain large well-formed crystals of opaque blue and white topaz. One group of these sky-blue crystals weighed more than 50 pounds. The largest crystal was nearly two feet long and six inches across. Although topaz was found in place in only four occurrences (Seerie, McGuire, Yammy Yogurt, and the Luster), it may be slightly more abundant than it seems since the white variety is especially easily overlooked. The crystals show various degrees of alteration, ranging from completely sericitized small crystals to essentially unaltered larger crystals; but most commonly they have a thin rind of waxy green sericite. Many crystals are highly fractured and crumble easily. The more coherent ones commonly are completely intergrown aggregates which also break readily into smaller pieces. The refractive index of both types is about the same, n_B = 1.619 for the blue and 1.620 for the white, corresponding to an OH:(OH+F) ratio of 14 and 15 percent, respectively.

Cores

Two core types occur which are correlative with the overall zonal pattern of the entire pegmatite. Nearly pure, milky-white, monomineralic, "bull" quartz cores characterize pegmatites containing well-developed intermediate zones of microcline-perthite. These massive quartz cores are monotonously uniform except for minor marginal replacements or sparse crosscutting fracture fillings of secondary albite or fluorite.

Steeply dipping zones of shearing and fracturing are conspicuous in some quartz cores. They are confined to the cores and apparently have no common orientation with shear zones in other pegmatites or with regional faulting. Commonly open spaces, or vugs, develop along the shear zones in which secondary quartz crystals have formed. Usually these fractured areas are stained reddish-brown by limonite and hematite.

The second core type occurs, with a single exception, in pegmatites which developed no intermediate zone. These cores are essentially bimineralic and are classified as composite. They are characteristically composed of a heterogeneous mixture of microcline-perthite and quartz. The feldspar which envelops scattered, rounded, anhedral pods of milky quartz is virtually identical to that of the intermediate zone in the quartz-core type pegmatites. The quartz pods, which are irregularly scattered throughout the core, vary greatly in size not only between deposits but also within a single core. The pods may range from fist-sized bodies a few inches in diameter to large rounded masses over ten feet in diameter in some of the larger pegmatites. The quartz from both core types is indistinguishable. Apparently the only difference is that in the composite-core deposits the feldspar and quartz were not segregated into separate zones. These cores are similar to some cores of Alabama Piedmont pegmatites, characterized by a "quartz plate" structure (Heinrich and Olson, 1953).

Few data are recorded on the grain size of quartz in quartz cores, but in this district two lines of evidence suggest that these cores are composed of aggregates of very large grains. In quartz-core pegmatites that have been sheared, the fragments in the secondary vugs along the shear are tabular quartz pieces commonly overgrown by later quartz. The overgrowths on the sheared slabby fragments tend to grow in crystallographic continuity with the original fragment forming thin tabular "crystals". In some cases these malformed crystals are more than one foot wide. These unusual, oriented overgrowths can be found in various stages of development, depending upon the space available for the crystal growth, and strongly suggest that the sheared fragments are pieces of large single quartz crystals. In addition, in a few rare occurrences, core quartz seems to have developed crystal faces where it grew in contact with intermediate-zone feldspar. Very rarely these faces can be observed after the feldspar has been removed. One extraordinary example of such a surface measured over five feet in length and about two feet in width.

Primary vugs or miarolitic cavities occur in both core types. Primary vugs are distinguished from fracture cavities by the absence of shearing and the presence of well-formed crystals. Primary vugs in the quartz cores contain only clear and smokey quartz crystals, whereas those in composite cores contain crystals of both quartz and microcline in the same vug. The vugs range from less than an inch across to several feet in diameter. The larger ones may contain extraordinarily large and well-developed crystals of quartz and microcline, some of which weigh over 50 pounds. The vug crystals are commonly sprinkled with encrustations of dusty hematite. Less commonly, small cubes of purple fluorite also are perched on the larger crystals of vug quartz and microcline. Many of these primary vugs, which are bounded by large crystal faces on either quartz or microcline, may have trapped remnants of the pegmatitic fluid which then crystallized as a closed microsystem analogous to that of the core phase of pegmatite formation.

Replacement Units

Characterization. Secondary mineralization in this district is complex and varied, and only the major types of replacement and their major minerals are considered here; but in general these account for more than 95 percent of the secondary phases. Generally one or two phases are dominant, and these form the basis of the classification of the replacement types.

Five categories of mineralization characterize the replacement units. In their approximate order of abundance, they are: albite, fluorite, hematite, rare-earth mineals, and sericite. Virtually every replacement unit examined contained one or more of these types as a principal constituent.

Selective replacement of the upper parts of many deposits (e.g. the Oregon No. 3) is a principal mode of secondary mineral localization. Thus, extensive replacement is especially common near core tops and along the upper core margins, producing vertically asymmetric core-margin replacement units.

Albite. Albite, the most common replacement mineral, typically replaces perthite particularly near core-margin areas and also in scattered places in wall and intermediate zones. Albite replacement units typically are either crosscutting or occur as isolated irregular patches in outer zones of the deposit. Many of these isolated bodies show no apparent connection with, or conduits to, the more widespread and common inner-replacement units. Crosscutting material is more commonly composed of bladed aggregates of cleavelandite; whereas the isolated irregular patches of granular, "sugary" albite tend to be xenomorphic or pseudomorphous after the primary mineral. Core margins typically contain relatively large amounts of secondary albite which is more commonly a pink sugary variety rather than cleavelandite. Fracture-controlled replacements and fracture-fillings of albite and fluorite also occur in some deposits. In a few places the albite has been altered to kaolinite, particularly along core-margin units directly adjacent to the core.

Fluorite. Several generations of fluorite are characteristically dispersed throughout almost every type of replacement unit (Table 3). Evidence for a range of replacement fluorite activity from the early stages extending well into the waning period of pegmatite development is supported by veining and replacement textures that this mineral shows toward primary and nearly all other secondary minerals, including many of the late rare-earth minerals such as allanite, gadolinite, and yttrofluorite.

Opaque purple fluorite, which is the most common replacement type, occurs as: (1) small irregular isolated patches and (2) crosscutting veins that have strongly corroded and embayed both primary and secondary species. Isolated purple fluorite, apparently unrelated to the clearly crosscutting and inclusion-rich variety, replaces quartz, perthite, and primary green fluorite, but seems to have a preference for quartz in the earlier green fluorite. Typically, the more common, crosscutting purple fluorite contains an abundance of rare-earth minerals that commonly occur as reddish-brown, dust-like inclusions within the fluorite. Fine-grained monazite and xenotime are the most common rare-earth inclusions, but gadolinite, allanite, yttrofluorite, bastnaesite, and other unidentified phases also may be present. Quartz is commonly also an abundant inclusion or remnant in this second type of purple

Table 3. Summary of Fluorite Types

Type	Color	Occurrence	Replaces	Inclusions	Notes
1.	Green	core margin	--- (primary)	---	may be idiomorphic enclosed by quartz or feldspar
2.	Purple	a) isolated patches	quartz, perthite, green fluorite	---	
		b) crosscutting veins	quartz, perthite, green fluorite	monazite, xenotime gadolinite, allanite, yttrofluorite, hematite, quartz	
3.	Colorless white brown	veins	quartz	---	
4.	Purple	crystals in vugs	---	---	very late crystals perched on other vug crystals
5.	Gray	masses in R.E.-rich replacement units	all primary minerals	hematite, doverite, quartz, fluorite	yttrofluorite-cerian fluorite associated with gadolinite

fluorite. In a few rare occurrences large, spectacular, euhedral crystals of rare-earth minerals as much as two inches long accompany the fluorite. In several deposits (e.g. Madonna No. 3) purple fluorite has selectively replaced quartz of the wall-zone graphic granite producing an unusual graphic feldspar-fluorite rock. Both types of purple fluorite have a refractive index of about 1.434, show no fluorescence with ultraviolet radiation, and despite the abundance of rare-earth inclusions in the second type, are not significantly substituted by rare earths as demonstrated by their cell edge values of about 5.46 A.

In addition to purple fluorite, spatially unrelated, colorless, white, and brown fluorites also have been observed. These fluorites tend to be much clearer and freer from inclusions than the purple variety which occurs separately. Colorless, white, and brown fluorites, which are much less common than the other fluorites, have only been found replacing core quartz. Their paragenetic relations are not clear, but they seem to be a relatively rare earth-free phase that formed early in the replacement stage.

A third type of fluorite is represented by transluscent, inclusion-free crystals perched on quartz and microcline crystals that occur in primary vugs. This third type occurs mainly as encrustations and rarely shows replacement textures. Thus, it is inferred to be a very late form of fluorite that grew from less corrosive fluids than the earlier types.

A fourth type of fluorite is a rare earth-rich yttrofluorite-cerian fluorite[1] which is an important replacement mineral in many deposits. This type will be considered in greater detail with the rare earth-rich minerals.

Hematite. Hematite also is characteristically dispersed throughout most replacement units, principally as fine dusty coatings on crystal surfaces and as impregnations in other replacement minerals. Biotite is especially susceptible to hematite alteration and is found in various stages of replacement. Where biotite has been almost completely altered, the hematite

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[1] Cerian fluorite is preferred by the writers, rather than the confusing and inconsistent term yttrocerite, which bears no relation to the mineral cerite.

occurs as reddish black to metallic pseudomorphs, which not uncommonly preserve the original mica cleavage. In other places all evidence of the original texture or mineralogy is completely obliterated; and here the hematite is present as dense, massive, metallic nodules of "iron ore". Typically the rock immediately surrounding the massive hematite also is impregnated with and deeply stained by hematite. A few massive hematite bodies appear to be isolated and show no apparent connections with other replacement units; but most hematite is clearly related to fracturing and late-stage replacements. Crosscutting alterations and impregnations commonly follow fractures within a deposit. Much of the specular metallic hematite is intimately intergrown with a very fine grained quartz which makes it extremely tough, like some taconites. An extraordinary large mass of solid hematite, which transects the wall zone, is exposed in the Janet Lutricia deposit (Plate 24). This mass of iron ore measures 3 x 2 x 2 feet and is estimated to weigh over 300 pounds.

Pyrolusite. Parallel growths of lustrous, metallic, acicular crystals of pyrolusite occur rarely in vugs and in less spectacular crystal aggregates in replacement units of few pegmatites. Small bluish tinged steel-gray crystals less than an inch in length are perched on crystals of microcline and quartz growing in vugs at the Dazie Bell pegmatite. Larger crystals as much as two inches long are embedded in quartz along the core margin of the Oregon No. 3 pegmatite, and radiating aggregates are found in a few other replacement units.

Sericite and muscovite. Two forms of sericite occur as minor accessory minerals and both are products of late-stage alterations. The first type is the dense, waxy, greenish-yellow sericite that forms as alteration rims around topaz. In some cases small crystals of muscovite up to about 1/4 inch are present but the microcrystalline variety is more common.

The second type ranges from a cryptocrystalline to a slightly coarser flaky muscovite. This more abundant type occurs as a late replacement-stage product commonly intergrown with purple fluorite impregnated with rare-earth minerals. Also, small crystals of muscovite are common in intensely corroded sponge-like quartz that has been almost entirely dissolved away by late-stage fluids. Here, fine-grained muscovite occurs principally as coatings and fillings in the jagged openings in the quartz and appears to have crystallized after the removal of the original quartz. This second type of muscovite, which X-ray fluorescence reveals as rare-earth bearing, displays unusual physical properties. In plane polarized light it is slightly pleochroic in shades of yellow to buff. Megascopically it ranges from yellowish-green to greenish-yellow. The greenish-yellow cryptocrystalline variety is referred to as "epidote" by the pegmatite miners.

Rare-earth minerals. Minerals rich in rare earths occur as major replacement phases in most of the larger secondary units. The assemblages are typically complex, containing numerous minor species. Multiple oxides, simple oxides, halides, carbonates, phosphates, and silicates constitute the most abundant mineral classes (Table 4). Phosphates and silicates are the most prevalent and widespread; but, locally, halides are the most abundant, constituting the sole RE phase in some units.

Samarskite and fergusonite containing minor pyrite inclusions occur in core-margin replacements, typically in the more extensively albitized zones. The most notable occurrence of samarskite is in the Oregon No. 3 where nodules as much as one foot in diameter are present in the core-margin replacement unit. One such nodule weighed over 75 pounds. A large body of core-margin replacement rock near the top of the pegmatite contained a concentrated cluster of nodules from which more than a ton of samarskite and some fergusonite was collected by the miners. The nodules appear to be radial aggregates which developed from a central nucleus, and commonly have crude crystal-face terminations along their outer surface. The nodules are highly radioactive and the surrounding albite is heavily fractured and discolored. In the Oregon No. 3 unit most of this albite has also been kaolinitized.

Fergusonite occurs in outer-intermediate zones in rare euhedral to subhedral crystals of typical pyramidal habit and more commonly as anhedral masses interleaved with giant biotite crystals and in associated small fractures.

Table 4. Replacement Mineralogy of South Platte Pegmatites

CLASSIFICATION	MAIN CATIONS	MINERAL
Simple oxides	Fe	Hematite
	Fe	Limonite
	Mn	(Pyrolusite)[1]
Multiple oxides	Y, Nb, Fe	Samarskite
	Y, Nb	Fergusonite
	Y, Ta, Fe	(Yttrotantalite) (?)
Halides	Ca	Fluorite
	Mg	(Sellaite)
	Y	Yttrofluorite
	Ce	Cerian fluorite[2]
Carbonates	Fe	(Siderite)
	Ca	(Calcite)
	Y-Ce, F	(Doverite-Synchisite)
	Ce, F	(Bastnaesite)
Sulfides	Fe	(Pyrite)
	Mo	(Molybdenite)
Sulfate	Ca	(Anhydrite)
Phosphates	Ce	Monazite
	Y	Xenotime
	U	(Autunite)
Silicates	K, Al	Sericite, (Muscovite)
	Na	Albite, Kaolinite
	Th	Thorite
	U, Th	(Thorogummite)
	Zr, Y	Cyrtolite
	Y, Fe, Be	Gadolinite
	Y	(Thalenite)
	Ca, Ce, Fe	Allanite
	Be	(Beryl)
	Be	(Bertrandite) (?)
	Mg, Al, Fe	Prochlorite

[1] Very rare species in parentheses.

[2] Yttrocerite is preferred by some authors. However, cerian fluorite is a clearer name since it is a fluorite, not a cerite structure.

A very rare mineral tentatively identified by X-ray measurements as yttrotantalite is found in the Little Patsy pegmatite associated with quartz and microcline at the core margin.

Primary fluorite is characteristically selectively replaced by a rare earth-rich fluorite of the yttrofluorite-cerian fluorite series, which transects the original zonal structure. X-ray fluorescence and electron microprobe analyses indicate that either yttrium-group or cerium-group elements may predominate. By far the largest concentration of this mineral was found in the White Cloud pegmatite, where it was also noted by Haynes (1965), but it also occurs in much smaller amounts as replacements of primary fluorite in several other deposits. RE fluorite typically occurs as opaque, cream to pale gray, anhedral masses with a weakly developed octahedral cleavage. Much of this fluorite has a dirty appearance and is cut by small fractures discolored by hematite and other unidentified phases. Less commonly RE fluorite is pseudomorphous after primary fluorite crystals. RE fluorite is easily distinguished by its high specific gravity (3.5), higher refractive index (1.464), pale orange or apricot fluorescence in shortwave ultraviolet radiation, and its significantly larger cell edge (5.51), compared with a density of 3.2, refractive index of 1.434, no fluorescence, and a cell edge of 5.46 A for the purple fluorite without REE.

The rare fluoride, sellaite (MgF_2), occurs as minute birefringent inclusions in secondary purple fluorite from the Dazie Bell pegmatite and was identified by means of X-ray diffraction. The mineral is very rare, and has previously not been reported from pegmatites.

In addition to very minor calcite and siderite which are found as late coatings in a few vugs and replacement units, clearly secondary, replacement rare-earth carbonates occur in the White Cloud, Snowflake, and Big Bear No. 2 pegmatites and to much lesser extent in other deposits. Doverite ($CaY(CO_3)_2F$, was reported by Haynes (1958) at the White Cloud, which is the second world locality for this mineral. Here it occurs as dark-red, fine-grained, granular masses intimately associated with fluorite, hematite, yttrofluorite, quartz, and sericite. These fine-grained intergrowths generally appear to be related to the late-stage alteration products monazite, xenotime, allanite, gadolinite, and thalenite. Doverite appears to replace both quartz and fluorite, and in a few cases pseudomorphs after the latter preserve the original fluorite cleavage. Optically, the mineral is uniaxial positive with indices of w = 1.644 and e = 1.75 which are very close to those of synchisite. Two semiquantitative electron microprobe analyses of slightly impure material give yttrium > cerium, but the almost unavoidable presence of yttrofluorite (verified by X-ray diffraction) makes the result, as well as older analyses reported in the literature, somewhat questionable. Doverite and synchisite are very difficult to distinguish either optically or by X-ray diffraction (Levinson and Borup, 1962); but of the five separate specimens tested only one yielded a pattern closer to that of doverite than that of synchisite. Minute quantities of a doverite-like mineral also occur in the Snowflake, Dazie Bell, Big Bear No. 2, and Madonna No. 3 deposits; but these are yet to be verified.

Bastnaesite, (La, Ce, etc.) FCO_3, is verified for the first time in this district as a pegmatitic species. Adams and Young (1961) reported bastnaesite as a minor accessory in the Pikes Peak granite. Their bastnaesite is closely associated with accessory allanite which it replaced to varying degrees, and they conclude that the bastnaesite formed from the allanite by reaction with late-stage magmatic solutions. Pegmatitic bastnaesite occurs also as replacements of allanite as in the granite and as alterations or replacements of gadolinite. Only a few examples of the former type have been found. They occur as dark red to brown alteration rinds that surround and corrode allanite. Positive identification is possible only by X-ray diffraction which yields patterns identical to those of bastnaesite from Mountain Pass, California. The latter fluocarbonate is present at the White Cloud and Snowflake pegmatites; it may prove to be the yttrium analogue of bastnaesite. At the White Cloud, where the largest amounts occur, the mineral forms dark reddish brown alterations and replacements of gadolinite crystals, some of which have been almost completely pseudomorphed. X-ray diffraction yields patterns almost identifical with those of bastnaesite; but, since gadolinite is an yttrium mineral, late-stage carbonate alterations are likely to result in an yttrian fluorcarbonate. The similarity of the d-spacings is not surprising in view of the very small difference in X-ray patterns between synchisite and doverite (Levinson and Borup, 1962).

Yttrium- and cerium-group anhydrous phosphates are widespread throughout the district as minor phases associated principally with late-stage purple fluorite. Both xenotime and monazite commonly are restricted to fluorite in which they occur as microscopic inclusions. Rarely they are found replacing quartz and even more rarely replacing (?) topaz in which they also occur in interstices between crystals. Two deposits contain notable concentrations of these minerals in unusually large and spectacular crystals. Resinous, reddish-brown crystals of xenotime in slender, tetragonal dipyramidal prisms, which are up to two inches in length and nearly one-half an inch in width, occur in replacement fluorite at the Big Bertha pegmatite. The crystals are uniaxial positive and were positively identified by x-ray diffraction. Equally extraordinary monazite occurs in the McGuire pegmatite. Here distorted, tapered, tabular monoclinic crystals are found associated with core-margin topaz and quartz. One clove-brown, subtranslucent crystal was collected which was almost three inches in its maximum dimension. The high-grade hand-picked ore reported by Heinrich (1958) consisted of fluorite with microscopic inclusions of monazite and xenotime.

Minor amounts of probably supergene autunite are present chiefly as coatings along small fractures in some of the replacement units. It appears to be a weathering product of a primary uranium mineral, probably samarskite or thorogummite.

Crystal aggregates of cyrtolite, the rare-earth zircon, typically occur partially embedded in biotite of the outer-intermediate zone. Most crystal groups tend to be restricted to the outer margins of the biotite crystals and typically extend with euhedral terminations into the surrounding feldspar. The embedded part of the crystal aggregates characteristically has a flattened radiating habit with superimposed concentric steps or striations that are parallel to the biotite cleavage, suggesting that its principal growth direction was perpendicular to the biotite cleavage. The euhedral part of these groups have the characteristic curved tetragonal habit shown by most cyrtolite. Cyrtolite groups are intergrown with thorite in places, and Haynes

(1965) has termed the unusual morphology of these aggregates "step-sided pyramidal roots." The natural surfaces of these crystals are a dull dark red-brown color; but broken surfaces are glassy and range from an opaque chocolate-brown to a subtranslucent orange color. Crystal groups are typically about an inch in their maximum dimension; rarely large aggregates eight to ten inches across, weighing over ten pounds, are found. Less commonly cyrtolite occurs along fractures or interfaces of biotite crystals and enclosed in perthite of the outer-intermediate zone. In both occurrences the contiguous perthite commonly is deeply corroded and replaced by hematite, or has been albitized. On close examination, biotite at the interface with cyrtolite is distorted and crinkled and appears to have been forced aside by the growth of the latter. In addition, abundant cyrtolite-thorite aggregates are generally associated with clearly secondary mineralization of thorite, fergusonite, and other RE species. These minerals typically invade and replace biotite along cleavage planes and transect the cleavage along small fractures which extend into the surrounding perthite in some cases.

Gadolinite and allanite are associated with replacement purple fluorite in a number of pegmatites throughout the district, the most notable of which are the White Cloud, Dazie Bell, Big Bear No. 2, Madonna No. 2, Big Bertha, and Shuttle Run which have all been mined for these minerals as rare-earth ore (Robert Beal, pers. comm.). Gadolinite, the iron-beryllium-yttrium silicate, occurs as long slender prismatic crystals with pyramidal terminations and diamond-shaped cross sections. Crystals which are as much as two inches long usually are embedded in fluorite and yttrofluorite. The black to greenish black crystals are brittle and break with a conchoidal fracture. Optically, non-metamict grains are positive with a large 2V and indices of refraction near 1.80. Most crystals are metamict or highly altered by subsequent fluocarbonate mineralization; and X-ray patterns show only alteration products. Qualitative electron microprobe analysis indicates that in addition to yttrium-group elements, cerium-group elements also are present. Thus this material may actually be a cergadolinite (gadolinite-Ce, Levinson, 1966).

Allanite occurs in shiny black radioactive masses which are typically about the size of a walnut, but rarely larger pieces as much as eight inches in diameter also are found. The massive, irregular lumps are brittle and show no distinct cleavage. Optically the mineral is metamict and has a dark grayish-green color. The index of refraction is about 1.70.

Some crystals are a mixture of metamict and crystalline material which is pleochroic in shades of brown and optically negative. Unlike gadolinite, allanite is also found as isolated anhedra enclosed in altered and discolored perthite. This type of allanite typically has an anisotropic, yellowish-red rind of bastnaesite. Qualitative electron microprobe analysis reveals the presence of only cerium-group rare earths. Thorium accounts for the radioactivity.

The idiomorphism of allanite and gadolinite in quartz (which is not a widespread mode of occurrence) is taken by Haynes (1965) as evidence that these minerals crystallized before the quartz and thus before the replacement units which cut the quartz. But the close spatial association of these minerals to obvious replacement mineralization is indicative that they are related to late-stage replacement processes. Haynes has apparently failed to consider the possibility of proximal quartz recrystallization accompanying the replacement activity.

Thalenite, a very rare yttrium silicate, occurs at the Snowflake pegmatite and the White Cloud pegmatite, which are respectively the second (Adams and others, 1962) and third (Adams and Sharp, 1971, 1972) localities in North America. At the Snowflake thalenite is associated with perthite, yttrofluorite, quartz, albite, fluorite, and molybdenite. In the White Cloud it occurs with allanite and fluorite in replacement units of yttrofluorite. Most of the material occurs as small pink to yellowish pink anhedra intimately associated with allanite in yttrofluorite. Adams and others (1962) report that thalenite from the Snowflake is associated with an unidentified carbonate-bearing alteration product.

Thyorogummite, a basic thorium-uranium silicate, occurs as a minor accessory in the Seerie pegmatite.

GEOCHEMISTRY

Bulk Composition

Compositions of both types of pegmatites are shown in Table 5 in terms of the relative areal extent of each zone. Areas were determined by planimeter measurements of each zone and are expressed as a percentage of the whole pegmatite. Twenty-four large, well-exposed pegmatites with well-developed internal zonal structures were chosen for analysis. Results show that wall zones average about 57 percent of the quartz-core type and about 52 percent of the composite-core type. In quartz-core pegmatites intermediate-zone microcline averages about 13 percent and quartz cores about 29 percent, a sum of 42 percent. This compares closely with the composite-core average of 47 percent. The total amount of replacement material for the district is about one percent for both pegmatite types and core-margin fluorite is about 0.5 percent.

The large range in values for the major zones shows the effect of vertical asymmetry and individual irregularity on the areal extent at the given level of exposure. Consequently, differences of less than five percent are probably insignificant considering the room for error in this type of calculation. The close correspondence between the sum of intermediate-zone microcline and core quartz with the composite-core value suggests that the major difference between the two pegmatite types is physical rather than compositional. Thus it appears that quartz-core types are more segregated equivalents of the composite-core type. An "average" South Platte pegmatite is calculated to consist of approximately 55 percent wall zone and 44 percent composite core which would be equivalent to 55 percent wall zone, 14 percent intermediate zone, and 30 percent quartz core. The remaining 1 percent is replacement with minor primary fluorite.

Wall-zone modal composition determined from thin sections and stained slabs averages:

Microcline	53%
Albite (perthitic)	14%
Quartz	30%
Biotite	3%

Intermediate-zone thin section modal composition averages:

Microcline	84.0%
Albite (perthitic)	15.5%
Quartz	0.5%

Combining the zonal percentages with the compositional data yields a modal bulk composition for an "average" South Platte pegmatite of:

Microcline	42%
Albite	10%
Quartz	46%
Biotite	2%

This composition is representative of the bulk composition only insofar as the overall average is representative of the entire volume of pegmatitic material and is not influenced by a bias in the vertical levels of exposure. The data contained in Table 5 come from an extensive sampling of pegmatites at various (i.e., random) levels of exposure and were selected to give as representative a group as possible. Although the assumption that composite cores are equivalent to an intermediate zone plus quartz core can be questioned, since at this time there are no quantitative supporting data, we believe that field evidence qualitatively supports this equivalence. Hence, the results are believed to give a representative indication of the bulk composition of a hypothetical average pegmatite for the whole district. The implication is that these data give an insight into the general bulk composition of the pegmatitic fluids which evolved in this part of the batholith. However modal composition alone

Table 5. Zonal Compositions of Selected Quartz-Core and Composite-Core Pegmatites.

Quartz-Core Pegmatites	Plate Number	Areal Percent					
		Wall Zone	Intermediate Zone	Core	Core-Margin Fluorite	Outer-Intermediate Zone Biotite	Replacement Units
Oregon No. 1½	5	70.9	2.2	25.9	1.0	0.0	0.0
Oregon No. 2½	3	78.8	14.2	4.8	0.0	2.3	0.0
Oregon No. 3	2	63.3	0.0	34.8	0.0	0.0	2.0
Luster No. 1	7	43.8	16.5	35.0	2.1	2.6	0.0
Luster No. 1½	8	52.8	12.7	33.0	2.9	0.0	0.0
Lesser White Cloud	11	44.9	37.0	5.0	0.0	0.0	13.2
Little Patsy	9	35.9	21.3	37.9	1.5	3.2	0.0
Dazie Bell (eastern)	12	45.7	0.0	54.1	0.0	0.0	0.1
Average		54.5	13.0	28.8	0.9	1.0	1.9
Composite-Core Pegmatites							
Twin Cedars	14	62.0		38.0			
Madonna No. 1	19	42.3		57.7			
Madonna No. 2	20	42.3		57.7			
Madonna No. 3	21	33.2		65.4	1.4		
Oregon No. 1 (western)	6	59.1		40.9			
Oregon No. 1 (eastern)	6	46.3		53.5			0.2
Big Bear No. 2	13	84.3		14.3			1.4
Big Bear No. 2 (eastern)	13	53.4		36.7			10.0
White Cloud	10	50.2		46.5			3.2
Big Bertha	25	20.7		79.0		0.3	
Dazie Bell (central)	12	65.1		35.0			
Black Cloud	30	62.7		37.3			
Gemini (southern)	23	67.6		32.4			
Gemini (northern)	23	53.8		46.2			
Teller	31	31.0		68.5			0.5
Shuttle Run	17	54.7		45.3			
Average		51.8		47.1	0.1	0.0	1.0

cannot measure submicroscopic perthitic plagioclase and is inadequate for determining the prevailing pressure and temperature parameters, which will have to await further chemical analyses. The modal composition given in Figure 11 clearly shows an enrichment of the late-stage fluids in quartz and albite over the granite.

Geochemical Characteristics

Most pegmatite districts or provinces are distinguished by the presence of a characteristic set of lesser elements which commonly occur in certain specific minerals. Conversely, some elements, "normally" concentrated in pegmatites, may be conspicuously absent or diminished. The South Platte district is no exception to this generalization. Its geochemical "fingerprint" pattern consists of very abundant fluorine, rare-earth elements and iron, the absence of boron, and a dearth of beryllium.

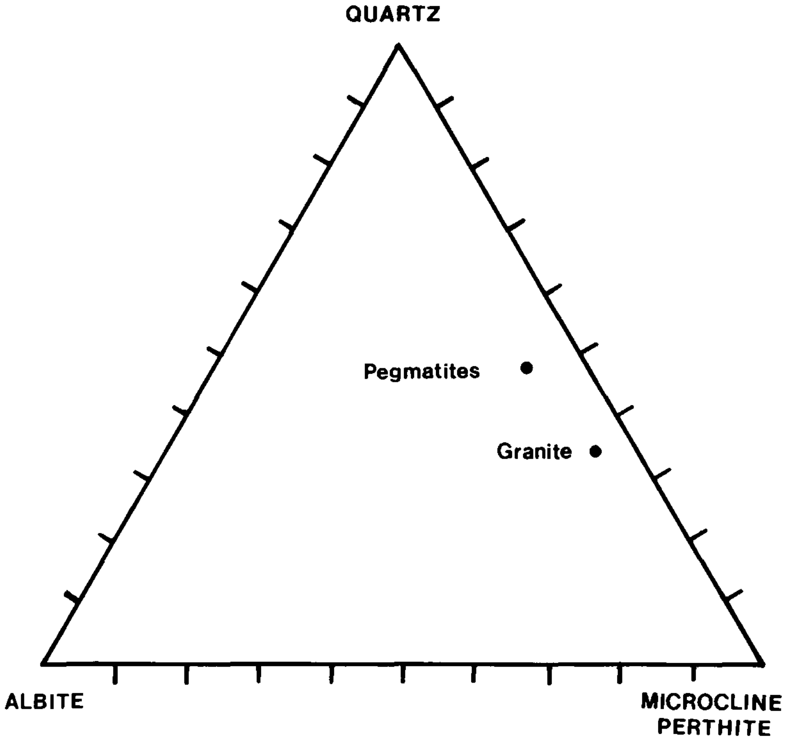


Figure 11. Modal composition of South Platte pegmatites and granite, showing enrichment of late-stage fractionates in quartz and albite.

Pegmatites of the Eight Mile Park, Trout Creek, Micanite, of the Colorado Front Range, and similar districts are noted for their contents of boron and beryllium species. The South Platte district is exceptional in having virtually no tourmaline and no beryl; mineralogically boron is not represented, and beryllium appears only to a minor extent in gadolinite.

Abundant fluorine is highly characteristic of the district, occurring in nearly all the pegmatites as accessory fluorite. Although fluorite has been reported as an accessory in other Colorado pegmatites (Heinrich, 1957), in this district it is abundant as a major accessory and is represented by at least five paragenetic types.

Rare-earth mineralization is perhaps the most diagnostic geochemical characteristic of these pegmatites. Typically the rare-earth minerals present include some combinations of: yttrofluorite, cerian fluorite, monazite, xenotime, allanite, fergusonite, samarskite, gadolinite, cyrtolite, thorite, thalenite, doverite, or bastnaesite. In some deposits one or more of these minerals may be very abundant in replacement units.

Ferric iron is also exceptionally abundant in this district. The presence of hematitic phases containing specular hematite appears to be unique to the district. The presence of biotite in lieu of essential muscovite, so characteristic of many other Colorado pegmatite districts, is notable and reflects the abundance of iron in the pegmatitic system.

The obvious geochemical differences between the South Platte pegmatites and those of other Front Range districts are significant since a number of thse (Eight Mile Park, Trout Creek, Micanite, and others) have been cited in earlier reports as genetically related to the granitic rocks of the Pikes Peak batholith. Such distinct differences in minor element chemistry suggest that the pegmatites from these other districts may not have been derived from the Pikes Peak batholith but from another episode of magmatism. Recent Rb-Sr dates of pegmatite and granitic rocks of the Royal Gorge and Blue Ridge areas by Vera and Van Schmus (1974) are further evidence that many of these other Front Range districts may be related to a different, older period of igneous activity.

Thus, the evidence seems to suggest that minor element geochemistry and accessory mineral assemblages are diagnostic of the genetic affiliation of these districts. If this is true, then the Eight Mile Park, Trout Creek, Micanite, and similar districts characterized by assemblages of muscovite, beryl, and tourmaline are probably related to an older magmatic event instead of the Pikes Peak.

FRACTIONATION OF RARE-EARTH ELEMENTS

Introduction: Rare-earth minerals are much more abundant in South Platte pegmatites than in most other pegmatites of the United States. In mineralogy, abundance of rare species, and other characteristics, the South Platte suite closely resembles those of the Swedish pegmatite districts near Osterby, Ytterby, and Finbo (Sjogren, 1906; Mason and Roberts, 1949; Mason, 1971; and Heinrich, pers. obs.). The only pegmatite district in the United States in which the concentration of REE may be comparable to that of South Platte is Llano County, Texas.

The question never successfully answered is whether such unusually high concentrations of these elements result from processes of extreme fractionation which concentrated the elements in the late phases or whether the parent magma must have an anomalous concentration of these elements before subsequent further concentration is possible. If scavenging actually occurs, the minor-element content of the granite should be well below the average granite content of these elements. If, alternatively, a certain threshold concentration must be exceeded before late-stage concentrations can occur, the parent magma and its resulting granite should show an anomalously high minor-element abundance.

Various authors (Rankama and Sahama, 1950; Ringwood, 1955a, 1955b; Beus, 1962; and Smith, 1963) have suggested, principally from theoretical considerations, that many late-stage pegmatite enrichments are caused by partitioning processes of early-stage magmatic consolidation which crystallochemically or thermodynamically selectively exclude certain ions or elements; consequently, the concentration of these ions progressively increases as crystallization continues until they ultimately precipitate as separate minerals in the pegmatites. Although there is good analytical evidence supporting these general trends, there have been a few studies which seem to indicate that processes other than fractionation alone are responsible for major concentrations of certain rare-element enrichments.

A report by Bray (1942) lists spectroscopic minor-element analyses of igneous rocks from the Jamestown district, Boulder County, Colorado. His results indicate that the cerite-bearing pegmatites of the area are related to a cerium-rich granite, the Silver Plume, which Goddard and Glass (1940), on the basis of field studies, also genetically relate to the cerite deposits.

Field relationships of tantalum-bearing pegmatites in a Finnish Precambrian igneous complex indicate that the pegmatites are genetically related to only the youngest granite of the complex, which also was shown by spectrochemical analyses to be the only tantalum-bearing granite of teh complex (Rankama, 1944).

A report on the geochemistry of tantalum in the Harding pegmatite, Taos County, New Mexico (Montgomery, 1950) describes another tantalum-rich pegmatite and its relation to the adjacent Dixon granite to which, on the basis of field relations and petrologic and mineralogical evidence, the Harding pegmatite is genetically related. The granite contains a notable enrichment of tantalum-bearing sphene, locally up to four percent. However in the area immediately adjacent to the pegmatite the abundance of the accessory sphene in the granite diminishes to only traces. This aureole of tantalum depletion has been cited as a source of the very abundant tantalum (one pound per eight tons of pegmatite) contained in the pegmatite (Montgomery, 1950; and Ringwood, 1955a, 1955b). Although the quantitative grounds for this conclusion may be somewhat moot, the significant conclusion remains that the Harding deposit developed from a notable tantalum-enriched parental granite.

Several more recent studies also lend credence to this concept of original enrichment. Von Knorring (1960) describes a columbite granite province in South-East Uganda and notes that Nb-rich pegmatites are associated with the high-Nb Lungo granite. Stavrov (1961) studied the rare-element content of quartz and found that the quartz from lithia-bearing pegmatites and their genetically related granites contains greater quantities of lithium than quartz from non-lithia pegmatite-granite complexes--a relationship that he reports also for boron. He states that "the lithium content in quartz of granites and pegmatites depends directly on the content of this element in the magma." Heinrich (1962) shows that the micas of beryl-bearing pegmatites are beryllium-rich. Oftedal (1967) reports on an association of Pb-rich pegmatites with Pb-rich granites in southern Norway.

Thus in the light of these studies and in the belief that, because of its accessibility, exposure, and unambiguous relation to its parental granite, this district was ideally suited for a similar study, an investigation was undertaken to determine the degree of depletion or enrichment of REE in the granite associated with these anomalously rare-earth-rich pegmatites.

Samples: Twenty-seven samples for analysis were chosen from scattered areas in the northern end of the batholith (Figure 12). Samples were collected from all of the granitic rock types mapped as well as other types described by Hutchinson (1960). In addition to granite, samples from the main pegmatites zones also were obtained. One pegmatite, the Seerie (Plate 26), which is exceptionally fresh and well exposed, is the source of a suite of six granite samples collected from the contact away from the pegmatite for a distance of 11 feet as well as a suite of pegmatite rocks (Table 6). The 27 analyzed specimens were chosen on the basis of their fresh and unaltered appearance and their contribution to a representative geologic coverage. Table 6 contains the sample numbers, a description of each sample, and its location.

The very coarse grain size of the granite presents a problem for obtaining representative samples. Thus samples selected weighed about 800 to 1000 grams. Samples this large are intended to be homogeneous representative of an outcrop. The uniformity of the analytical results tends to substantiate this judgment.

Each entire sample was pulverized, thoroughly mixed and quartered several times. Fifty- to one hundred-gram portions were then ground to below 100

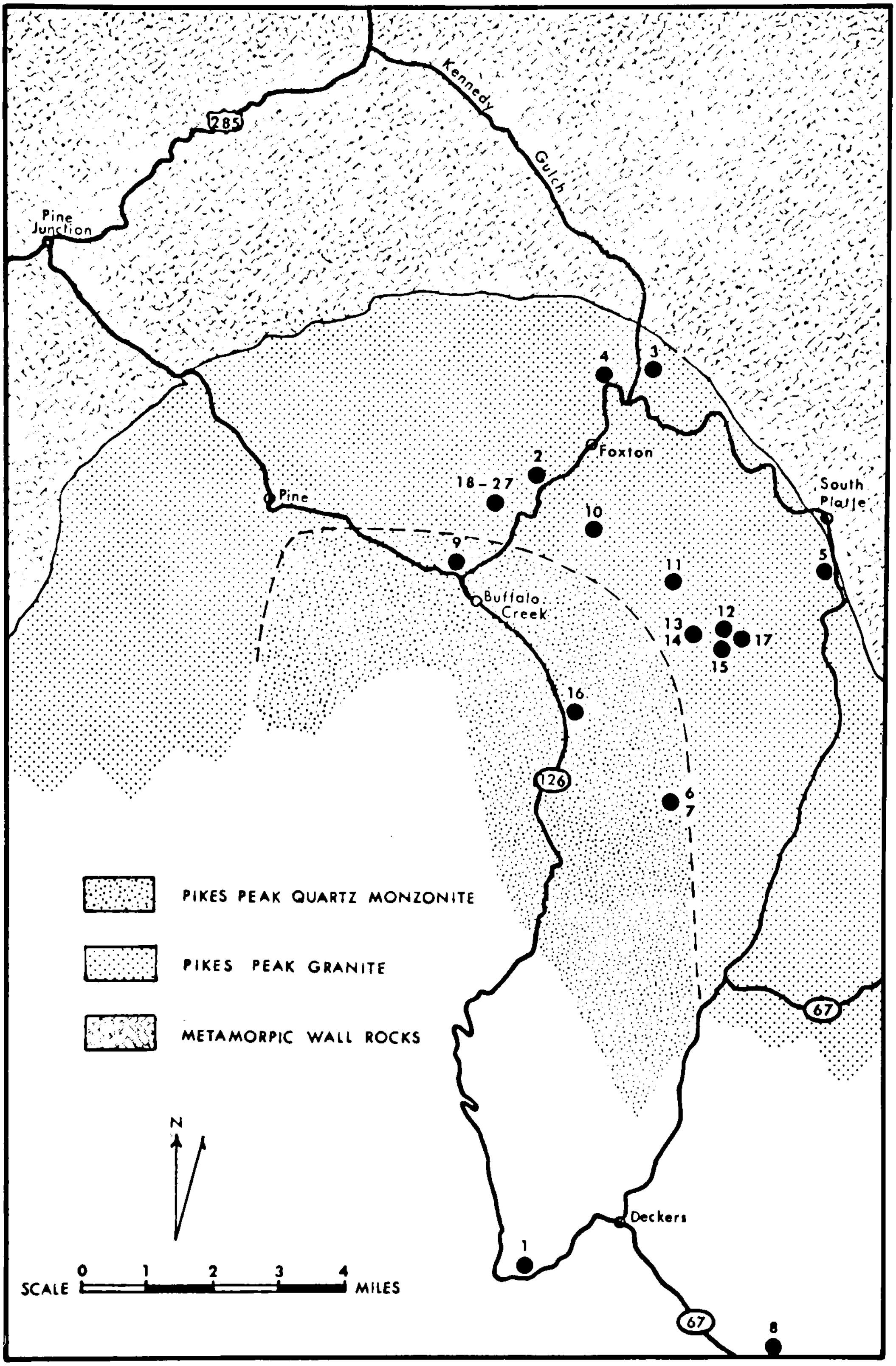


Figure 12. Location of samples for activation analysis. This geologic map of the northeastern end of the Pikes Peak batholith, modified from Hutchinson (1960), shows the rock type and the location of each sample in the batholith. Individual sample descriptions are listed in Table 6.

Table 6. Location and Description of Analyzed Samples.

SAMPLE NUMBERS	LOCATION[1]	DESCRIPTION
1	SPG-9	Quartz monzonite, 2.5 miles northwest of Deckers
2	SPG-5	Granite, quarry 1 mile south of Foxton
3	SPG-3	Granite
4	SPG-1	Granite, Petter Bossie Quarry
5	SPG-4	Granite, 3/4 mile south of South Platte
6	SPG-6	Core feldspar, Big Bertha pegmatite
7	SPG-7	Wall zone, Big Bertha pegmatite
8	SPG-10	Granite, 6.35 miles south of Deckers on Col. 67
9	SPG-15	Quartz monzonite, quarry near Buffalo Creek
10	SPG-16	Granite, Chair Rocks
11	SPG-30	Granite, Raleigh Peak
12	SPG-42	Granite, 3" from contact Dazie Bell pegmatite
13	SPG-48	Granite, 100' from contact Big Bear pegmatite
14	SPG-49	Wall rock, Big Bear pegmatite
15	SPG-55	Granite
16	TWG-1	Quartz monzonite, road to Top of World picnic ground
17	Q-12	Quartz, Madonna Eastern pegmatite
18	SER-100	Wall zone, Seerie pegmatite
19	SER-101	Border zone, Seerie pegmatite
20	SER-102	Contact, Seerie pegmatite
21	SER-103	8" from contact, Seerie pegmatite
22	SER-104	3" from contact, Seerie pegmatite
23	SER-105	6' from contact, Seerie pegmatite
24	SER-106	11' from contact, Seerie pegmatite
25	SER-107	Core feldspar, Seerie pegmatite
26	Q-40	Core quartz, Seerie pegmatite
27	SER-108	Core margin biotite, Seerie pegmatite

[1] See Figure 12 for the location of samples in the batholith.

microns. One-half gram aliquots were then sealed in medical quality polyethylene containers for neutron activation analysis. For a complete detailed description of the analytical techniques and problems consult Simmons (1973).

Analytical Results: Whole-rock, rare-earth element (REE) content of granitic rocks, pegmatite wall rocks, and principal pegmatite minerals are given in Table 7, together with their means, standard deviations, and coefficients of variation (% S.D.).

The anomalously large abundances of these elements in the granitic rocks are immediately apparent. Several samples contain over 300 ppm cerium. The sum of the granitic-rock mean La, Ce, Sm, Tb, Yb, and Lu values ( ) is about 450 ppm, which is nearly twice the concentration of the total lanthanide content, including Y, for most granitic rocks (Wedepohl, 1969, Handbook of Geochemistry), they appear to be among the most RE-rich granites ever described. They are exceeded only by granite from Obnas, Finland, which contains over 1300 ppm total lanthanides. By comparison with typical values listed in the Handbook of Geochemistry, South Platte granitoids certainly surpass most granites in their lanthanide content. In fact, from the data summarized in the Handbook of Geochemistry, South Platte granitic rocks are estimated to contain about 1000 ppm, or 0.1% total rare earths, a copious enrichment. "Enrichment factors" for each element (see Table 8) were calculated from a composite western United States Precambrian granite (Gehl, 1964), quoted from Haskin and others (1966). These factors also emphasize the RE-rich character of these rocks in comparison to similar Precambrian granites.

In contrast, the pegmatite wall-zone rocks are notably depleted of rare earths, relative to the parental granite (see Figure 13). Although the wall-zone samples show considerably more variation in their RE content than the granites, wall-zone RE abundances were significantly lower. is only about 60 ppm for these rocks and, by comparison to analyzed granites with very similar individual RE contents and values (Handbook of Geochemistry), wall-zone rocks can be extrapolated to contain between 100 and 200 ppm total rare earths. This is about an eightfold decrease in lanthanides compared with the adjacent granites.

Table 7. Rare-Earth Content of South Platte Granitoids, ppm.

SAMPLE NUMBERS	La	Ce	Sm	Tb	Yb	Lu
GRANITE						
SPG-5	188.6	394.5	37.8	2.5	24.6	7.6
SPG-16	162.0	335.2	30.6	2.4	24.7	7.2
TWG-1	151.7	304.1	21.1	0.9	6.7	4.0
SPG-9	148.1	306.7	34.5	1.7	23.2	6.5
SPG-55	129.2	268.8	27.8	2.1	17.1	5.7
SPG-3	127.9	255.4	25.5	1.5	15.5	4.8
SPG-15	123.8	254.3	27.4	2.9	17.5	6.3
SPG-30	112.7	220.3	28.0	1.6	19.5	5.9
SPG-48	110.4	234.4	21.0	1.2	4.3	3.6
SPG-4	103.1	215.4	23.4	1.2	16.1	5.1
SPG-1	86.9	176.7	21.7	2.1	16.6	5.3
SPG-10	143.7	228.6	15.2	0.5	5.7	2.5
SER-102	132.1	283.4	35.3	2.6	23.0	8.8
SER-103	90.5	194.3	26.4	n.d.	13.0	7.1
SER-104	186.0	347.4	35.9	n.d.	12.5	7.1
SER-105	113.2	241.6	29.5	2.1	15.1	6.2
SER-106	115.8	226.5	28.0	3.2	21.7	4.2
SPG-42	90.2	189.3	21.5	1.4	2.0	4.9
MEAN	128.7	259.8	27.3	1.9	15.5	5.7
S.D.	30.2	59.9	6.1	0.7	7.0	1.6
% S.D.	23.5	22.7	22.4	39.9	45.5	27.7
ENRICHMENT FACTOR	2.3	2.5	3.4	1.7	3.6	8.4
WALL ZONE						
SER-101	26.8	47.9	5.1	0.7	4.2	1.7
SER-100	23.6	58.0	10.3	0.8	13.3	9.6
SPG-7	3.1	9.3	0.4	0.2	1.4	0.9
SPG-49	8.9	14.8	1.0	0.3	3.4	2.2
MEAN	15.6	32.5	4.2	0.5	5.6	3.6
S.D.	11.4	24.1	4.6	0.3	5.3	4.0
% S.D.	73.4	74.1	109.5	63.8	94.9	110.8
PEGMATITE MINERALS						
SER-108	8.1	--	n.d.	0.7	0.5	0.8
SER-107	0.2	0.8	0.3	n.d.	3.0	1.0
Q-40	0.5	n.d.	n.d.	n.d.	n.d.	n.d.
SPG-6	3.0	0.2	n.d.	0.0	n.d.	0.1
Q-12	1.2	n.d.	n.d.	n.d.	n.d.	0.0

Table 8. Filling Temperatures of Fluid Inclusion

Mineral	Location		Type of Inclusion	Number Tested	Filling Temperature °C
Green fluorite	White Eagle	CM	(?)	3	121-123
Green fluorite	Last Dollar	CM	(?)	1	114
Green fluorite	Quartz Knob	CM	P (?) I	4	150-153
Green fluorite	Little Bill	CM	P (?) I	6	295-324
Green fluorite	Little Bill	CM	PS (?) I	1	308
Green fluorite	White Cloud	CM	PS (?) I	3	98-136
Clear & smoky quartz	Quartz Knob	C	S I	4	286-308
Clear & smoky quartz	Quartz Knob	C	PS IIa	1	370
			PS IIb	1	370
			PS IIc	4	370-423
Clear quartz	White Cloud	C	S I	2	195-223
Smoky quartz	Snowflake	C	S I	4	119-122
Smoky quartz	Black Cloud	C	S I	10	124-256
Smoky quartz	Black Cloud	C	P IIa	24	>431[1]
			P IIb	1	>338
			P IIc	1	>414
Clear quartz	Dazie Bell	C	S I	3	154-158
Clear quartz	Dazie Bell	C	PS IIb	3	379-381
Smoky quartz	Yammy Yogurt	C	S I	3	120-178
Smoky quartz	Yammy Yogurt	C	P IIa	1	283

[1] All CO_2-rich inclusions exploded before filling was complete.
P-primary, PS-pseudosecondary, S-secondary, C-core, CM-core margin.

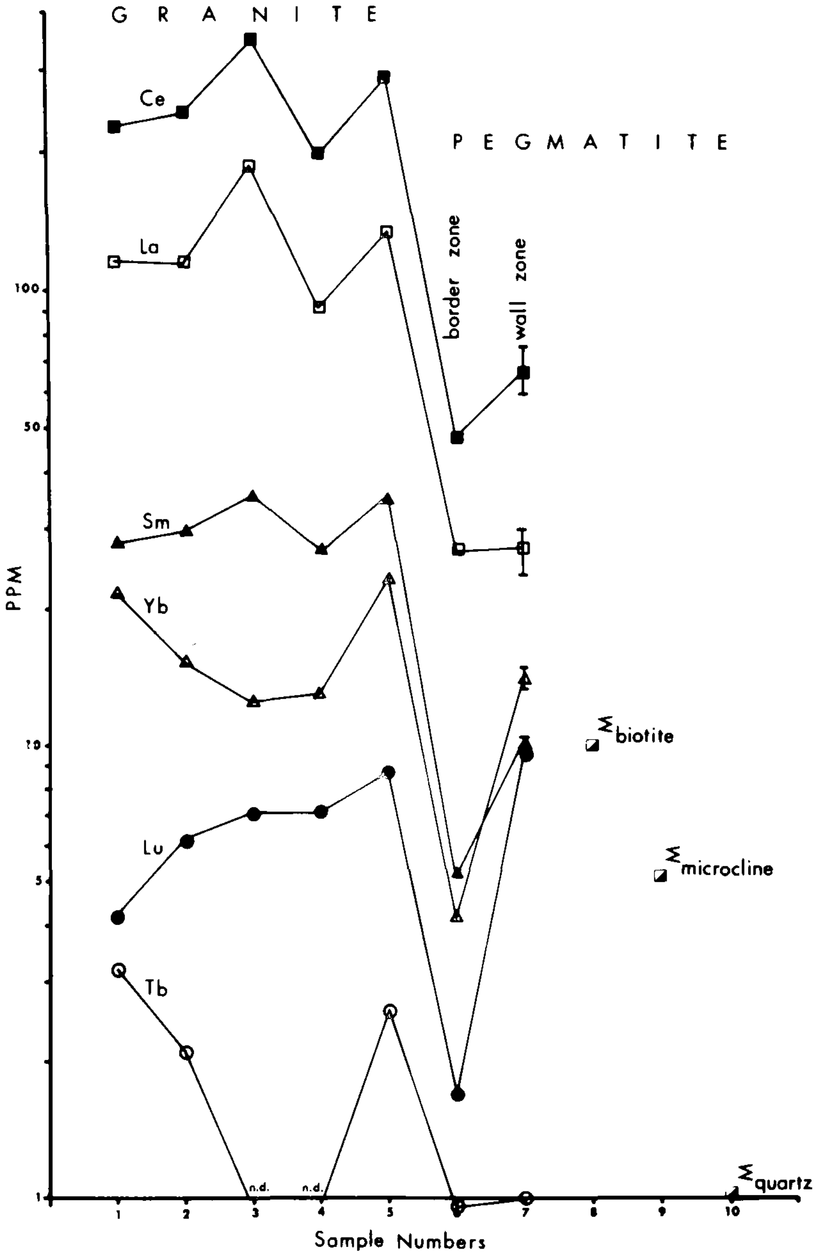


Figure 13. Rare-Earth Abundances of Pegmatitic Rocks and Adajcent Granite. This figure shows the variation of rare-earth content of pegmatite zonal species and surrounding granite. The granite samples, 1-5, were collected horizontally away from the pegmatite and are, respectively, 11', 6', 3', and 8" from the contact. With the possible exception of Lu, fluctuations of the granite values show no strong trends and are probably a result of heterogeneous distribution of rare-earth accessories in the sample.

Border- and wall-zone rocks show a significant depletion in rare earths relative to the granite. Interior zonal species show even greater depletion. The points for biotite, microcline, and quartz are e values, the sum of all elements analyzed.

Expected errors, larger than those indicated by the size of the points, are shown by a vertical bar for sample 7. Errors were determined from replicate analyses.

Light lanthanides seem to be more strongly depleted than the heavy group. The granite contains nearly eight times the light lanthanide content of the wall-zone rocks but only about 2.5 times their heavy lanthanide content. Thus, assuming that the wall-zone fluids evolved from the granite magma, nearly 90 percent of the rare earths have been removed and fractionated into the replacement units in the interior of the pegmatites.

Results for the primary pegmatite zonal minerals, intermediate-zone microcline-perthite, core-margin biotite, core microcline-perthite, and core quartz, reveal that these species contain even smaller quantities of rare earths than the wall-zone rocks (see Figure 13). None of the five analyzed samples contained more than eight ppm for any one element, and most were either below or verged on the threshold of detectability. is about 10 ppm for biotite, 3 to 5 ppm for feldspar, and 1 ppm or less for quartz. Thus the interior zonal rocks contain less than 2 percent of the lanthanide abundance found for the granite, indicating that nearly all of these elements were fractionated into the late-stage fluids instead of precipitating with the primary minerals.

Another interesting result is the abrupt change in the lanthanide content of the granite-pegmatite contact immediately adjacent to the pegmatite wall zone. This narrow, commonly indistinct border zone is typically too small and discontinuous to be mappable. But at the Seerie pegmatite the zone is well developed, and analysis reveals that it is even more depleted in lanthanides than the wall-zone rocks. Again, light lanthanides appear to have been much more drastically affected than the heavy lanthanides. Figure 13, a plot of the rare-earth abundances of adjacent granite versus the horizontal distance from the pegmatite contact for the Seerie pegmatite, clearly shows this abrupt change in rare-earth content in this transitional zone.

Conclusions: The exceptional enrichment of rare-earth elements in the Pikes Peak granitic rocks and their spatial and temporal association with the pegmatites indicate that the South Platte pegmatites were engendered from a granitic magma replete with rare-earth elements. Results of the whole-rock minor element analyses strongly suggest that the principal factor contributing to the formation of these unusual rare earth-rich pegmatites is their genetic relationship to the super-RE-enriched granitic magma.

Although original enrichment appears to have played a paramount role in the development of these deposits, fractionation processes unquestionably are important also. The question is to what extent and at what stage in the magmatic process did RE fractionation become important?

From the pegmatite bulk-chemistry computations discussed earlier it appears that an "average" South Platte pegmatite contains about 2 percent secondary mineralization. If 2 percent replacement is accepted as a close volumetric value, we can make an estimate of the total rare-earth content of the entire pegmatite.

The Oregon No. 3 pegmatite, which was being quarried at the time it was mapped, was chosen for this computation because it was studied and sampled in more detail than most of the other pegmatites. Also, the replacement body in this pegmatite is a well-defined unit and is relatively simple mineralogically. Although the replacement body is somewhat atypical in its mineralogy, the structural relations of this body and the pegmatite as a whole are clearly defined, and several tons of material from the unit as it was being mined were available for detailed examination.

Visual estimates within the quarry and point counts from photographs covering over 200 sq ft of replacement material were used to determine the abundance of large samarskite nodules within the unit. These nodules represent the predominant rare-earth mineralization. Results indicate that approximately 1.6 percent of this replacement unit is composed of these large nodules, some of which weigh over 75 pounds.

Typical total rare-earth values for samarskite are about 15 percent (Palache and others, 1944). This gives a 0.24 percent total RE content for the replacement unit assignable only to the large samarskite nodules. To this must be added a contribution from small accessories or other sources of rare earths such as yttrofluorite. Although the effect of such additions is not definitely known, their contribution is believed to be small, probably less than 0.1 percent.

The core of the Oregon No. 3 is pure quartz, with a total RE content of only about 0.0002 percent. Wall-zone rocks contain approximatley 0.0150 percent total rare earths. Combining these data with the weight percent figures for each unit gives us an estimate of 1.4 weight percent for the total rare-earth abundance for the entire pegmatite. Adding 0.1 percent to the replacement-unit value (as the small-accessory contribution) yields a total of 1.6 percent, which shows the relatively small change of the total produced by adding a relatively large accessory RE contribution to the replacement unit.

Thus, it appears that a reasonable estimate of the RE abundance of this pegmatite is between one and two percent. Relative to the granite, this represents about an order of magnitude enrichment of lanthanides.

Fractionation of lanthanides between the granite magma and the pegmatitic fluids definitely appears to have contributed signficantly to the abundance of these elements in the pegmatites but not to such an extent as to cause a major depletion of rare earths from the magma.

Textural evidence suggests that the bulk of the rare earths remained with the residual silicate melt during crystallization until their solubility products were exceeded near the latter stages of crystallization. At this time most of the rare earths began to crystallize as interstitial accessory minerals in the granite.

A second hydrous fluid phase, which probably had already begun to segregate, apparently had a larger capacity for these elements than the remaining silicate melt and consequently additional quantities of lanthanides were fractionated into these fluids. Once in the pegmatitic fluids, the rare earths were strongly partioned into the progressively more hydrous-rich phases as crystallization continued. Only small quantities precipitated in the wall-zone rocks and virtually none in the intermediate microcline, core-margin biotite, core quartz, or core feldspar.

After large bodies of these pegmatitic fluids had coalesced, it is probable that these highly mobile fluids promoted the selective transfer or partitioning of rare earths out of the border or transitional zone into the pegmatite.

Rare earths continued to fractionate into the residual fluids well into the replacement stage of pegmatite formation after the bulk of the pegmatite had crystallized. Eventually these fluids, which were very rich in H_2O, RE, F, Fe, Na, and so on, began to precipitate and replace earlier formed minerals which were no longer stable with these fluids, giving rise to the unusual secondary mineralization characteristic of this district.

In summary, the unusual mineralogy of these pegmatites results from a combination of the original chemical nature of the magma and the late-stage fractionation of these elements during the pegmatitic phase. The most important factor appears to be the super-enrichment of the original parental magma with rare-earth elements, iron, and fluorine. Fractionation, although important, was dependent upon the primary concentration and, thus, appears to have played a secondary role in the production of these elemental enrichments (Heinrich and others, 1978).

PARAGENESIS

Fluid-Inclusion Studies

Initial examination of core quartz and core-margin fluorite revealed the presence of numerous inclusions amenable to visual fluid-inclusion thermometry. These studies were undertaken in order to gain insight into the range of composition of inclusion fluids and their approximate temperatures of entrapment. Since the use of this technique began, there have been a number of reports of fluid-inclusion investigations of pegmatitic minerals, especially from Russian workers (Polykovskii, 1962; Sheshulin, 1961; Lyakhov, 1966; and Yermakov, 1965). In this country Cameron and others (1953), Weiss (1953) and Roedder (1963) have systematically examined a large number of specimens from pegmatites.

Examinations were confined to inclusions in core quartz and core-margin green fluorite for which approximate fluid-inclusion compositions and entrapment temperatures were determined.

Techniques employed, other than those discussed below, were the same as those described in detail by previous workers and are not elaborated here (see Kelly and Turneaure, 1970). Filling temperatures were measured microscopically with the same heating stage described by Kelly and Turneaure (1970). The only difference was that an iron-constenten thermocouple was used with a digital thermometer. The thermocouple was calibrated with boiling water (100°C) and boiling ethyl alcohol (78.2°C) and within this range was found to be linear and accurate to within 1.5 percent. Under actual working conditions near the center of the cell the melting points of "Tempil" powders and elemental sulfur were determined and found to range from about one to four percent from their known values. Variations are mainly due to difficulties in observing the precise point of melting. Repeated filling-temperature measurements for the same inclusion generally differed by less than 4C°. Recorded values are believed to be accurate to within 10C°.

The importance of distinguishing between primary and secondary inclusions in inclusion-thermometry studies has been repeatedly emphasized by previous workers. The same criteria for classification used here have been discussed by Roedder (1967). Several hundred inclusions were studied, but only a relative few of these could be categorized with a high degree of certainty. Although primary growth zoning could be observed in both quartz and fluorite, no unmistakable correlations could be established between these or other features of known primary origin and the distribution of the inclusions. In all cases, isolated inclusions with no obvious planar arrangement were assumed to be primary. This criterion is much more subjective, and there is, therefore, some degree of uncertainty inherent in the corresponding classification. In some cases primary fluid inclusionjs appear to have originated at the site of a solid inclusion trapped by the crystal during its growth.

Numerous inclusions related to secondary fracturing were observed in all the minerals studied. Unmistakable examples of pseudosecondary inclusions initiating from interior growth surfaces were not observed. Short, healed fractures with negative crystal inclusions within the interior of a crystal were assumed to be pseudosecondary. High filling temperatures support this classification in most cases.

Planes of secondary inclusions occurring along healed fractures which completely crosscut the host crystal are ubiquitous in both minerals. Many of these inclusions have been recrystallized to uniformly small and evenly spaced negative crystals. Inclusions displaying obvious recrystallization features were not utilized in heating tests.

Natural leakage does not appear to have affected most of the primary inclusions. Uniform gas-liquid ratios for families of inclusions and the close agreement of the results of duplicate heating runs indicate that leakage effects are minimal.

Two types of fluid inclusions were distinguished on the basis of their composition and degree of filling:

TYPE I. Type I inclusions are liquid-rich with a vapor phase occupying from 2 to 30 percent of the inclusion volume. These commonly occur in both fluorite and quartz and generally contain very little CO_2. Their salinities, equivalent NaCl determined from freezing point depression, range from over 40 percent in a few inclusions with large salt cubes to almost pure water. Most of those tested that contain no daughter salt have relatively low salinities, between 5 and 15 percent.

A few Type I inclusions in both minerals contain minor, but detectable, quantities of CO_2 which condenses as a thin rim around the gas phase upon cooling below 31°C. In freezing tests CO_2 hydrate is indicated by a faint, jagged, and irregular boundary between the aqueous and the liquid CO_2 (see Roedder, 1968).

TYPE II. Type II inclusions are gas-rich, containing from 40 to 95 percent vapor at temperatures just over 31°C. They are characterized by their relatively large CO_2 vapor content and occur exclusively in core quartz. Type II inclusions contain sufficient quantities of compressed CO_2 to form appreciable volumes of liquid CO_2 even at room temperature. Type II inclusions resist freezing with only brief immersions in dry ice and alcohol. To eliminate this supercooling, most inclusions must be held at -78.5°C for 12 hours or longer. Frozen inclusions typically contain both ice and CO_2 hydrate. Equivalent NaCl contents determined for the freezing point depression of the aqueous phase are between 7 and 14 percent. CO_2 hydrate persists above +1.0°C, which was the upper limit of the available equipment. The behavior of Type II inclusions on heating depends upon their CO_2 content and their degree of filling. The three types of homogenization observed for these inclusions serve as a basis for additional subdivision. Types IIa and IIb occur in approximately equal proportions. Type IIa homogenized by vapor expansion, whereas in Type IIb the liquid phase expands to fill the inclusion. Rare Type IIc inclusions homogenize by a gradual fading of the meniscus between the liquid and gas.

Except for a few Type I inclusions containing small amounts of CO_2, the two types do not appear to intergrade. However, since small amounts of CO_2 are difficult to detect, intergradation could be more extensive. Type II inclusions are present in all the quartz examined with only one exception (Oregon No. 3 quartz contains only small volumes of liquid CO_2.

The liquid CO_2, typical of Type II inclusions, provides evidence for a minimum pressure for their formation, since more than 70 bars is required to form liquid CO_2 at temperatures just below 31°C (Takenouchi and Kennedy, 1964). Evidence of the high pressures confined with these inclusions is further demonstrated by the instability of the Type II inclusions during heating tests. Almost all of these inclusions exploded during heating. This marked tendency to fracture when heated made reliable temperature determinations impossible to obtain. In most plates virtually every inclusion ruptured before filling temperatures were reached.

The inclusions contain a number of different daughter salts. The most common is halite, identified by its cubic habit, isotropism, low coefficient of thermal solubility, and the formation of $NaCl°2H_2O$ in freezing tests. A second less common isotropic mineral, usually poorly crystalline, was identified as sylvite on the basis of its more rapid rate of solution upon heating. Halite and sylvite are restricted to Type I inclusions, but occur in both minerals.

Another daughter mineral, found only in Type I inclusions of fluorite, consists of large anisotropic euhedral platelets which occur in secondary and extensively necked inclusions in purple fluorite. The plates, which also occur as solid inclusions (i.e., free of attached fluids) in the fluorite, are biaxial positive with a moderate 2V and show parallel extinction. Electron microprobe analysis of a large (0.5 mm) solid inclusion exposed at the surface of one plate revealed the salt to be anhydrite. Apparently this is the first verification of this mineral as a daughter salt. It is a notably rare pegmatite mineral.

Another interesting daughter mineral occurs as felted aggregates of tiny fibers within negative-crystal Type I inclusions in quartz. These crystal aggregates are strongly birefringent and very similar in form to those of dawsonite described by Coveney and Kelly (1971).

In a few cases Type II CO_2-rich inclusions in quartz also contain daugher minerals; at least one such inclusion contained ten distinct crystals of the same daughter salt. Typically no more than two crystals, separated by a large liquid CO_2 bubble, are present in an inclusion; but rarely a single inclusion may contain a number of separate crystals of the same daughter mineral. Somewhat surprisingly these salts are most abundant in inclusions containing the least volume of water-rich liquid. The identity of these crystals is unknown, but they all have identical optical properties, dissolve at about the same temperature (130°C-150°C), and hence appear to be the same mineral. The presence of numerous separate crystals of the same daughter salt is unusual, since generally only one crystal of a given daughter salt is observed in inclusions which have not been previously heated or frozen (Wm. C. Kelly, pers. comm.). Most crystals are irregular thin plates but a few subhedral crystals appear to have hexagonal outlines. They are anisotropic with a high birefringence and perhaps could be some type of carbonate.

Filling temperatures, corresponding to the moment of fluid homogenization of 80 selected inclusions, are listed in Table 8. Filling temperatures range from slightly less than 100°C to more than 431°C for all inclusions tested, but this large range is restricted by considering inclusion types individually.

Green fluorite Type I inclusions which were assumed to be primary give filling temperatures ranging from 98°C to 324°C, averaging about 192°C.

Type I inclusions in quartz also include a wide range of homogenization values from just over 100°C to 308°C, averaging about 163°C. Quartz Type I inclusions fill at distinctly lower temperatures than the gas-rich Type II inclusions, probably indicating that they were secondary.

Type II CO_2-rich inclusions, which are restricted to quartz, gave the highest values of homogenization, ranging from slightly below 300°C to more than 431°C. The marked tendency of these inclusions to rupture severely limited the number of successful runs and prevented recording temperatures above the latter value. However, large numbers of these inclusions were observed to explode very near or at the moment of homogenization; and a sufficient number filled within this range to indicate that the higher values are near their upper limit.

According to the phase equilibria data discussed previously, the load pressures under which this granite-pegmatite system crystallized were several orders of magnitude larger than those usually encountered in inclusion thermometry studies. P-V-T data on the H_2O-NaCl and the H_2O-CO_2 systems at pressures near 5000 bars are sparse, and consequently pressure-salinity corrections could not be determined. However, the experimental studies of the NaCl-H_2O system by Klevstov and Lemmlein (1959) provide a basis for making minimum corrections for the Type I inclusions in fluorite. Although their experiments were conducted only up to 1700 atm., they give extrapolated data to 2500 atm.

At 324°C, the maximum value obtained for the fluorite Type I inclusions, the temperature correction for a 10-percent solution at 2500 bars is about

260°C, which gives a corrected temperature of approximately 580°C. The lower filling temperatures for these inclusions, near 150°C, yield corrected temperatures of about 340°C. The true entrapment temperatures, or formation temperatures if the inclusions are primary, probably would be considerably higher, provided that the slope of the isochores does not change radically at higher pressures. Since these are minimum corrections, the apparent temperature range is not necessarily real.

Primary Type IIa and Type IIb inclusions, which occur in the same crystals of quartz with one type (IIa) homogenizing as a liquid and the other (IIb) as a gas, appear to represent a set of immiscible fluids. Type IIc inclusions may represent rare mixing of Type IIa and IIb fluids. Potentially, such a set of fluids can yield the temperature of formation directly from filling temperature measurements without the necessity of a correction for pressure. However the tendency of these inclusions to rupture before filling made it impossible to collect sufficient data for temperature determinations. Thus, 431°C represents an uncorrectable minimum temperature of formation.

The principal conclusions that can be drawn from this limited inclusion study are that core-margin green fluorite did not form below 340°C and that the core quartz containing Type II inclusions did not form below about 430°C. These temperatures suggest that the core quartz may have formed at a higher temperature than the core-margin fluorite; but the effect of the higher pressure corrections is only vaguely known and this inference is, therefore, only speculative at best.

The presence of apparently primary fluid-rich Type I and gas-rich Type II inclusions in the same crystals of quartz was initially believed to have resulted from entrapment of a heterogeneous or boiling mixture of liquid and gas. However, the much higher filling temperatures for Type II inclusions suggest that in quartz the Type I inclusions are secondary. This conclusion raises doubt concerning the validity of the classification of the fluorite Type I inclusions, since the same criterion was used to classify the inclusions of both minerals. However, if at least some of these inclusions are primary, then these minerals must have precipitated from a water-rich solution. A dilute

H_2O-CO_2 solution would require replenishment to precipitate the volume of quartz found in the cores. Field evidence almost conclusively indicates that the bulk of the pegmatites crystallized under closed conditions. Two possibilities come to mind: (1) that the inclusions are all secondary and (2) that the minerals crystallized from a dilute H_2O-CO_2 solution which was replenished by some unexplained method of selective transfer or exchange of constituents with a coexisting silicate-rich phase. These or other possibilities cannot be evaluated with the data at hand and the need for a much more exhaustive inclusion study is indicated.

Compromise Surfaces

Haynes' (1965) conclusion that cyrtolite, thorite, fergusonite, gadolinite, and allanite are primary and not related to a replacement origin is not supported by this study. In our opinion the bulk of the evidence supports a replacement origin for all of these minerals with the possible exception of isolated allanite in perthite, for which little evidence is available. The validity of Haynes' conclusions, which are based on the presence of step-sided crystals and interfaces that he assumes to be "compromise surfaces" caused by simultaneous crystallization, is here considered.

The presence of grooved, deeply striated, or stepped crystal surfaces which some of the minerals of this district typically display has been described and interpreted by Haynes (1959, 1965) to be the result of simultaneous growth of two adjacent crystals with different growth velocities. Undoubtedly, deviations of the boundary faces from the crystal habit that would develop during unrestricted growth may occur for certain minerals in contact during simultaneous growth. Fixed growth velocities, as in eutectic solidification, should result in a planar boundary face at some angle to the face which would have developed during unrestricted growth. Fixed growth velocities imply constant temperature and nutrient concentration of the magma or parental liquid. Regular changes of either or both of these parameters during the course of crystallization should result in curved surfaces. Haynes has invoked abrupt changes in temperature and concentration to explain the stepped surfaces. He suggests that these abrupt fluctuations are caused by thermal convection in the crystallizing pegmatite. It should be noted that a large number of oscillatory changes is required by this explanation since alternate steps tend to parallel, even those separated by as many as 20 or more steps. This type of change is significantly different from the "cyclic variations" suggested by Haynes.

Although no conclusive evidence to the contrary has been found in this study, it is difficult to visualize conditions of thermal convection that would provide a satisfactory explanation for the observed crystal surface features. Also, the unusual cyrtolite morphology, which Haynes ascribes to simultaneous crystallization, is common to numerous pegmatites throughout the district; and in most cases these aggregates display virtually identical habits. Such a uniformity implies that the thermal convective histories of numerous pegmatites were almost identical in detail, which also seems unlikely.

Haynes seems to imply by his continual reference to these surface features as "compromise surfaces" that simultaneous growth is the only way that such features can develop. However, parallel lines or grooves (striations) on the surfaces of crystals are more commonly attributed to oscillatory combination which is a result of oscillation between different forms during growth. This process might just as well be the cause of the observed surface features. For example, if fluorite crystallized first, developing striations as it grew, and was subsequently enclosed by quartz (or microcline), surface features identical to those described above would result. Such a sequence could occur even during the replacement stage as long as quartz crystallized after the fluorite, either directly from the replacing fluids or by recrystallization of primary quartz.

The unusual morphology of cyrtolite also appears to be consistent with a different interpretation involving selective replacement followed by continued crystallization of the new mineral. The evidence favoring this interpretation is: (1) no completely isolated cyrtolite surrounded by unaltered biotite has been found; crystal aggregates are only partially embedded in biotite or occur along fractures; and (2) cyrtolite is persistently associated with adjacent corrosion and replacement minerals. This evidence suggests that, like the other RE minerals, cyrtolite also is secondary in origin. A possible explanation is that small primary zircon inclusions in biotite were selectively replaced by late-stage residual rare earth-rich solutions which invaded the biotite and furnished nutrients for continued crystallization of the new rare-earth zircon. As the cyrtolite grew, it extended upward perpendicular to the biotite cleavage and outward pushing against and slightly crinkling the biotite. Thus the interference of successive layers of biotite with the lateral growth of the cyrtolite could have produced the flattened, step-sided surfaces rather than simultaneous growth.

The absence of "compromise surfaces" has also been taken by Haynes to indicate that the two minerals did not crystallize simultaneously. This conclusion is true only if the growth velocities of the interfering faces are not drastically different. However, if the growth velocity of the host is either very slow or very rapid compared with the second mineral, it can be included without the development of a compromise surface, i.e., one face may grow so slowly as not to interfere with the other mineral. Thus the absence of "compromise surfaces" does not necessarily indicate that the two minerals did not crystallize simultaneously. A number of such examples can be cited of minerals which grew simultaneously and in contact with one another and have no grooved or stepped interfaces (e.g. quartz and epidote, quartz and tourmaline, and quartz and muscovite).

Haynes' paragenetic conclusions are based primarily on the presence of striated or stepped crystal surfaces or interfaces that he assumes to be "compromise surfaces" always formed by simultaneous crystallization. Such assumptions appear unwarranted since exceptions occur and other explanations are possible, and this study has raised serious questions concerning the origin of these features and the validity of their use as paragenetic criteria. The alternate explanations offered here best fit the field evidence and we prefer them to those given by Haynes which are based on oscillatory thermal variations not supported by other evidence.

In summary, striated, grooved, or stepped crystal surfaces and interfaces should not be assumed to be "compromise surfaces" formed by simultaneous growth since identical features may develop in other ways. Moreover, the surfaces alone should not be used as paragenetic indicators.

Genetic History of the Pegmatites

The large, well-zoned pegmatites of the South Platte district consolidated late in the magmatic history of the northeastern end of the Pikes Peak batholith. As crystallization of the magma progressed, principally anhydrous minerals formed; and the water content and vapor pressure of the residual melt increased markedly until it became saturated with water. Further crystallization caused the eventual separation of a new aqueous phase, rich in volatiles, fluorine, rare earths, and iron. This supercritical, volatile-rich phase was highly fluid and coalesced into progressively larger obovate, bubble-like masses which were considerably less dense than the coexisting silicate melt that enclosed it. These bubbles of immiscible liquid then began to rise slowly through the denser silicate melt until their vertical ascent was halted by the increased viscosity of the more completely crystalized magma near the roof of the batholith. Consequently, a large number of individual masses of pegmatitic fluid were trapped at similar elevations near the top of the batholith, producing a niveau, or level, of pegmatites which began to crystallize under essentially the same conditions as the granite. Thus, fractional crystallization of the Pikes Peak magma resulted in water-enriched liquid segregates of residual fluids richer in quartz and albite than the granite magma, and these fractionates became the parent fluid from which the pegmatites crystallized.

Through a continued process of fractional crystallization not yet fully understood, pronounced segregation of the pegmatitc systems resulted in the zonation of the pegmatites during the crystallization of the primary minerals. Depending upon the degree of segregation, two zonal sequences with approximately the same bulk composition developed. The higher degree of segregation created three principal zones and is represented by pegmatites containing a nearly monomineralic quartz core, an intermediate zone of microcline-perthite, and a wall zone of graphic granite. In contrast, the lesser degree of segregation created pegmatites with only two principal zones, a composite core of of quartz-microcline and a wall zone of graphic granite. A concentration of the less dense aqueous fluid in the upper part of the crystallizing pegmatite probably accounts for the vertical asymmetry of most pegmatites. A general increase in grain size from the walls toward the center of the pegmatites suggests that in general crystallization proceeded from the walls inward. However, this interpretation should not be rigidly adhered to because some of the internal zones may have crystallized at about the same time. For example, the distribution and occurrence of quartz and microcline segregations as core and intermediate zones suggest that in highly zoned pegmatites they are complementary features which may well have crystallized contemporaneously.

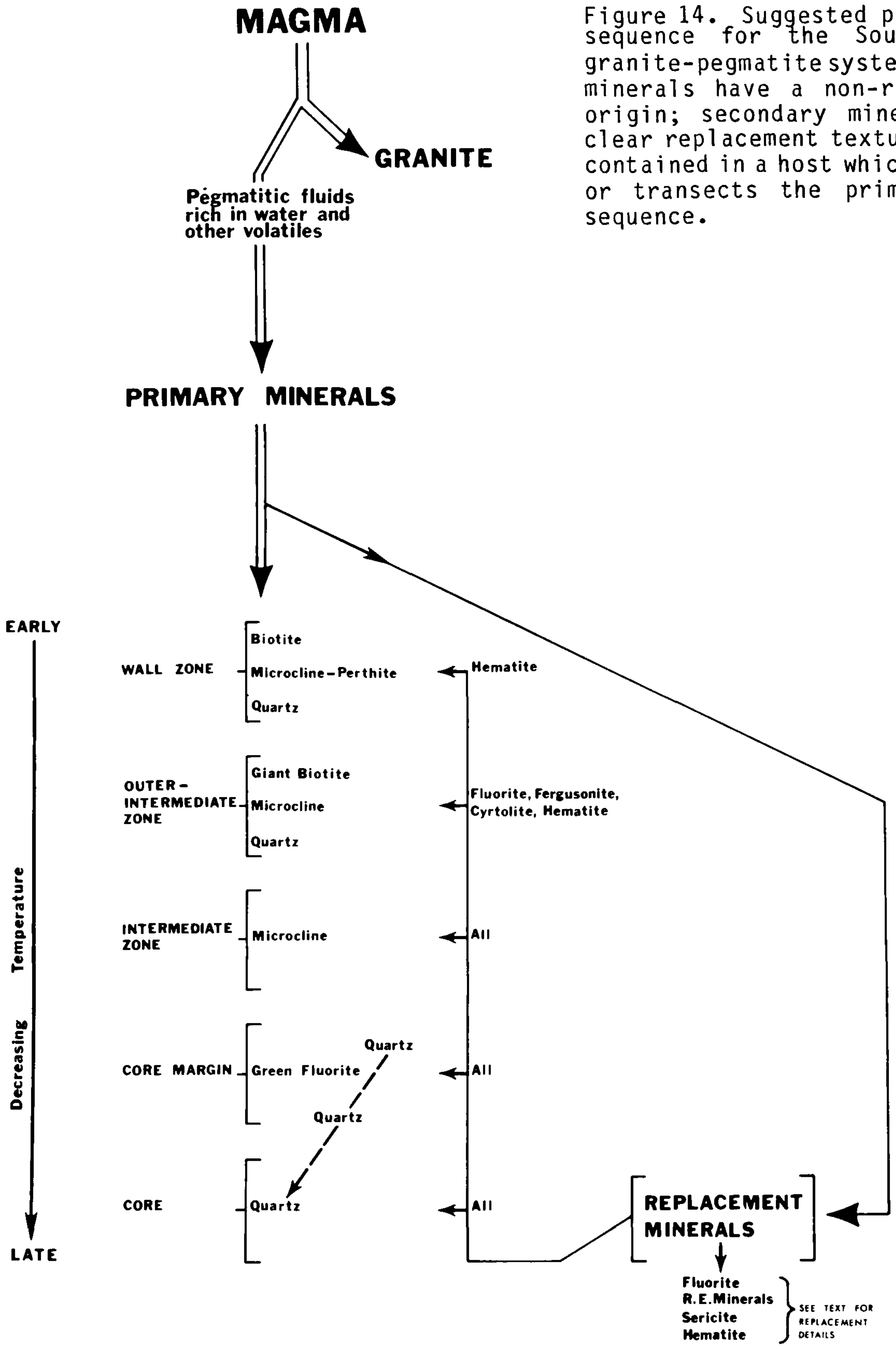
As in previous pegmatite studies, the factors that initiated and controlled segregation to form zones have not been satisfactorily explained. But here, as in other districts, the more highly zoned bodies have been replaced to a greater extent than the less well-zoned bodies, suggesting that minor compositional differences may have been important. In this district the more highly segregated quartz-core pegmatites contain about twice the volume of replacement material and several times as much primary fluorite as the less segregated composite-core pegmatites.

As crystallization of the primary pegmatitic minerals progressed, concomitant enrichment of the residual pegmatitic fluids in fluorine, rare earths, iron, and volatiles ensued. These fluids were the source of the replacement mineralization.

All of the minerals of Table 4 appear to be the products of a late-stage replacement episode in the pegmatite development. Thse minerals either show clear replacement textures or they are contained in a host which replaces or transects older material. Thus the replacement units appear to contain families of minerals which are among the last to crystallize from the pegmatitic fluids. A suggested paragenetic sequence is shown in Figure 14.

The aqueous granitic residuum responsible for secondary mineralization resulted from the penultimate stage of fractional crystallization that was directly related to the original magma and was probably not the result of additions of "new" material but developed under closed conditions within the pegmatite itself. However, the fluid inclusion compositions may indicate that

Figure 14. Suggested paragenetic sequence for the South Platte granite-pegmatite system. Primary minerals have a non-replacement origin; secondary minerals show clear replacement textures or are contained in a host which releases or transects the primary zonal sequence.



during the latter stages some form of replenishment occurred. CO_2 appears to have been an important constituent of this aqueous fluid as indicated by carbonate replacement mineralization and liquid CO_2 in fluid inclusions of quartz and fluorite. Late in magmatic history, as the silicate rest-magma was consumed and the temperature decreased, the residual aqueous fluid may have become subcritical, resulting in the appearance of an aqueous vapor phase that may have also participated in the replacement activity. Whether or not this occurred is not known; but, in either event, these essentially aqueous residual fluids eventually become unstable with respect to some of the earlier formed minerals, which were consequently replaced and corroded as the fluids themselves began precipitating new phases in response to falling temperatures.

Partial recycling of some elements that were originally constituents of primary pegmatite minerals undoubtedly takes place during replacement. K, Al, and Si of secondary muscovite and sericite are probably derived in part from replacements of primary perthite which may also contribute its albite component to secondary albite. In some cases late-stage quartz has been recrystallized; and the release of Ca accompanying the RE-fluorite replacement of primary fluorite may be the source of Ca for some of the very late, nearly pure fluorite.

Following the period of replacement activity, any remaining fluids were expelled through fractures which probably opened in response to the high pressures that these fluids were exerting on the enclosing rock. This period of rupturing is likely the cause of the sheared and slabby quartz found in the cores. Most of the dissolved components were apparently almost exhausted by this time, since only quartz and minor amounts of hematite and fluorite are associated with the fractures, and there is no evidence of alteration. With this final exhalation, the Pikes Peak sequence of magmatic activity came to an end in the South Platte district.

ECONOMIC GEOLOGY

Feldspar

The main commerical product obtained from the South Platte pegmatites has been potash feldspars. It is believed that they were first prospected in the early 1920s, according to Mr. O. H. Jeckel (pers. comm., 1970). The Oregon and Little Patsy deposits were being mined in the 1930s at which time they were evaluated by the Fair Geologic Engineering Association of Denver, Colorado.

In all, 30 pegmatites have been mined and have produced significant amounts of feldspar. About ten more have been prospected for feldspar. It is estimated that the district has produced in the order of 300,000 tons of feldspar between 1920 and about 1970. Several deposits were being actively mined for feldspar in the late 1950s when Heinrich first examined them and mining continued at a few deposits (Patsy, Oregon No. 3, Luster No. 1) into the 1960s.

Because the pegmatites contain neither beryl nor book muscovite, they were not studied during World War II when the U.S. Geological Survey examined Colorado pegmatites for deposits of these minerals (Hanley and others, 1950).

Much of the feldspar obtained from the South Platte pegmatites was not first-grade ceramic feldspar owing to its red color resulting from exceedingly minute hematite inclusions. Most of the larger deposits have been mined out and no substantial reserves of potash feldspar remain.

Quartz

In Colorado a market for coarsely crushed snow-white quartz fragments stems from its initial use as decorative material on the roof of the chapel of the U.S. Air Force Academy at Colorado Springs. One of the first deposits used as a source of this material was the Black Cloud pegmatite (Heinrich and Gross, 1960) near Divide, Colorado. With this introduction to the market, quartz-core mining for terrazzo stone spread to other Colorado pegmatite districts, including South Platte where quartz mining begain in the 1960s. The main deposits whose cores have been mined are the Oregon No. 3, Luster No. 1, and the Dazie Bell claims.

Quartz utilized for terrazzo stone must be of uniform whiteness and thus free of limonite staining. It is estimated that the South Platte deposits have yielded a minimum of about 200,000 tons of such material.

Fluorite

Acid-grade fluorite in small quantities has been mined from several deposits, usually by expensive, selective mining and even hand-cobbing. About 1957 some 50 tons of acid-grade green fluorite was mined from the Luster No. 1 pegmatite by Robert Beal and his associated of Green Mountain Falls, Colorado. Fluorite also has been mined from the Little Bill and Dazie Bell pegmatites. Total reserves of recoverable fluorite are small inasmuch as the core-margin fluorite zones are thin and/or incompletely developed. In 1958 about 15 tons of fluorite ore was stockpiled at the Madonna No. 3, and it was estimated that approximately another 50 tons was in the dumps and cut exposures.

Rare-Earth Minerals

The technological application of rare-earth elements has within the last few years experienced a major renaissance. The traditional uses, including lighter flints, polishing abrasives, arc carbons, and glass-ceramic additives, have remained as important consumers in the rare-earth industry. To these have been added catalysts for petroleum refining, additives in ductile iron and steel, and, as high-purity individual elements and their compounds, in color television picture tubes, fluorescent lamps and X-ray intensifiers. For the last three, europium and yttrium oxides are particularly important. Recently much interest has centered on the development of the extremely powerful rare earth-cobalt alloy magnets. Another interesting development is synthesis of yttrium garnet of a commerical scale for very attractive gemstones.

The demand for rare-earth elements increased rapidly between 1969 and 1978, and the probable domestic demand for the year 2000 is projected to be 57,000 short tons of rare-earth oxides.

Because of their geochemical dichotomy, Ce, La, and the lighter rare-earth elements are available in relatively large amounts in economically important deposits such as beach placers (monazite) and carbonatites (bastnaesite at Mountain Pass, California). In contrast Y and the heavier rare earths occur in minerals (e.g., xenotime, gadolinite) whose deposits are relatively scarce and unusually small. Inasmuch as the South Platte pegmatites contain several minerals enriched in elements of the Y-subgroup, these deposits have generated considerable interest as sources of these elements.

Rare-earth ores were first found in the South Platte district in the mid-1950s in fluoritic rock from the Deep Hole pegmatite. Mining in several deposits and in several dumps was carried out by Robert Beal and Associates of Green Mountain Falls in 1955-1957. The Deep Hole eventually produced 16 tons of handcobbed high-grade RE ore (fluoritic), all of it from the dumps. Some 15 tons of gadolinite-xenotime-monazite ore was obtained from the Snowflake deposit. It is estimated that another 50 tons could be recovered from that dump by hand picking.

Rare-earth minerals that have been produced from other South Platte pegmatites include:

Samarskite - Oregon No. 3, Luster No. 1
Gadolinite - White Cloud, Dazie Bell
RE-bearing fluorite - Big Bear No. 2
Allanite - Shuttle Run
Xenotime - Big Bertha

Hand-picked fluorite ore, in amounts of 10 to about 100 tons was obtained from the Big Bear No. 2 and several other pegmatites; these ores assayed 1 to 7.5 percent Y. The rare earths occur in microscopic inclusions of xenotime and monazite in the fluorite. Samples of a crude rare-earth concentrate prepared by Robert Beal and analyzed by Dow Chemical Company of Midland, Michigan contained 47.9% Y, 2.8% Gd, 2.3% Dy, 3.7% Nd, 1 to 2% Er, Sm, Ce, and 0 to 1% Ho, La, Tb, Pr (Heinrich, 1958).

In 1957 it was calculated that the Big Bear No. 2 contained, in measured reserves, about 120 tons of fluoritic RE ore. The Big Bear ores were sold to Gows Chemical Company which produced various RE salts in 60-percent oxide concentration. These were marketed through Rare Earth Chemical Company of Colorado Springs.

Reportedly, a "carload" (about 50 tons?) of gadolinite-rich ore was produced from the White Cloud deposit.

Although the deposits of the district contain at least several thousands of tons of RE-mineral rich pegmatite rock, it is widely scattered in small bodies or lies diluted in dumps. Thus no large-scale mining of rare-earth ores in the district can be anticipated. Selective mining of fluorite units and RE-rich replacement units is required. During feldspar mining, larger pieces and crystals of rare-earth minerals were saved by the miners and accumulated. Similar accumulations have developed along with the mining of the quartz cores. Of not inconsiderable value has been the separation and sale of some rare-earth mineral masses (especially samarskite, allanite, gadolinite, and cyrtolite) as rare-mineral specimen material. About a ton of specimen topaz also has been obtained from the McGuire dumps.

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APPENDIX I

CHARACTERISTICS OF INDIVIDUAL PEGMATITES

The characteristics of individual pegmatites, by plate number, are listed below, each with a synoptic summary of its mineralogical and structural characteristics. The general descriptive format is:

a) Name; synonyms
b) Location; plate number
c) Size; shape
d) Internal structure:
BZ = border zone; WZ = wall zone; OIM = outer-intermediate zone; IM = intermediate zone; CM = core-margin zone; C(Q) = quartz core; C((Q+M) = composite quartz-microcline core; R = replacement unit.
e) Characteristic mineralogical or structural features.
f) Economic significance.

1. a) Oregon No. 3; Quartz Knob; White Cap of Raleigh Peak group or Oregon group.
b) Easternmost pegmatite of the NE1/4 of the SE1/4 of Sec. 33, T7S, R70W; Plate 2.
c) 600' x 280'; elliptical.
d) WZ; CM; C(Q); CM-R.
e) Core-margin albite replacement unit with abundant samarskite nodules; dipping away from center of pegmatite; rare core-margin green fluorite; pyrolusite; large primary vugs with large (50 lb) smoky quartz crystals; apophysis to the south contains small quartz core; core cut and replaced by veins of albite.
f) Mined for quartz and specimen samarskite.

2. a) Oregon No. 2 1/2; Raleigh Peak No. 4; Big Dick.
b) Easternmost pegmatite of the SE1/4 of the SE1/4 of Sec. 33, T7S, R70W; Plate 3.
c) 210' x 165'; strongly elliptical wall zone, nearly circular core and intermediate zone.

d) WZ; IM; C(Q); CM-R.
e) Vertical core of quartz replaced on western margin by hematite-biotite replacement unit; exceptionally well-

f) Intermediate zone mined for microcline.
3. a) Oregon No. 2; Raleigh Peak No. 3.
b) Westernmost pegmatite of the SE1/4 of the SE1/4 of Sec. 33, T7S, R70W; Plate 4.
c) 225' x 285'; oval.
d) WZ; OIM; IM; C(Q); CM-R.
e) Outer-intermediate zone of biotite; core-margin replacement unit of hematite and biotite; tunnel through the eastern wall zone.
f) Intermediate zone mined for microcline.
4. a) Oregon No. 1 1/2; Raleigh Peak Big Bear.
b) NW1/4 of the SE1/4 of Sec. 33, T7S, R70W; Plate 5.
c) 180' x 225'; oval.
d) WZ; IM; CM; C(Q).
e) Core-margin zone of green fluorite; intermediate zone forms a "hood zone" of microcline-perthite.
f) Prospected for feldspar; mined for quartz.
5. a) Oregon No. 1; Raleigh Peak No. 2 and 2a.
b) Westernmost pegmatite of the NE1/4 of the SW1/4 of Sec. 33, T7S, R70W; Plate 6.
c) Two separate pegmatites: 125' x 100' and 100' x 100'; both circular.
d) WZ; C(Q+M); R.
e) SE pegmatite dips are toward the center, indicating that the pegmatite is "bottoming-out"; NE pegmatite has a crosscutting specular hematite replacement unit.
f) Both have been mined for quartz.
6. a) Luster No. 1; Lester; Oregon No. 3; Yttrium No. 1.
b) Southeastern pegmatite of the SE1/4 of the NE1/4 of Sec. 33, T7S, R70W; Plate 7.
c) 135' x 150'; oval.
d) WZ; OIM; IM; CM; C(Q); minor R.

e) Outer-intermediate zone of giant biotite and associated cyrtolite; core-margin zone of green fluorite displaced to the top; incompletely developed intermediate zone; abundant cyrtolite in outer-intermediate zone.
f) Intermediate zone mined for microcline; core margin mined for fluorite; outer intermediate prospected for rare earths.

7. a) Luster No. 1 1/2; Raleigh Peak No. 1.
b) Northwestern pegmatite of the SE1/4 of the NE1/4 of Sec. 33, T7S, R70W; Plate 8.
c) 70' x 80'; oval.
d) WZ; IM; CM; C(Q).
e) Intermediate zone and core-margin green fluorite incompletely developed and displaced toward the top of the pegmatite.
f) Intermediate zone mined for microcline.

8. a) Little Patsy; Patsy.
b) NW1/4 of the SE1/4 of Sec. 28, T7S, R70W; Plate 9.
c) 180' x 160'; circular.
d) WZ; OIM; IM; CM; C(Q); minor R.
e) Outer-intermediate zone of giant biotite with cyrtolite and fergusonite; core appears to "bottom-out".
f) Intermediate zone mined for microcline; core mined for quartz.

9. a) White Cloud.
b) Westernmost pegmatite of the SE1/4 of the SW1/4 of Sec. 36, T7S, R70W; Plate 10.
c) 300' x 125'; elliptical.
d) WZ; C(Q+M); R.
e) Crosscutting and core-margin rare-earth-rich replacement units of yttrofluorite, gadolinite-fluorite, sericite, doverite, minor core-margin green fluorite.
f) Mined for microcline and rare earths.

10. a) Lesser White Cloud.
b) Easternmost pegmatite of the SE1/4 of the SW1/4 of Sec. 36, T7S, R70W; Plate 11.
c) 105' x 75'; oval
d) WZ; IM; C(Q); R.

e) Crosscutting albite replacment unit that completely bisects the core; wall zone contains stellate groups of biotite laths.

11. a) Dazie Bell claim, group of seven pegmatites.
    b) SW1/4 of the SE1/4 of Sec. 2, T8S, R70W; Plate 12.
    c) From SE to NW: 75' x 105', 60' x 75', 30' x 30', 60' x 90', 60' x 75', 135' x 75', 30' x 30'; elliptical
    d) WZ; C(Q); C(Q+M); R.
    e) Steeply dipping ellipsoidal bodies with composite or quartz cores; minor fluorite-gadolinite replacement; minor allanite and pyrolusite; large primary vugs with well-developed smoky quartz, microcline, and fluorite crystals.
    f) Mined for quartz and gadolinite.
12. a) Big Bear No. 2; Big Bear; Little Bear; Big Bear No. 1.
    b) SW/14 and SE1/4 of Sec. 3, T8S, R70W; Plate 13.
    c) Two pegmatites: 75' x 50' and 150' x 300'; ellipsoidal.
    d) WZ; C(Q+M); R.
    e) Larger pegmatite contains large replacement unit, which transects the core and contains fluorite, yttrofluorite, gadolinite, monazite, and xenotime; smaller body contains a similar replacement unit and also has replacement (?) amethyst.
    f) Mined for rare earths in fluorite.
13. a) Twin Cedars.
    b) NE1/4 of the SE1/4 of Sec. 3, T8S, R70W; Plate 14.
    c) 120' x 40'; ellipsoidal.
    d) WZ; C(Q+M).
    e) Typical ellipsoidal, composite-core pegmatite; corroded beryl crystal found on dump with associated bertrandite(?).
    f) Mined for a small amount of quartz.
14. a) Deer Trail.
    b) SW1/4 of the NW1/4 of Sec. 11, T8S, R70W; Plate 15.
    c) 300' x 225'; oval.
    d) WZ; C(Q).
    e) Very large wall zone with a small 25' x 25' quartz core;

vugs contain excellent specimens of well-formed microcline crystals encrusted with hematite.

f) None.

15. a) Yammy Yogurt claim, group of four pegmatites.
    b) NW1/4 of the NW1/4 of Sec. 11, T8S, R70W; Plate 16.
    c) From E to W: 200' x 75', 25' x 50', 25' x 50', 50' x 75'; oval to ellipsoidal.
    d) WZ; C(Q+M); C(Q); R.
    e) Group of relatively small, steeply dipping, well-zoned pegmatites with minor rare-earth, albite, kaolinite, fluorite, and hematite replacements; the largest pegmatite contains topaz in and along the core.
    f) Mined for quartz.
16. a) Shuttle Run.
    b) Northeasternmost pegmatite of the NW1/4 of the NW1/4 of Sec. 11, T8S, R70W; Plate 17.
    c) 135' x 105'; oval.
    d) WZ; C(Q+M); minor R.
    e) No mappable replacement unit but dump contains abundant allanite and some cleavelandite.
    f) Mined for quartz, feldspar, and rare earths.
17. a) Little Bill.
    b) SW1/4 of the NW1/4 of Sec. 2, T8S, R70W; Plate 18.
    c) Two pegmatites: 30' x 45' and 30' x 45'; oval.
    d) WZ; CM; C(Q).
    e) Abundant core-margin green fluorite on dumps.
    f) Both pegmatites mined for fluorite.
18. a) Madonna No. 1; Madonna Eastern.
    b) Southernmost pegmatite of the SE1/4 of the SW1/4 of Sec. 2, T8S, R70W; Plate 19.
    c) 105' x 120'; oval.
    d) WZ; C(Q+M).
    e) Very large single crystals of quartz in core.
    f) Mined for quartz.
19. a) Madonna No. 2; Deep Hole.

b) Easternmost pegmatite of the SE1/4 of the SW1/4 of Sec. 2, T8S, R70W; Plate 20.
c) 60' x 75'; circular.
d) WZ; C(Q+M); minor R.
e) Very deep (about 50') cut into vertical core; core margin contains large 6-8 inch allanite crystals and minor fluorite.
f) Mined for quartz and microcline.

20. a) Madonna No. 3; Madonna Western.
b) Westernmost pegmatite of the SE1/4 of the SW1/4 of Sec. 2, T8S, R70W; Plate 21.
c) 100' x 120'; oval.
d) WZ; C(Q+M); R.
e) Crosscutting replacements of fluorite, yttrofluorite, gadolinite, monazite; selective fluorite replacement of wall zone graphic granite producing graphic fluorite-feldspar rock.
f) Mined for quartz, feldspar, and rare earths.

21. a) Hollingsworth.
b) Southernmost pegmatite of the SW1/4 of the SE1/4 of Sec. 2, T8S, R70W; Plate 22.
c) 75' x 60'; oval.
d) C(Q); R.
e) Pegmatite has no wall zone; core has been replaced by albite and specular hematite.
f) None.

22. a) Gemini.
b) Middle pegmatite of the SW1/4 of the SE1/4 of Sec. 2, T8S, R70W; Plate 23.
c) Two pegmatites from N to S: 75' x 45' and 60' x 75'; oval.
d) C(Q+M); R.
e) Pegmatite has no wall zone; quartz replaced by large mass of specular hematite; pegmatite cut by fault.
f) Mined for quartz.

24. a) Big Bertha.
b) SW1/4 of the NW1/4 of Sec. 22, T8S, R70W; Plate 25.

c) 285' x 120'; irregular.
d) WZ; IM; C(Q+M); minor R.
e) Small wall zone; huge football-sized allanite masses; minor fluorite-xenotime replacement units.
f) Mined for rare earths.

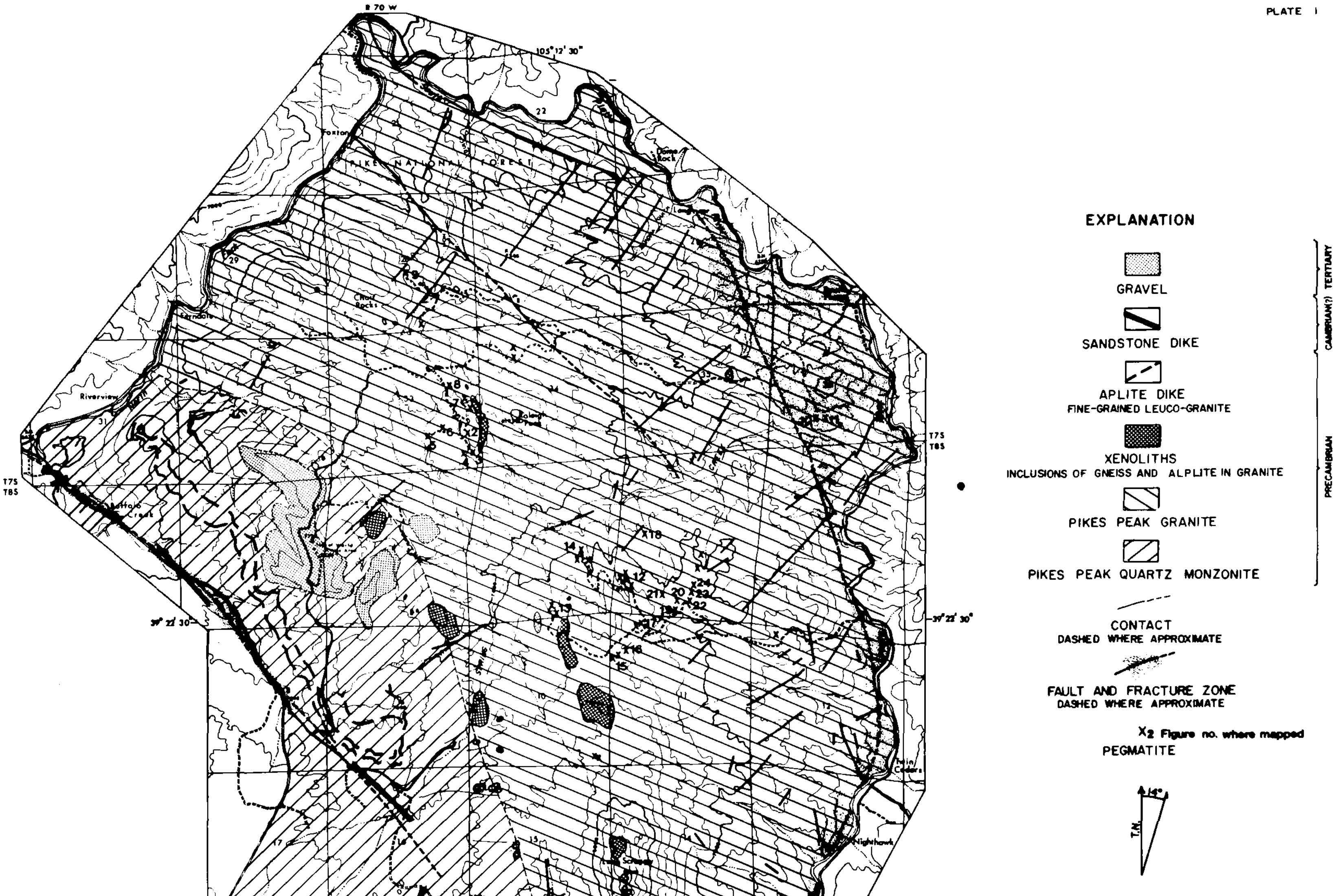
25\. a) Seerie; Cooper.
b) SW1/4 of the NE1/4 of Sec. 30, T7S, R70W; Plate 26.
c) 180' x 150'; oval.
d) WZ; IM; C(Q+M); minor R.
e) Large well-zoned pegmatite; the only pegmatite with both an intermediate zone of microcline and a composite core; large euhedral crystals of microcline in the core; primary vugs with quartz and microcline crystals; topaz; minor fluorite-RE mineral replacement; minor thorogummite.
f) Mined for quartz and feldspar; adit cut into core.

26\. a) Butterfield, group of three pegmatites.
b) Center of Sec. 23, T7S, R71W; Plate 27.
c) From N to S: 45' x 30', 30' x 15', 45' x 90'; oval.
d) WZ; C(Q+M); C(Q); R.
e) Primary vugs with small quartz crystals; replacement unit of samarskite and fergusonite.
f) None.

27\. a) McGuire; Lone Lode.
b) Sec. 23, T8S, R27W; Plate 28.
c) 210' x 150'; irregular.
d) WZ; C(Q+M).
e) Very small wall zone; cut by aplite dike; large topaz crystals in core with associated monazite and ilmenite.
f) Mined for feldspar and specimen topaz.

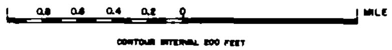
28\. a) Snowflake.
b) Approximately 6 1/2 miles northwest of Woodland Park in Teller County; Plate 29.
c) 400' x 475'; circular.
d) WZ; IM; C(Q); minor R.
e) Large wall zone with irregular intermediate zone of quartz and microcline and small core of quartz; minor replacements with fluorite, RE minerals, and thalenite.

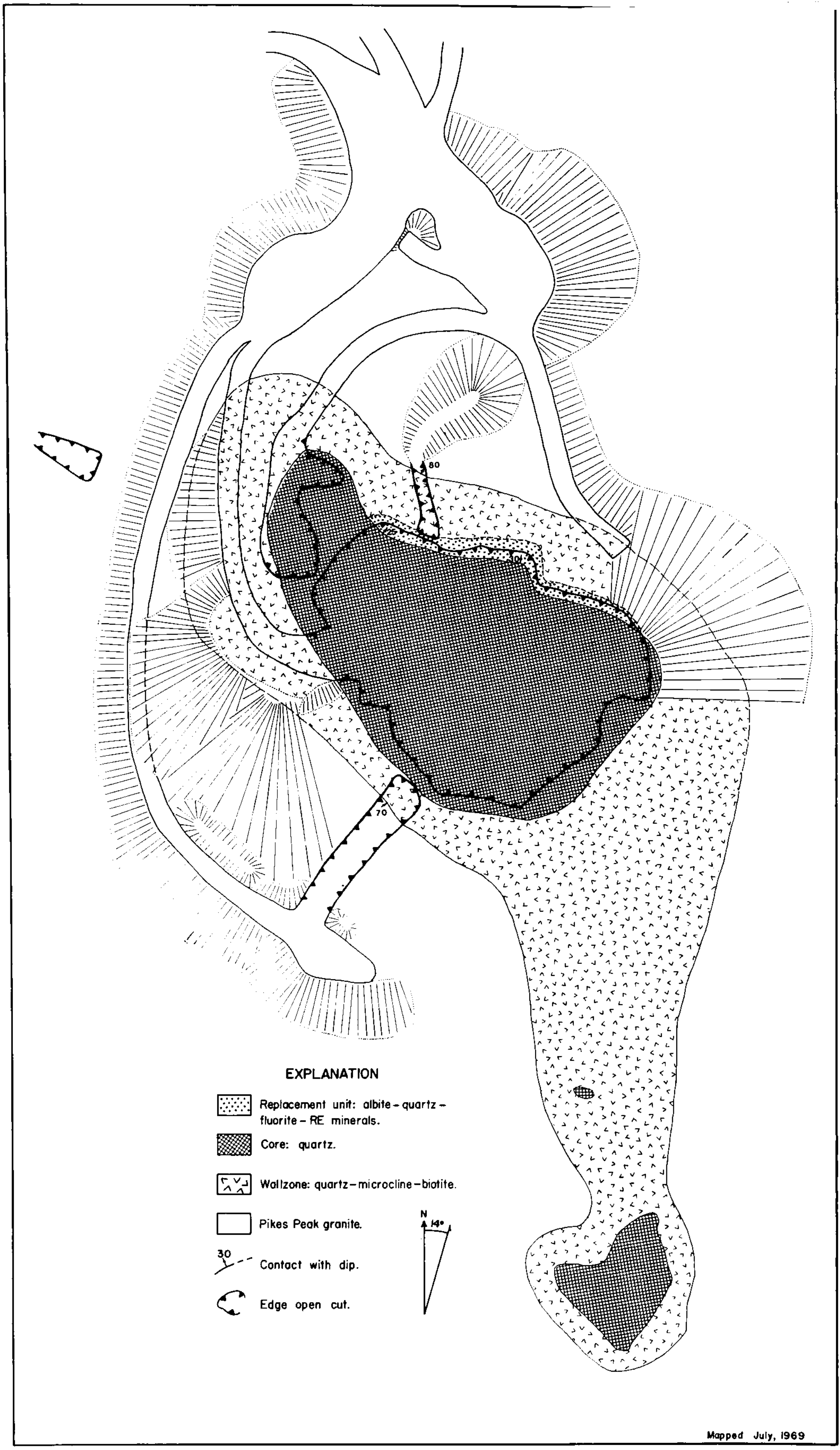
f) Mined for feldspar. 29. a) Ramona; Elizabeth.
b) Southernmost pegmatite of the NW1/4 of the NW1/4 of Sec. 34, T7S, R70W; not mapped.
c) 25' x 50'; elliptical.
d) WZ; IM; C(Q+M).
e) None. 30. a) White Eagle, group of three pegmatites.
b) NE1/4 of the NW1/4 of Sec. 2, T8S, R70W; not mapped.
c) Group of three: approximately 50' each; oval.
d) WZ; IM; CM; C(Q).
e) Core-margin green fluorite; clear to white fluorite; purple fluorite.
f) Prospected for quartz. 31. a) Last Dollar.
b) SW1/4 of the SE1/4 of Sec. 28, T7S, R70W; not mapped.
c) 40' x 35'; oval.
d) WZ; IM; CM; C(Q); R.
e) Steeply dipping; core-margin green fluorite; minor replacement albite and purple fluorite.
f) Prospected for quartz. 32. a) Luster No. 2
b) South of Luster No. 1, SE1/4 of the NE1/4 of Sec. 33, T7S, R70W; not mapped.
c) Approximately 50' x 50'; oval.
d) WZ; IM; C(Q); R.
e) Core margin unit of albite, kaolinite, and unusual doubly terminated milky quartz crystals.
f) Mined for quartz.



Geology by Wm. B. Simmons, Jr., 1969, 1970; information also modified from Peterson, 1964 and Hutchinson, 1960. Only patterned areas mapped
Topographic base from U.S. Geologic Survey maps of Platte Canyon, Deckers, Pine, and Green Mountain Quadrangles, Colorado.

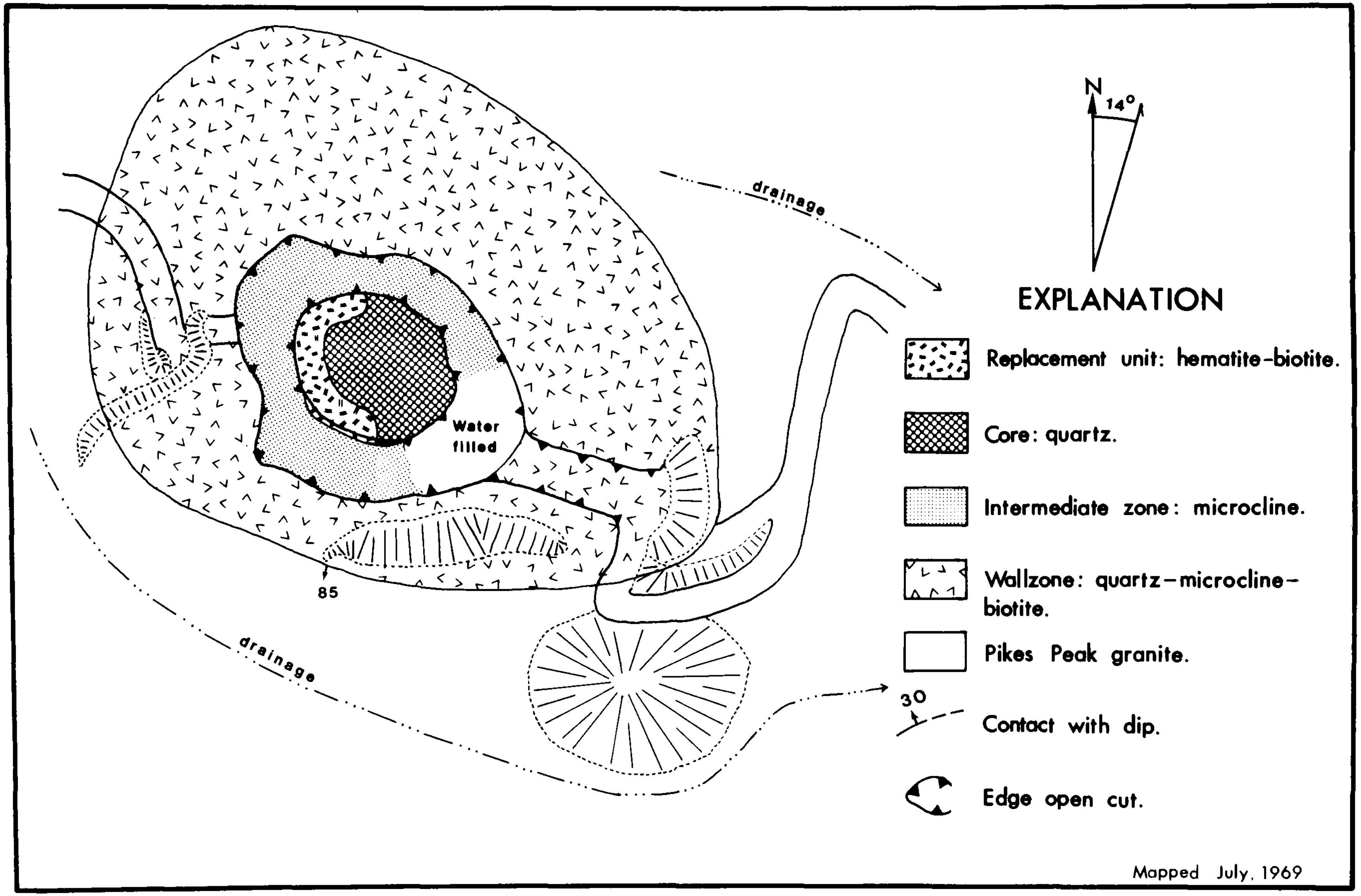
GEOLOGIC MAP OF THE SOUTH PLATTE PEGMATITE DISTRICT
JEFFERSON COUNTY, COLORADO





GEOLOGIC MAP OF THE OREGON NO. 3 PEGMATITE
SOUTH PLATTE, COLORADO

PLATE 3



GEOLOGIC MAP OF THE OREGON NO. 2 1/2 PEGMATITE

SOUTH PLATTE, COLORADO

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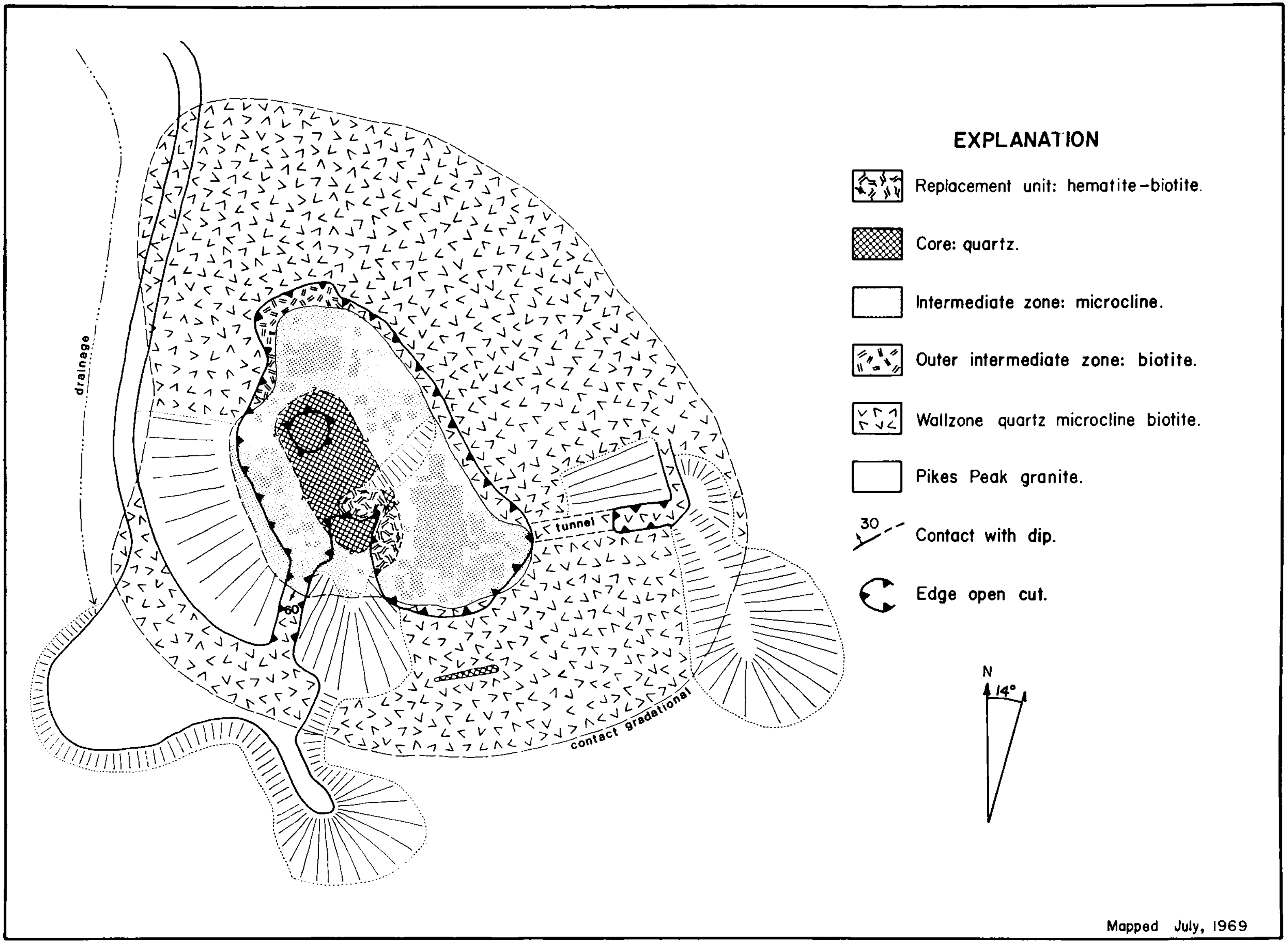
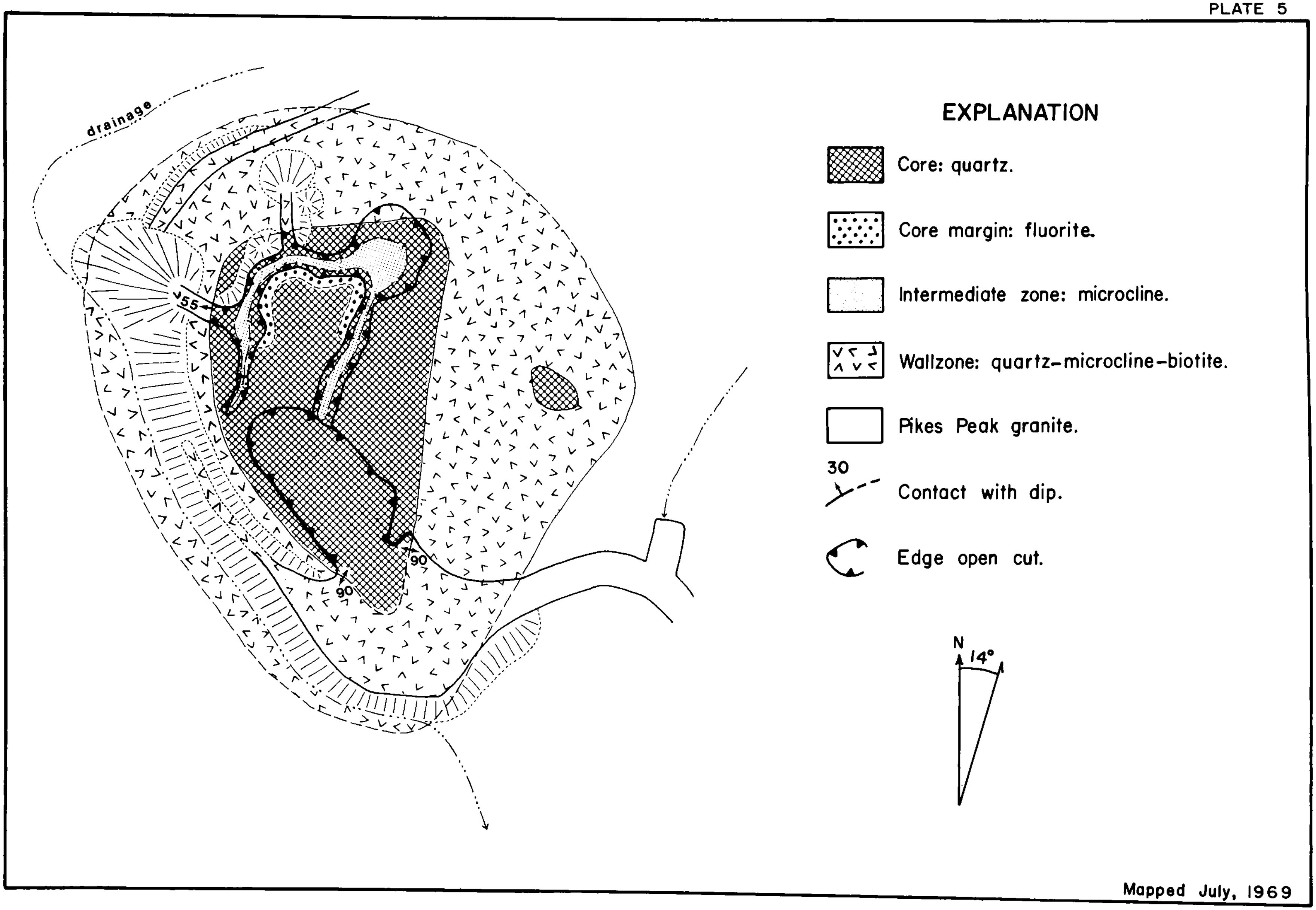


GEOLOGIC MAP OF THE OREGON NO. 2 PEGMATITE

SOUTH PLATTE, COLORADO

30 0 30 60 90 Ft.

PLATE 5

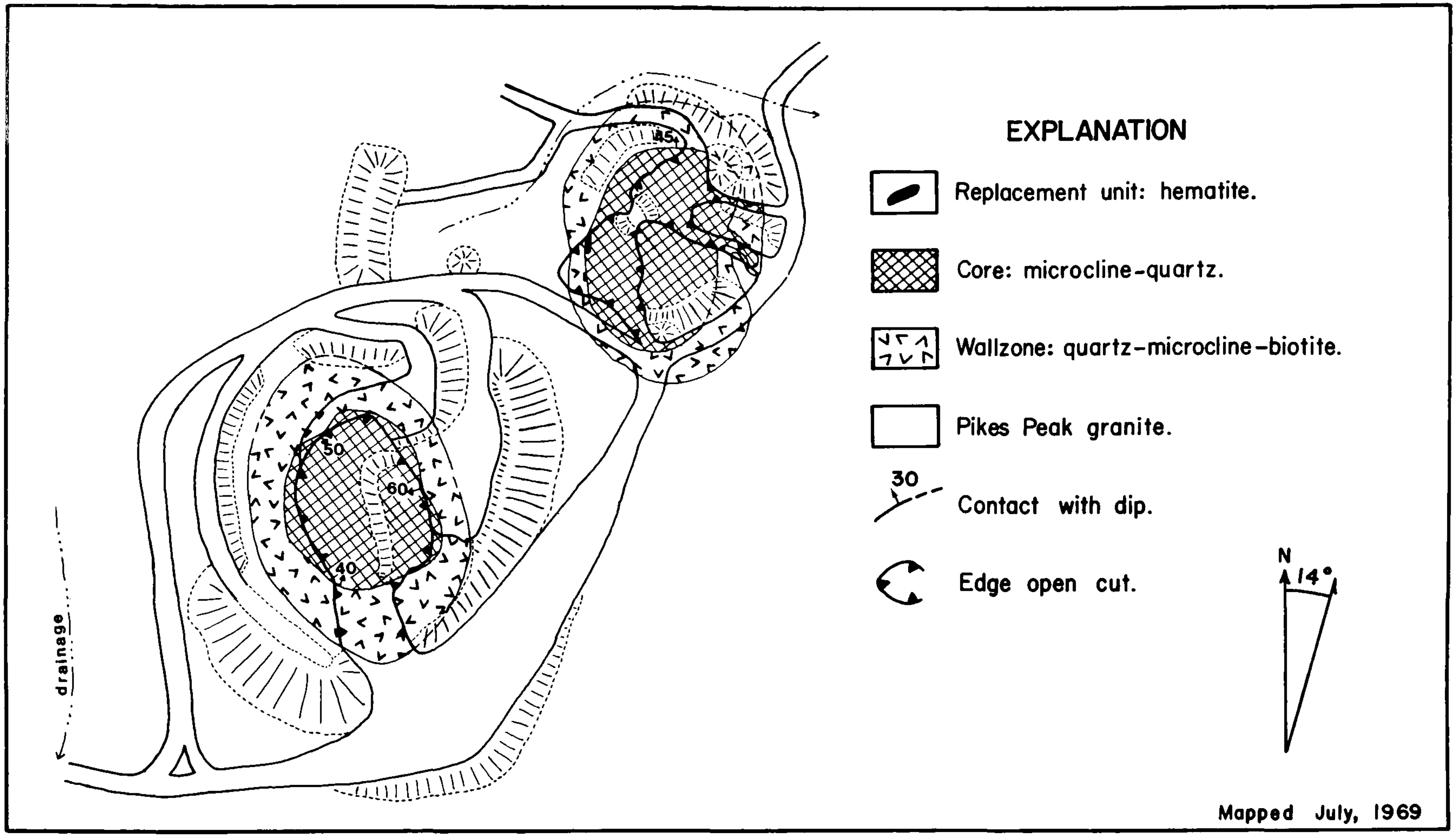


GEOLOGIC MAP OF THE OREGON NO. 1 1/2 PEGMATITE

SOUTH PLATTE, COLORADO

30 0 30 60 90 Ft.

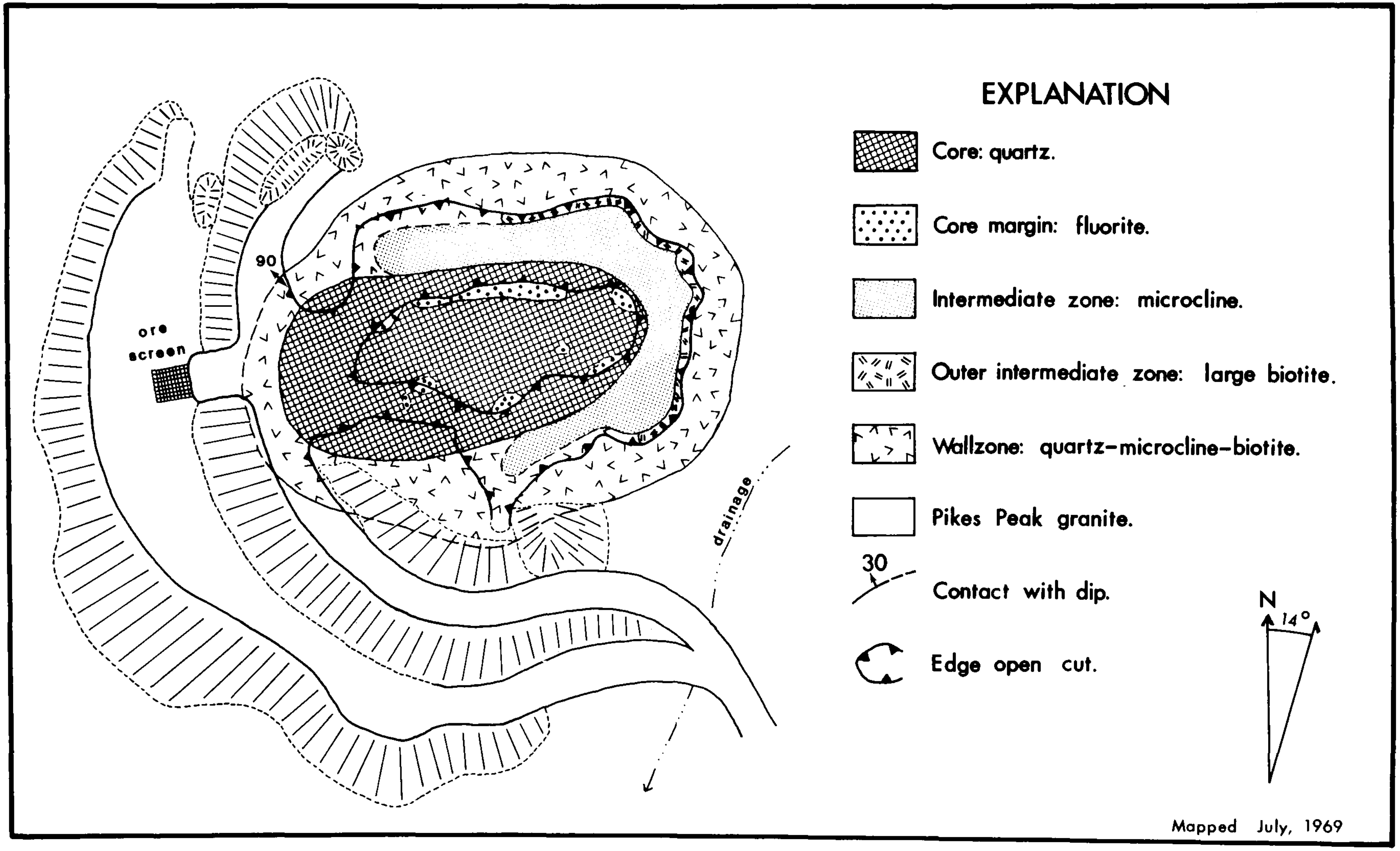
PLATE 6



GEOLOGIC MAP OF THE OREGON NO. I PEGMATITE
SOUTH PLATTE, COLORADO

50 0 50 100 150 Ft.

PLATE 7

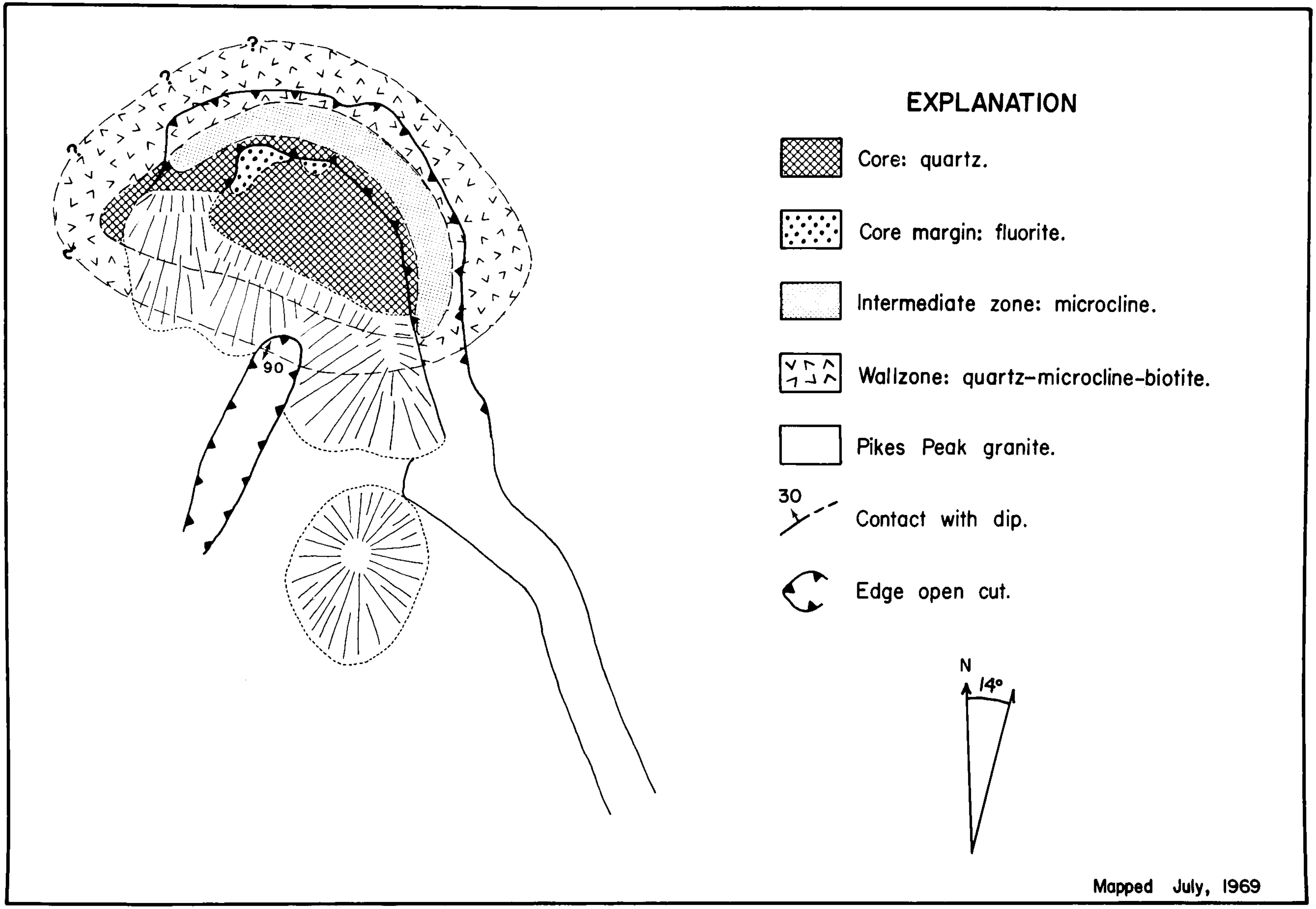


GEOLOGIC MAP OF THE LUSTER NO. 1 PEGMATITE

SOUTH PLATTE, COLORADO

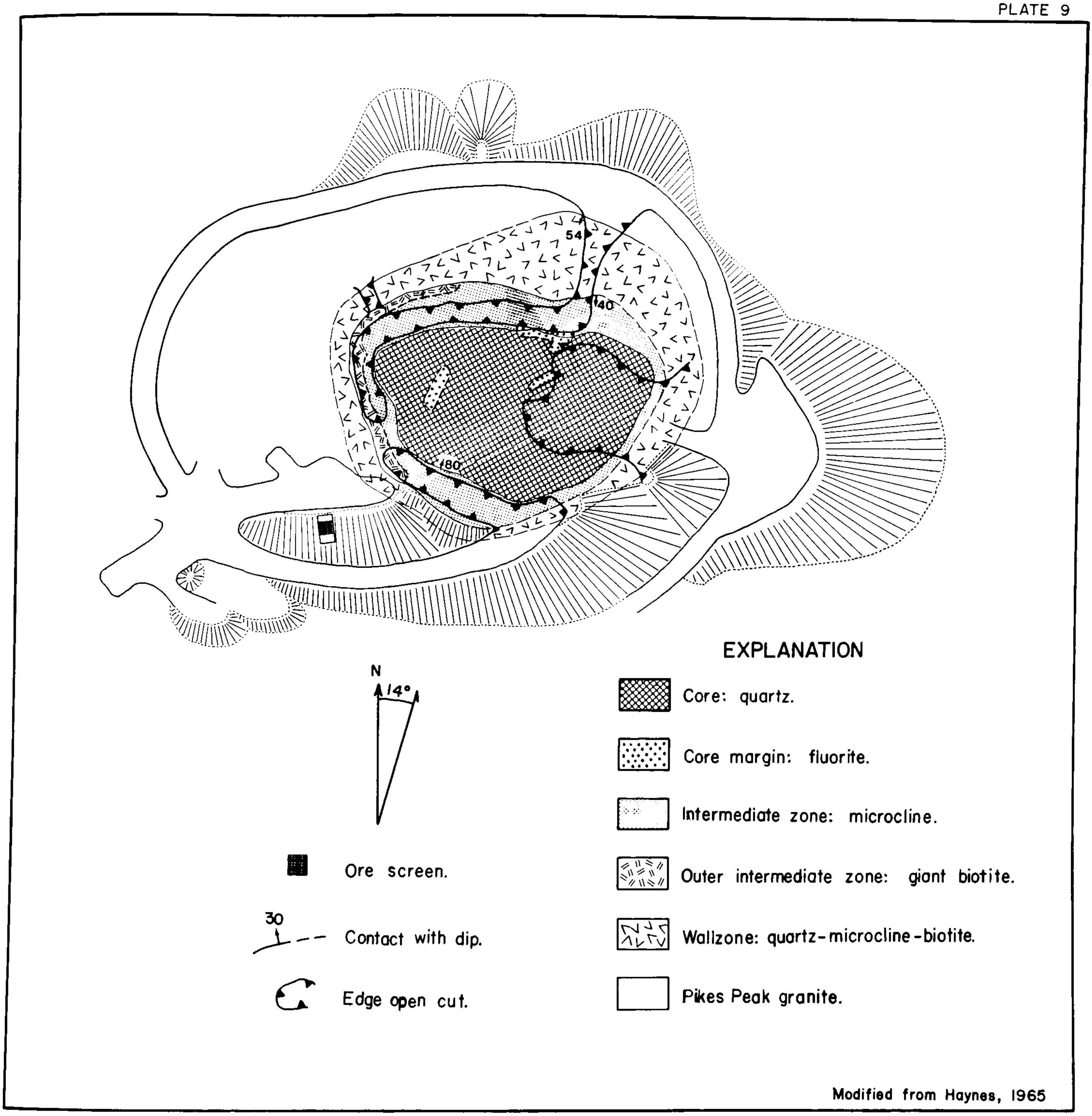
30 0 30 60 90 Ft.

PLATE 8



GEOLOGIC MAP OF THE LUSTER NO. 1 1/2 PEGMATITE
SOUTH PLATTE, COLORADO

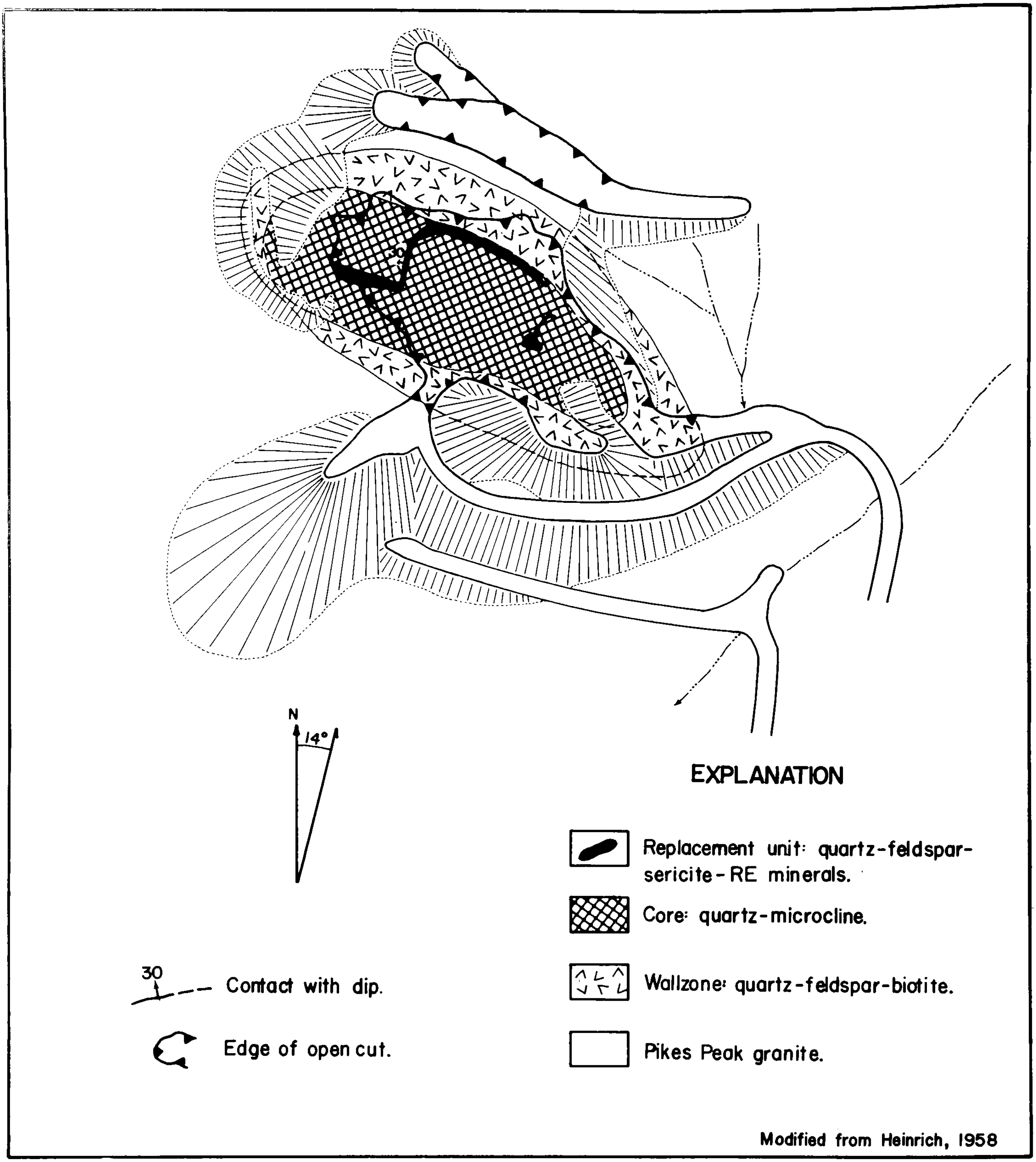
PLATE 9



Modified from Haynes, 1965

GEOLOGIC MAP OF THE LITTLE PATSY PEGMATITE
SOUTH PLATTE, COLORADO

40 0 40 80 120 Ft.

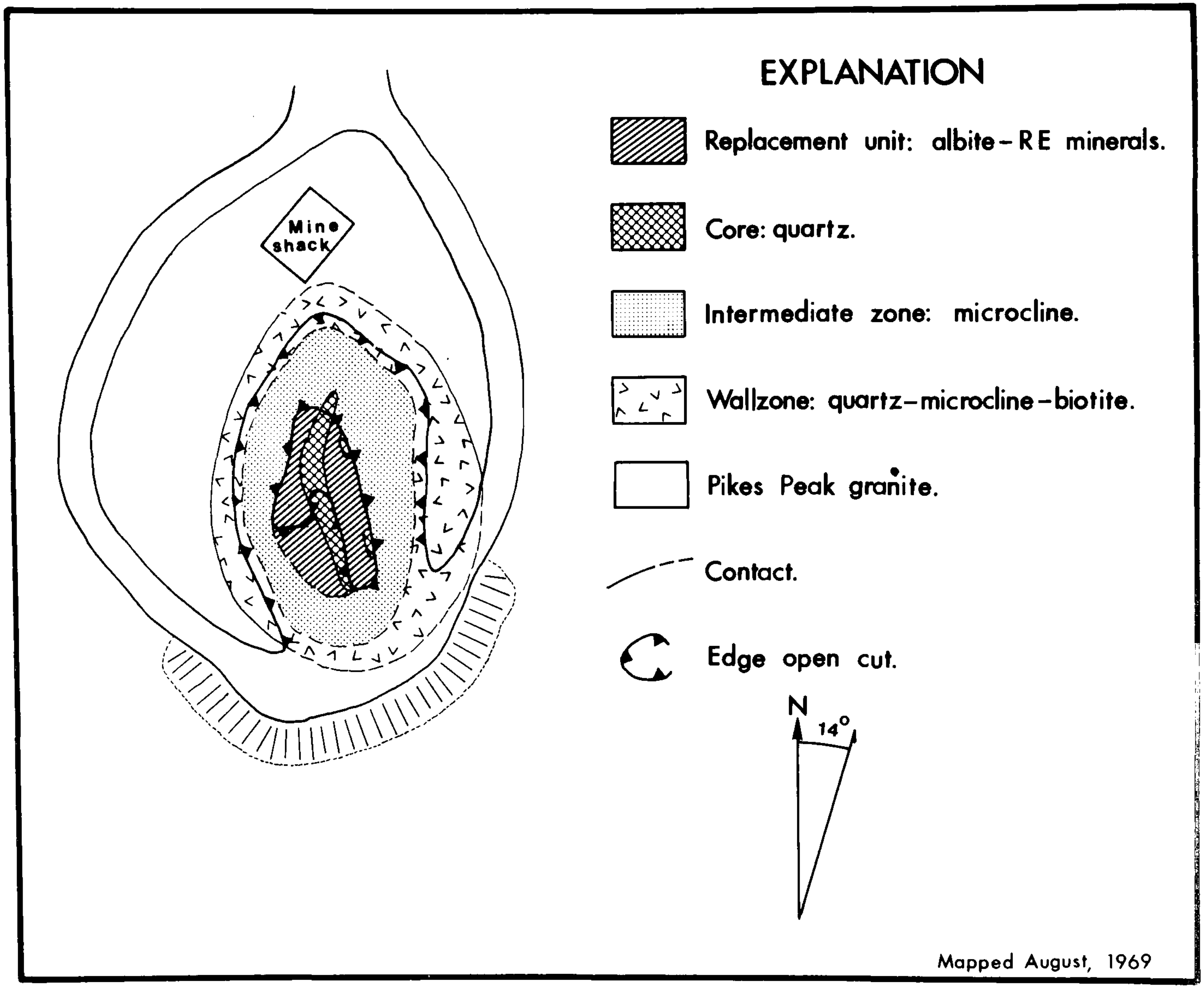


GEOLOGIC MAP OF THE WHITE CLOUD PEGMATITE

SOUTH PLATTE, COLORADO

50 0 50 100 150 Ft.

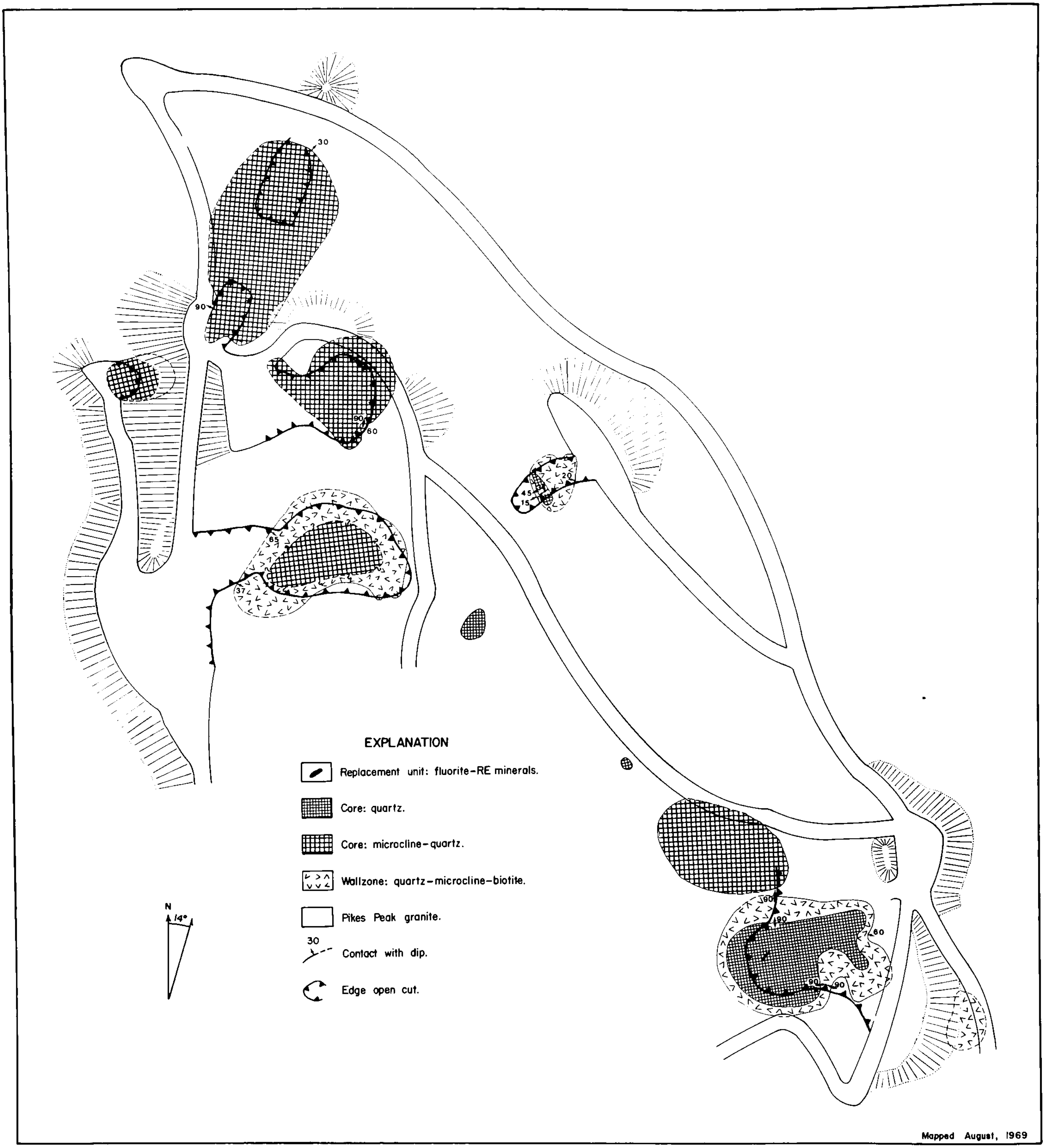
PLATE 11



GEOLOGIC MAP OF THE LESSER WHITE CLOUD PEGMATITE

SOUTH PLATTE, COLORADO

30 0 30 60 90 Ft.

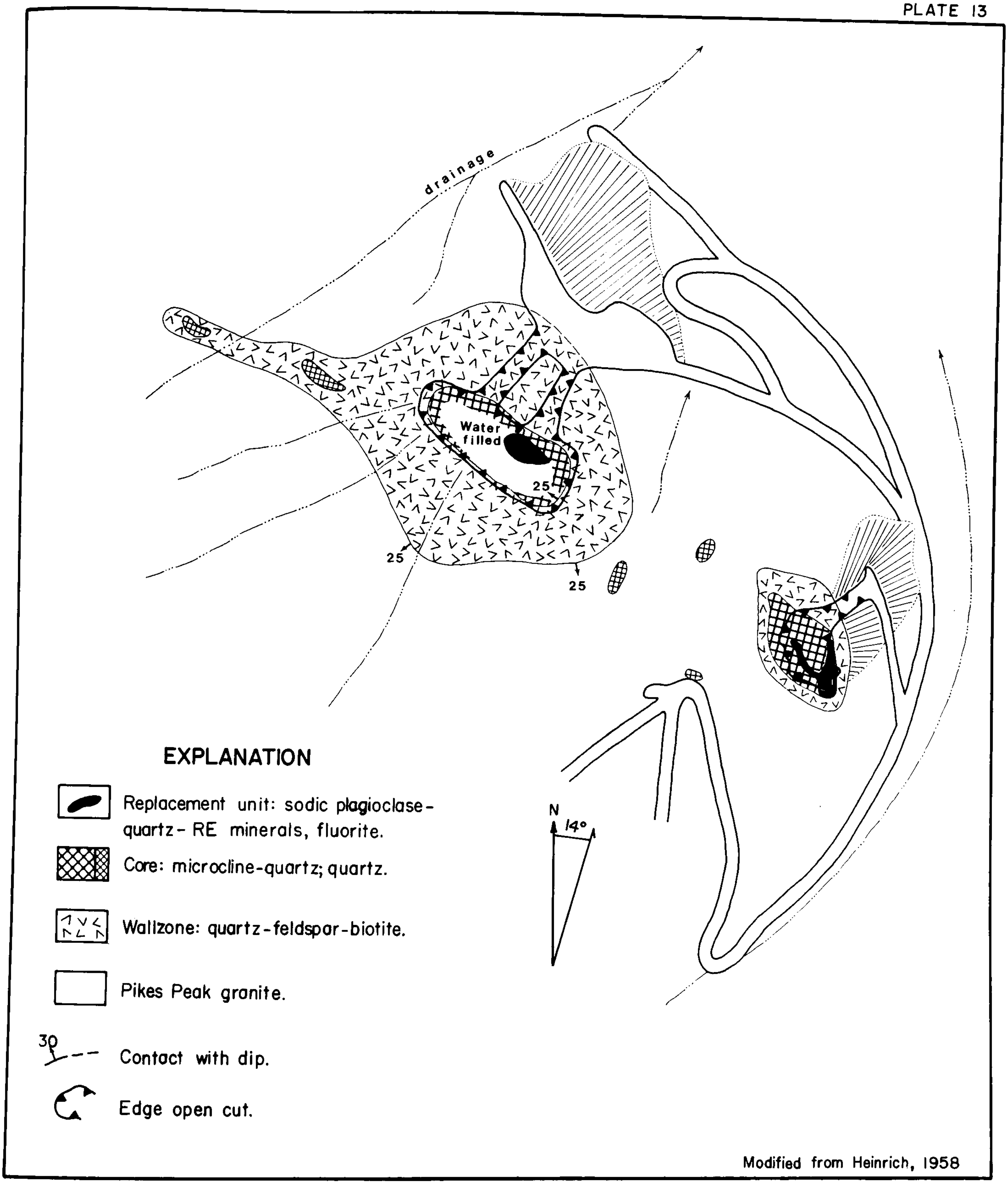


Mapped August, 1969

GEOLOGIC MAP OF THE DAZIE BELL PEGMATITES
SOUTH PLATTE, COLORADO

30 0 30 60 90 Ft.

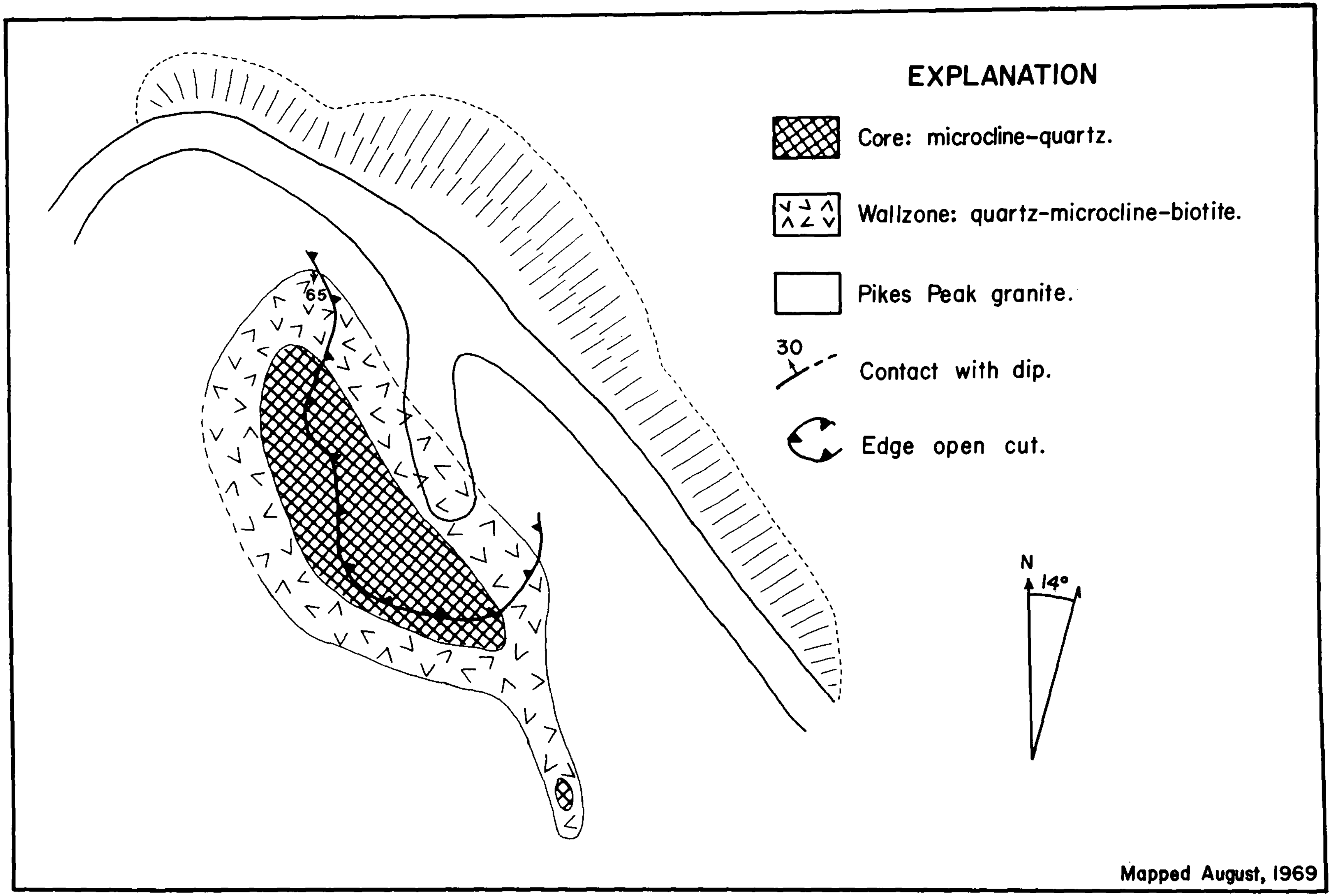
PLATE 13



GEOLOGIC MAP OF THE BIG BEAR NO. 2 PEGMATITE
SOUTH PLATTE, COLORADO

50 0 50 100 150 Ft.

PLATE 14



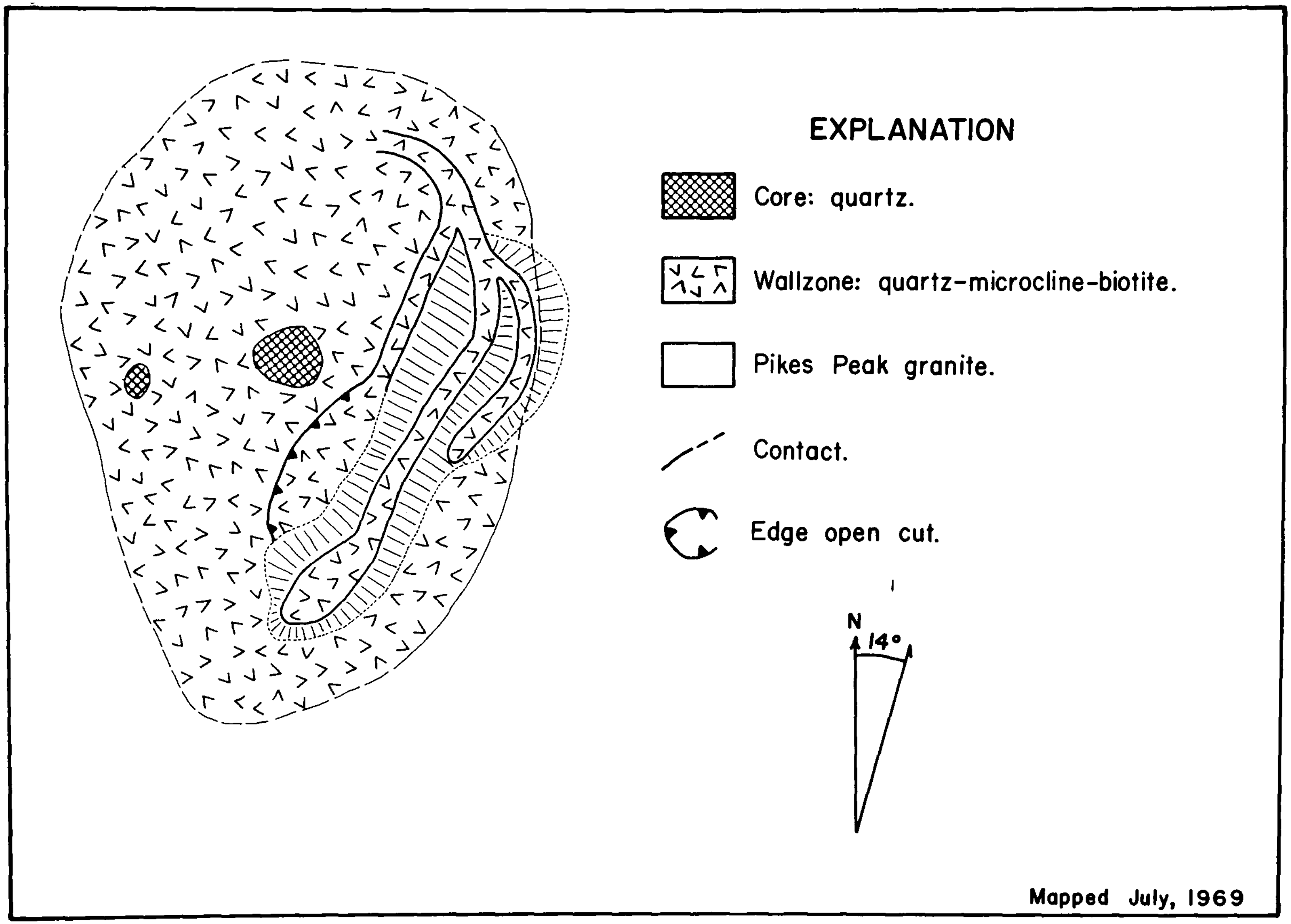
Mapped August, 1969

GEOLOGIC MAP OF THE TWIN CEDARS PEGMATITE

SOUTH PLATTE, COLORADO

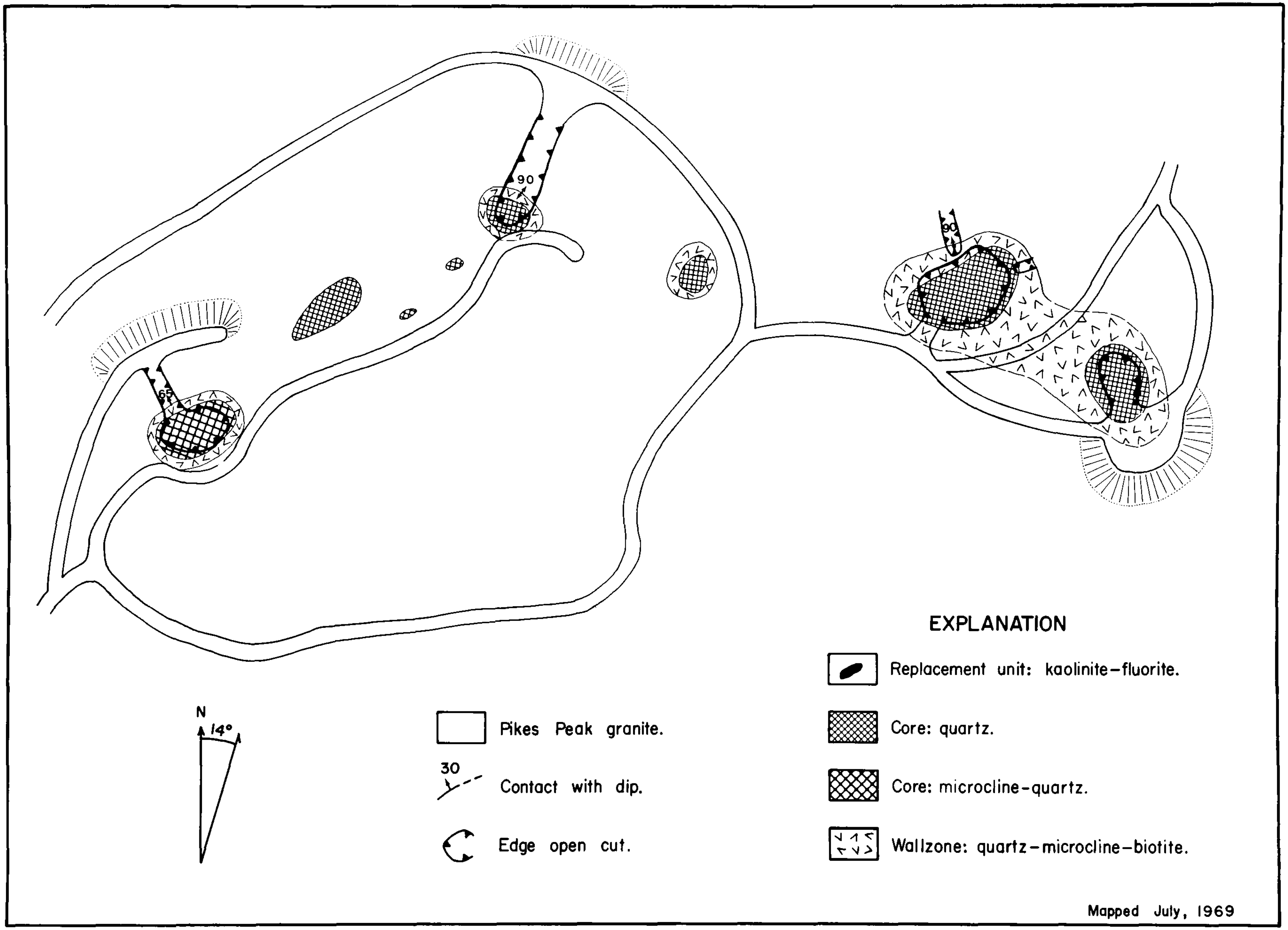
20 0 20 40 60 Ft.

PLATE 15



GEOLOGIC MAP OF THE DEER TRAIL PEGMATITE
SOUTH PLATTE, COLORADO

PLATE 16

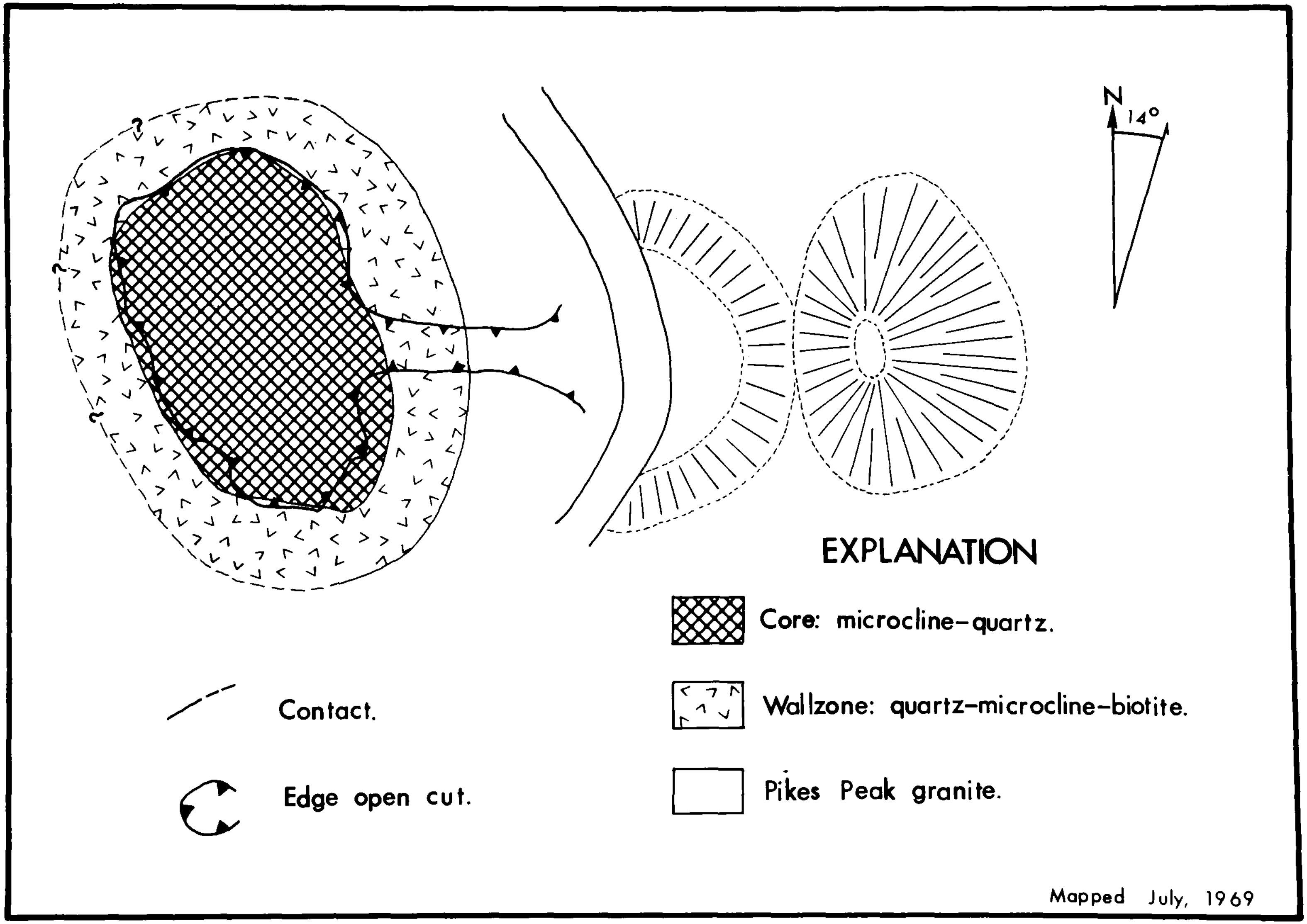


GEOLOGIC MAP OF THE YAMMY YOGURT PEGMATITES

SOUTH PLATTE, COLORADO

50 0 50 100 150 Ft.

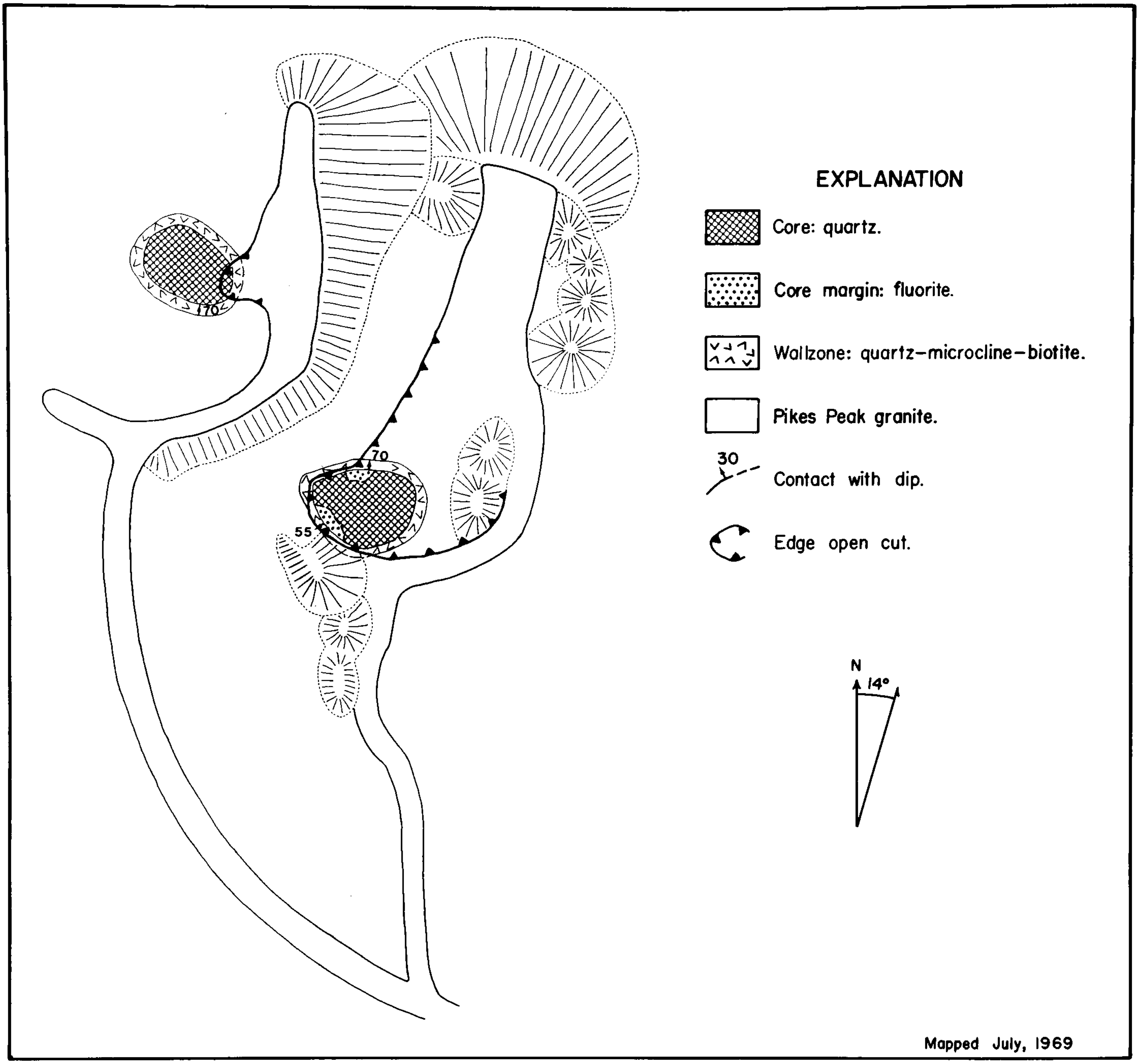
PLATE 17



GEOLOGIC MAP OF THE SHUTTLE RUN PEGMATITE

SOUTH PLATTE, COLORADO

PLATE 18



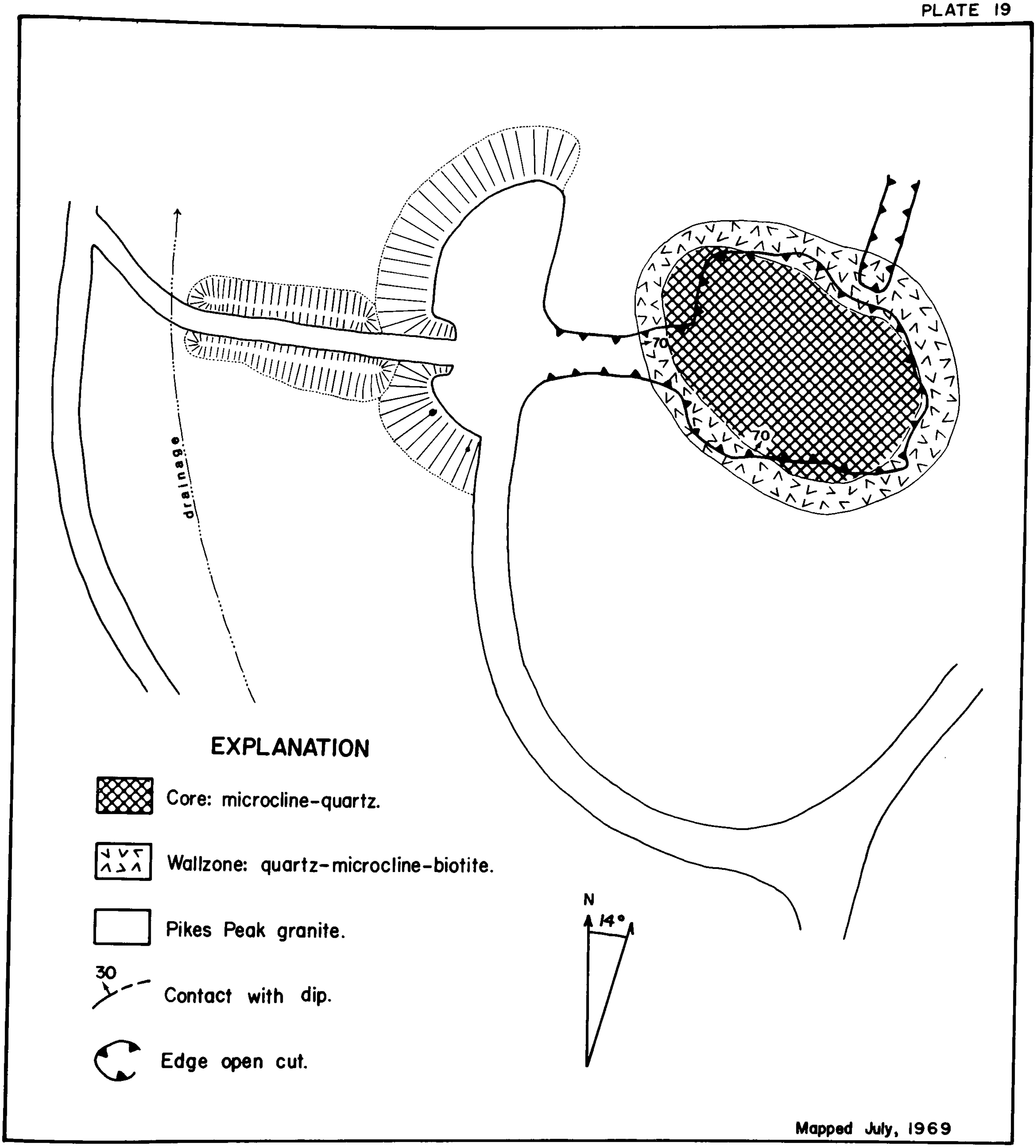
Mapped July, 1969

GEOLOGIC MAP OF THE LITTLE BILL PEGMATITE

SOUTH PLATTE, COLORADO

30 0 30 60 90 Ft.

PLATE 19

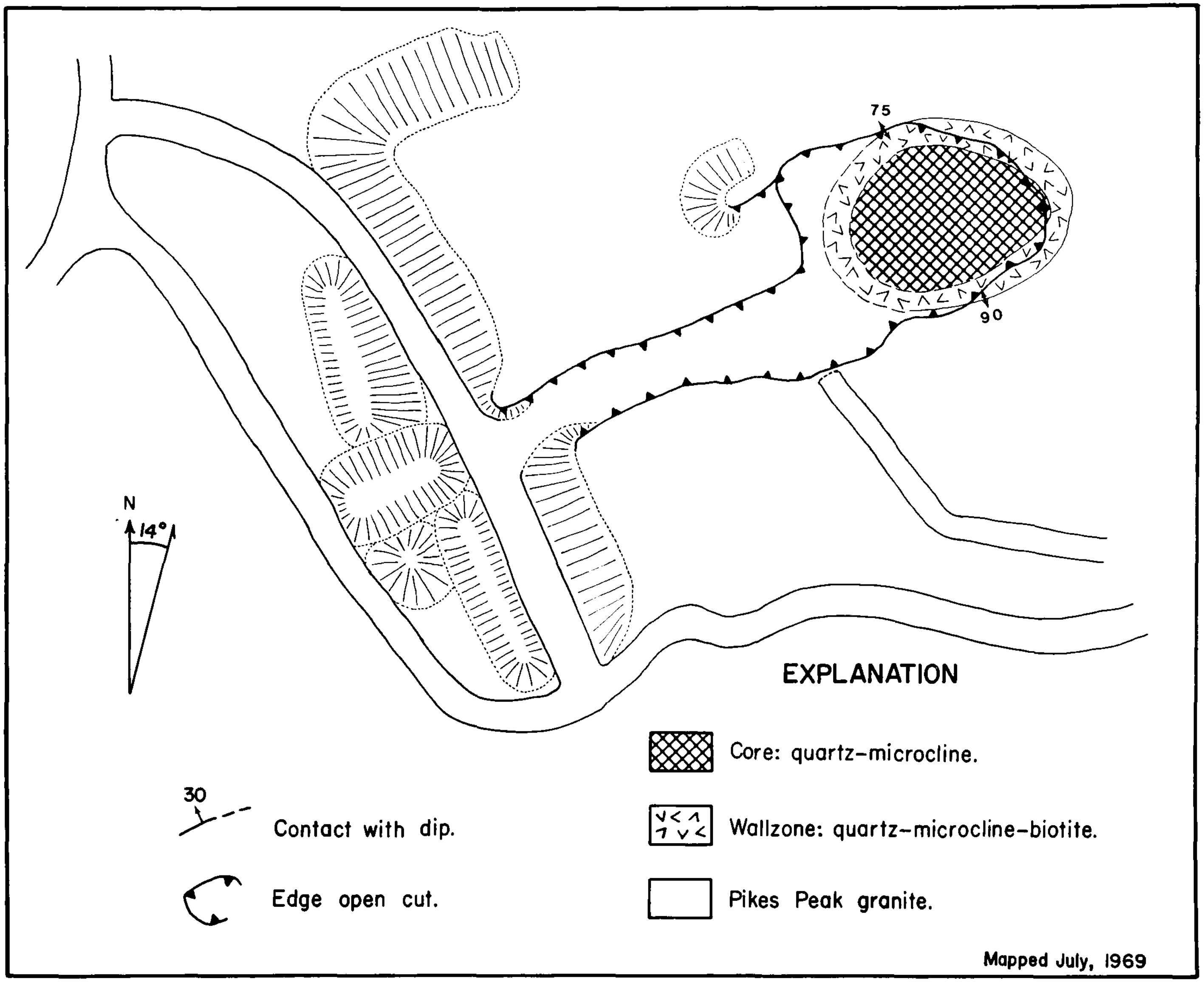


GEOLOGIC MAP OF THE MADONNA NO. 1 PEGMATITE

SOUTH PLATTE, COLORADO

30 0 30 60 90 Ft.

PLATE 20

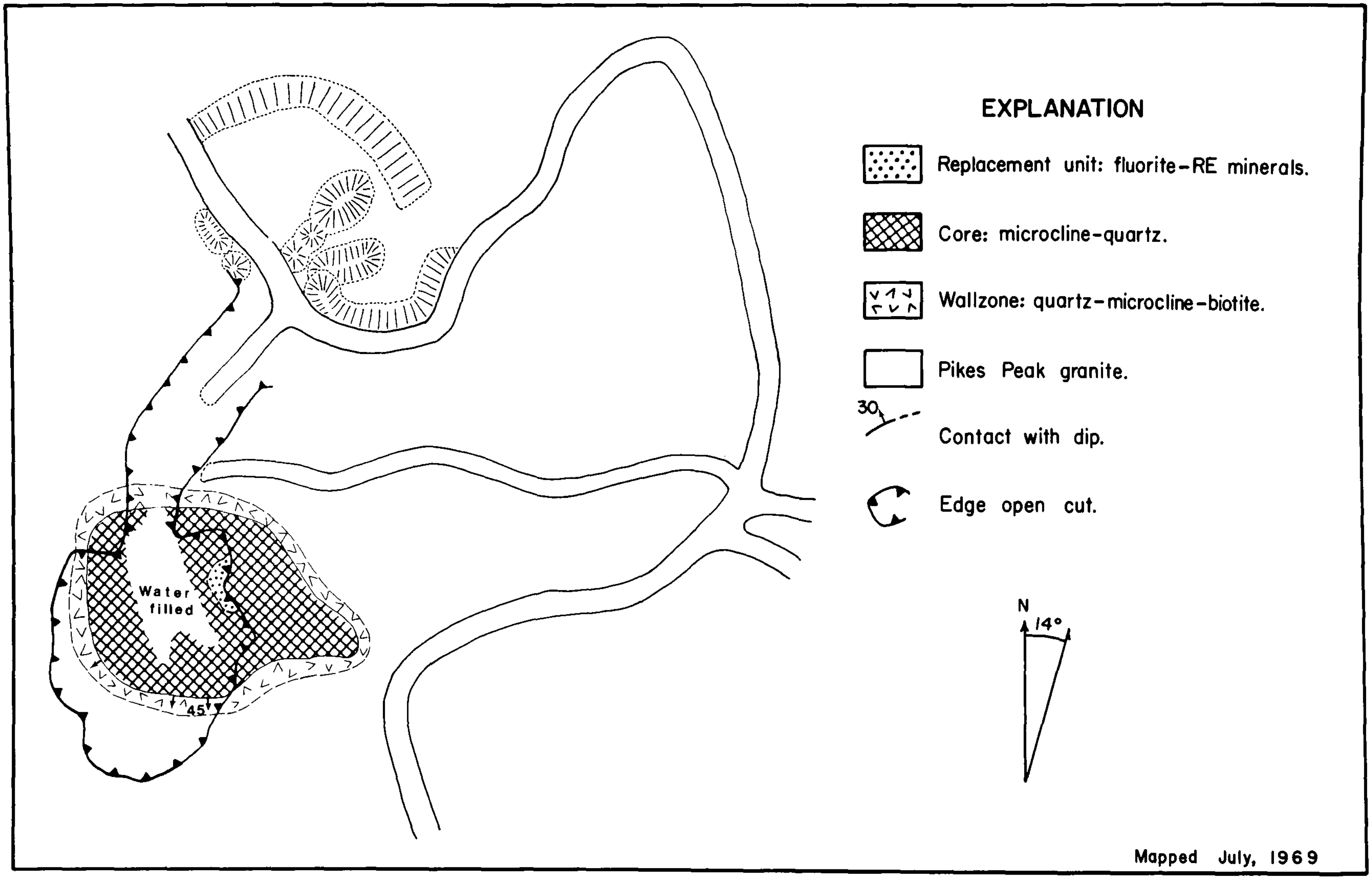


GEOLOGIC MAP OF THE MADONNA NO. 2 PEGMATITE

SOUTH PLATTE, COLORADO

30 0 30 60 90 Ft.

PLATE 21

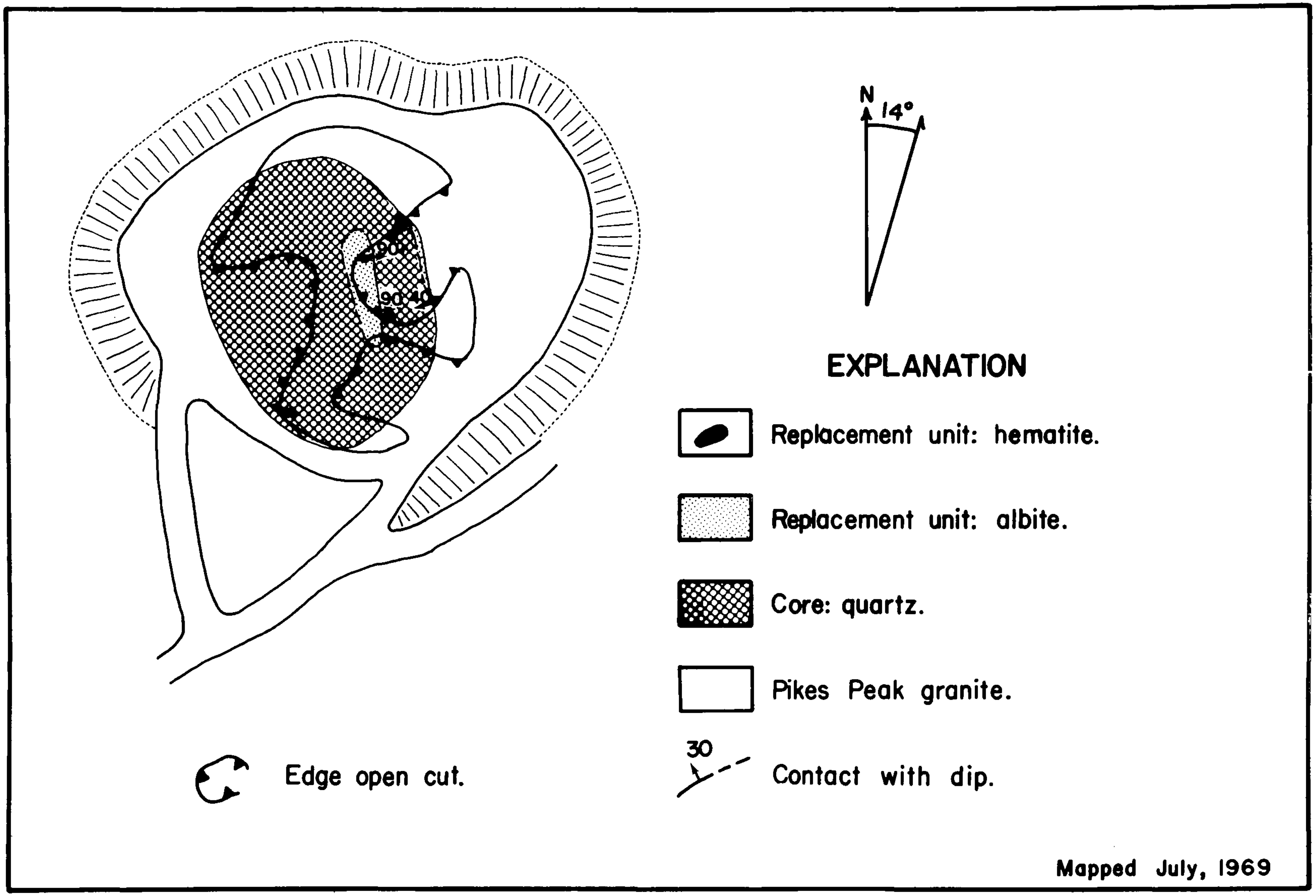


GEOLOGIC MAP OF THE MADONNA NO. 3 PEGMATITE

SOUTH PLATTE, COLORADO

40 0 40 80 120 Ft.

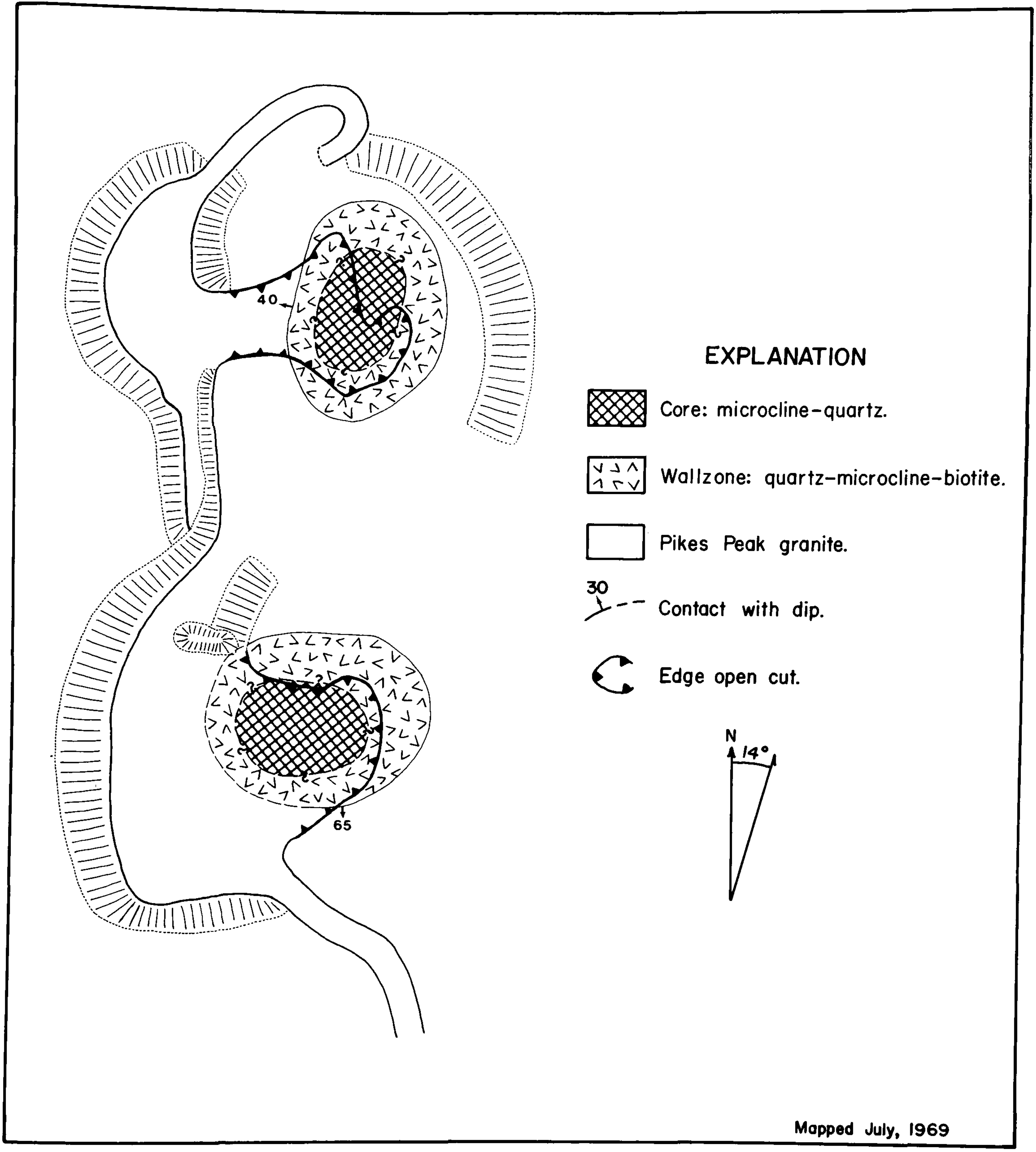
PLATE 22



GEOLOGIC MAP OF THE HOLLINGSWORTH PEGMATITE
SOUTH PLATTE, COLORADO

30 0 30 60 90 Ft.

PLATE 23

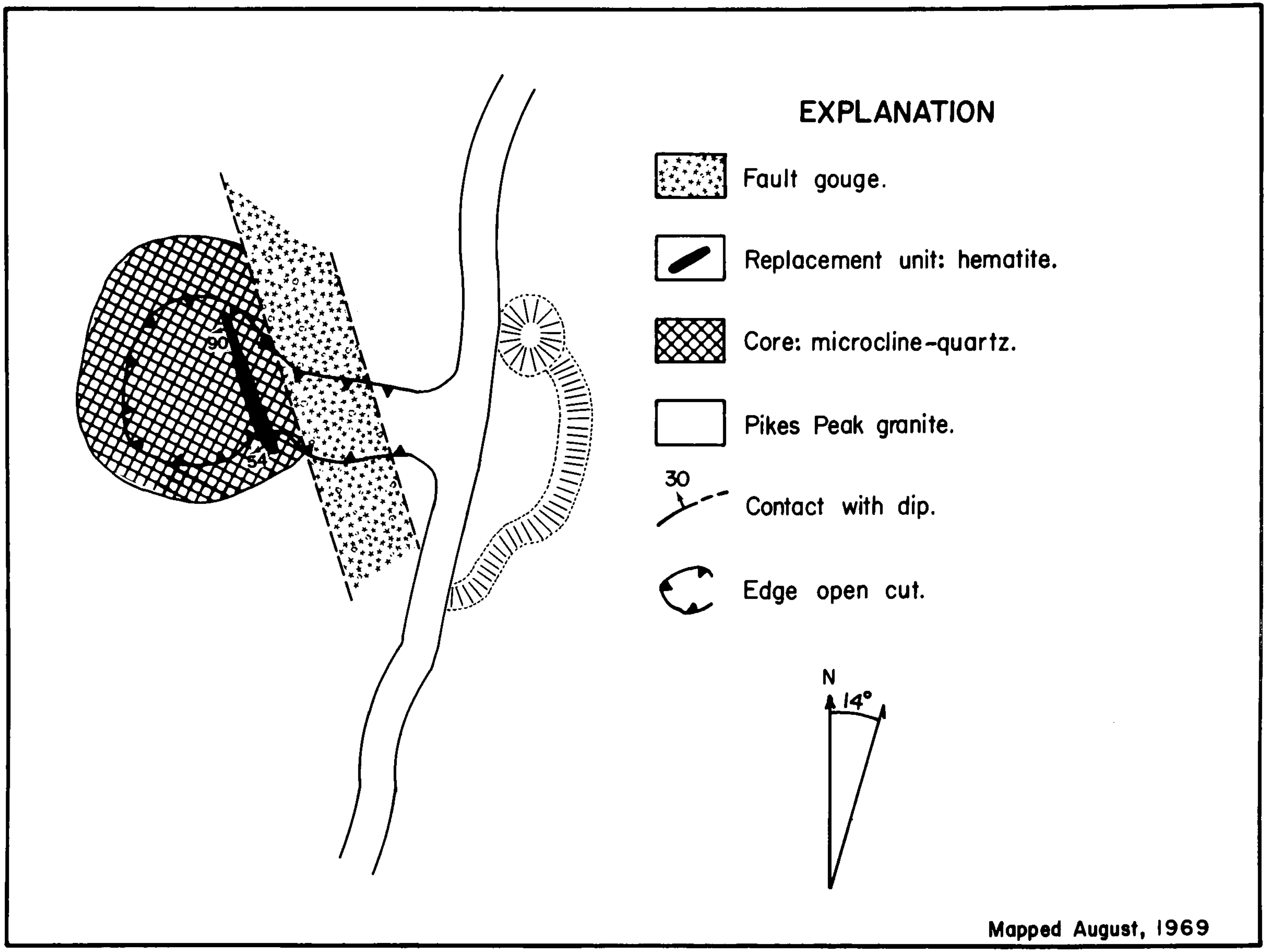


Mapped July, 1969

GEOLOGIC MAP OF THE GEMINI PEGMATITE
SOUTH PLATTE, COLORADO

30 0 30 60 90 Ft.

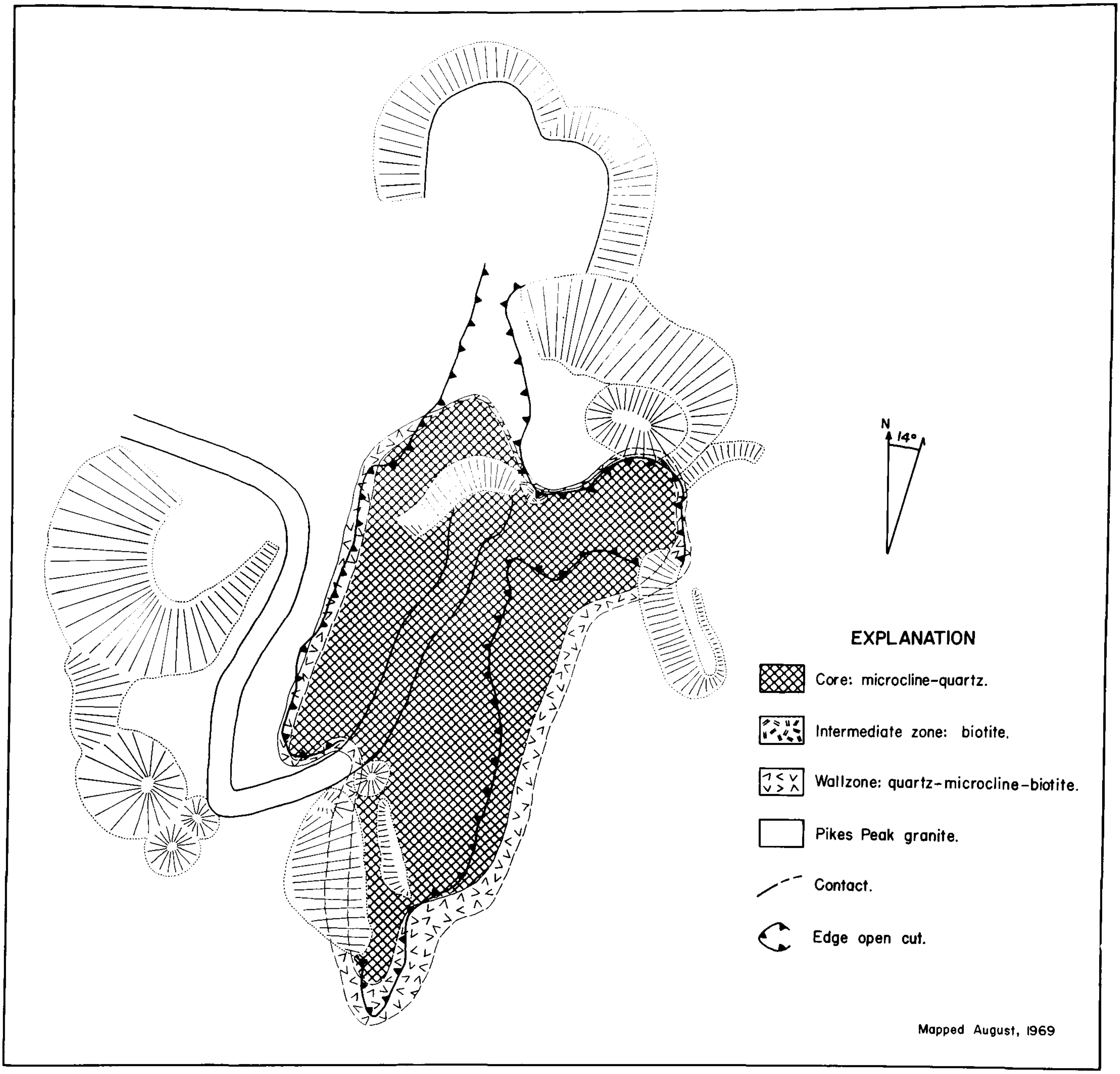
PLATE 24



GEOLOGIC MAP OF THE JANET LUTRICIA PEGMATITE

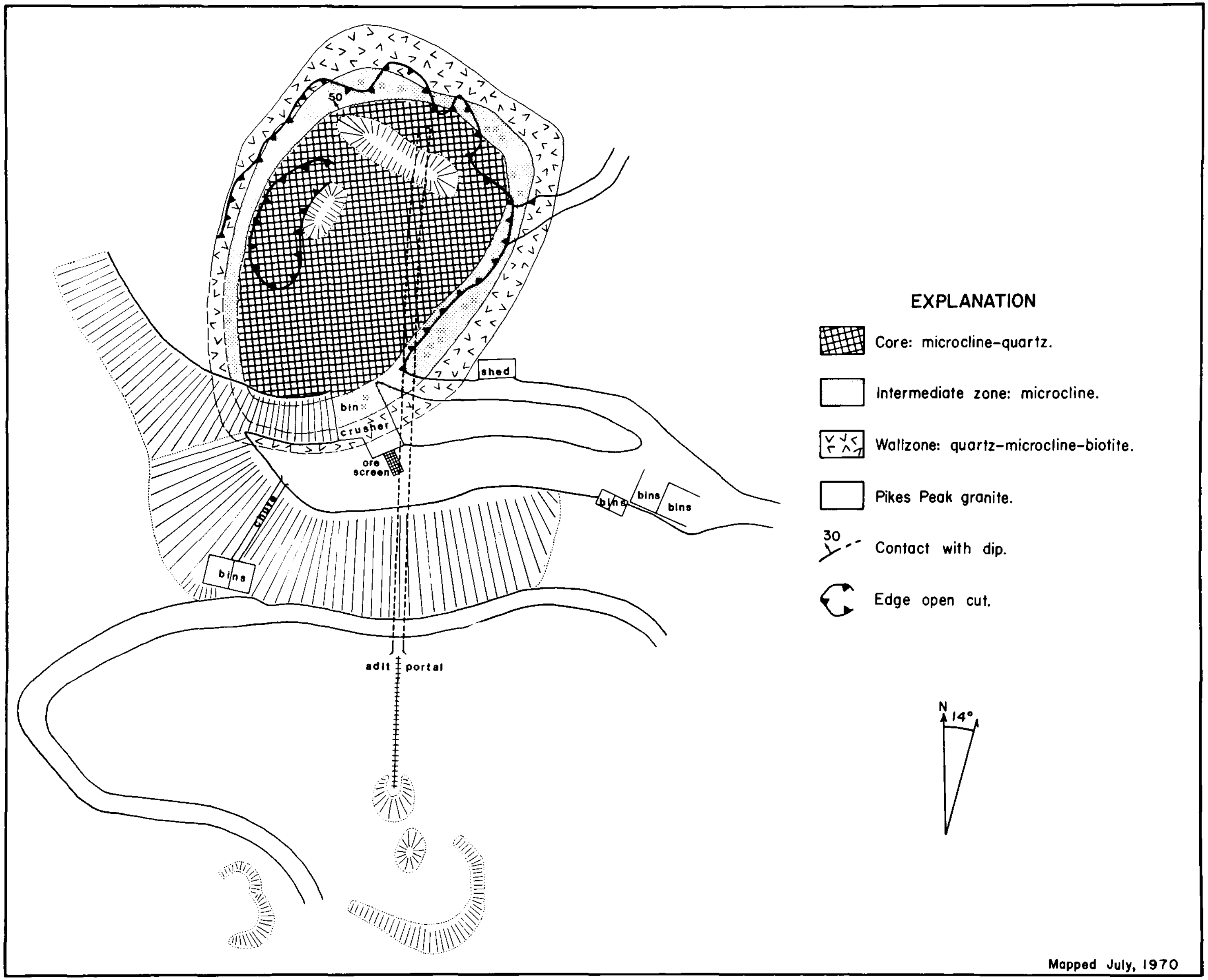
SOUTH PLATTE, COLORADO

30 0 30 60 90 Ft.



GEOLOGIC MAP OF THE BIG BERTHA PEGMATITE
SOUTH PLATTE, COLORADO

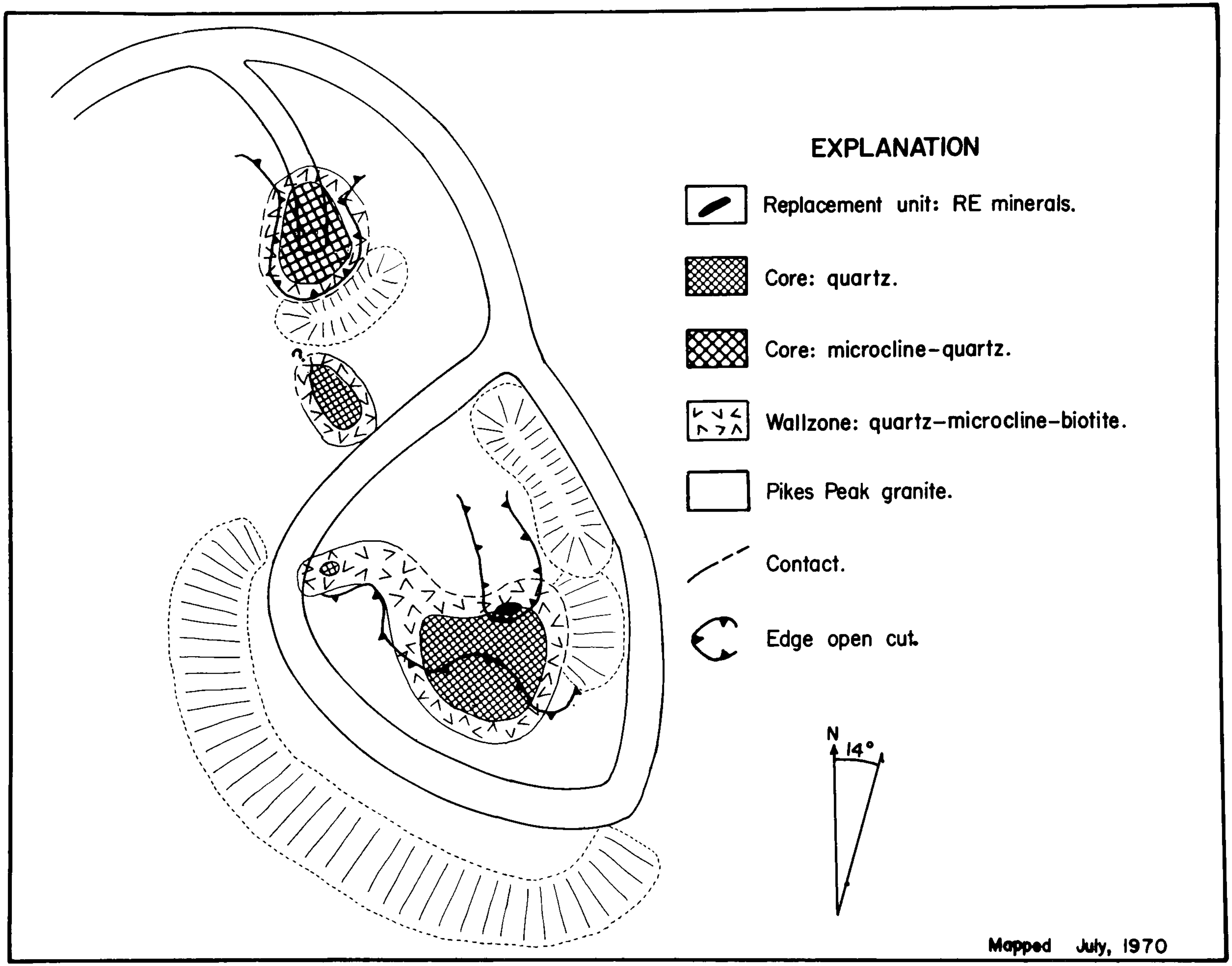
PLATE 26



GEOLOGIC MAP OF THE SEERIE PEGMATITE
SOUTH PLATTE, COLORADO

30 0 30 60 90 Ft.

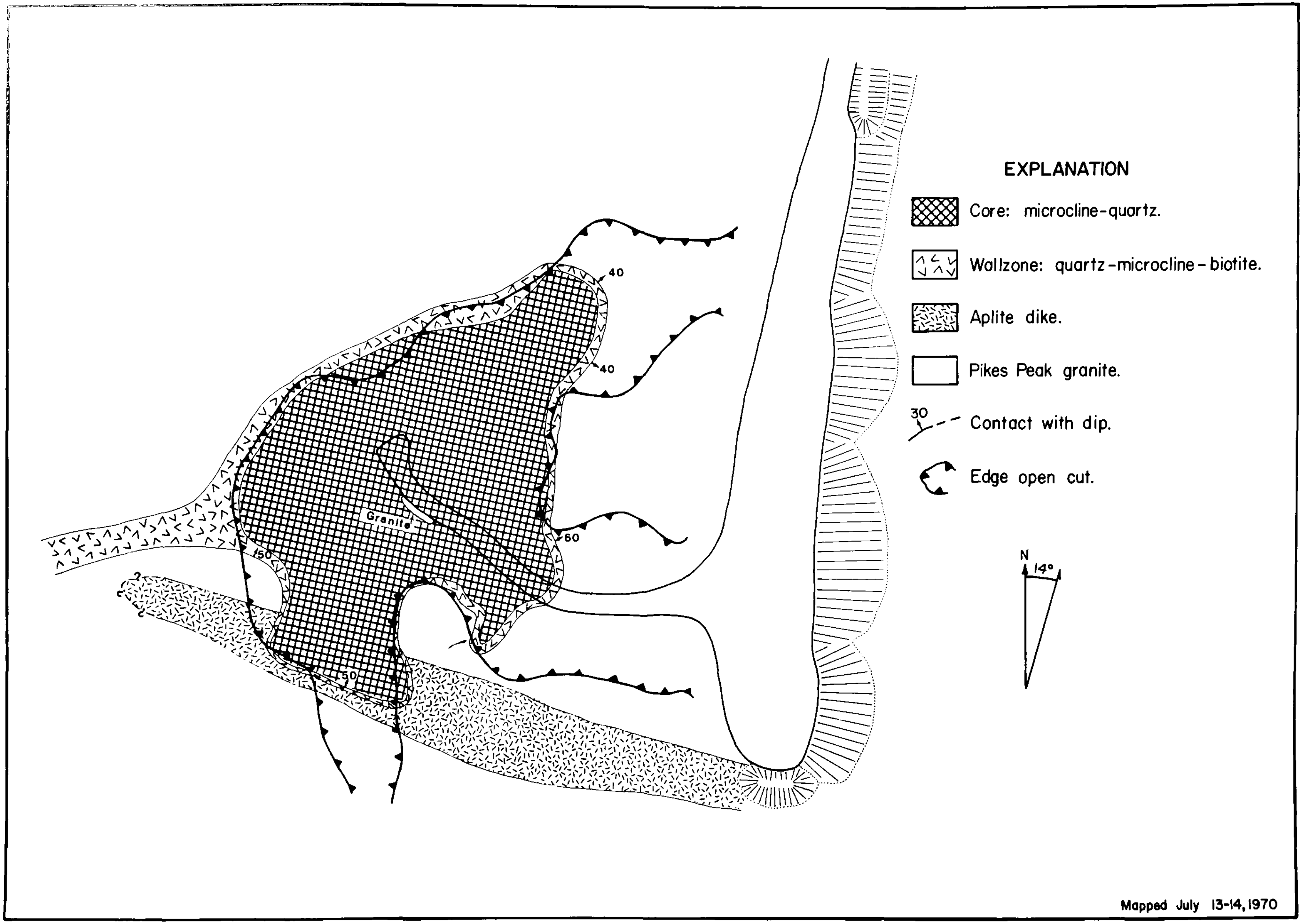
PLATE 27



GEOLOGIC MAP OF THE BUTTERFIELD PEGMATITE

SPHINX PARK, COLORADO

PLATE 28



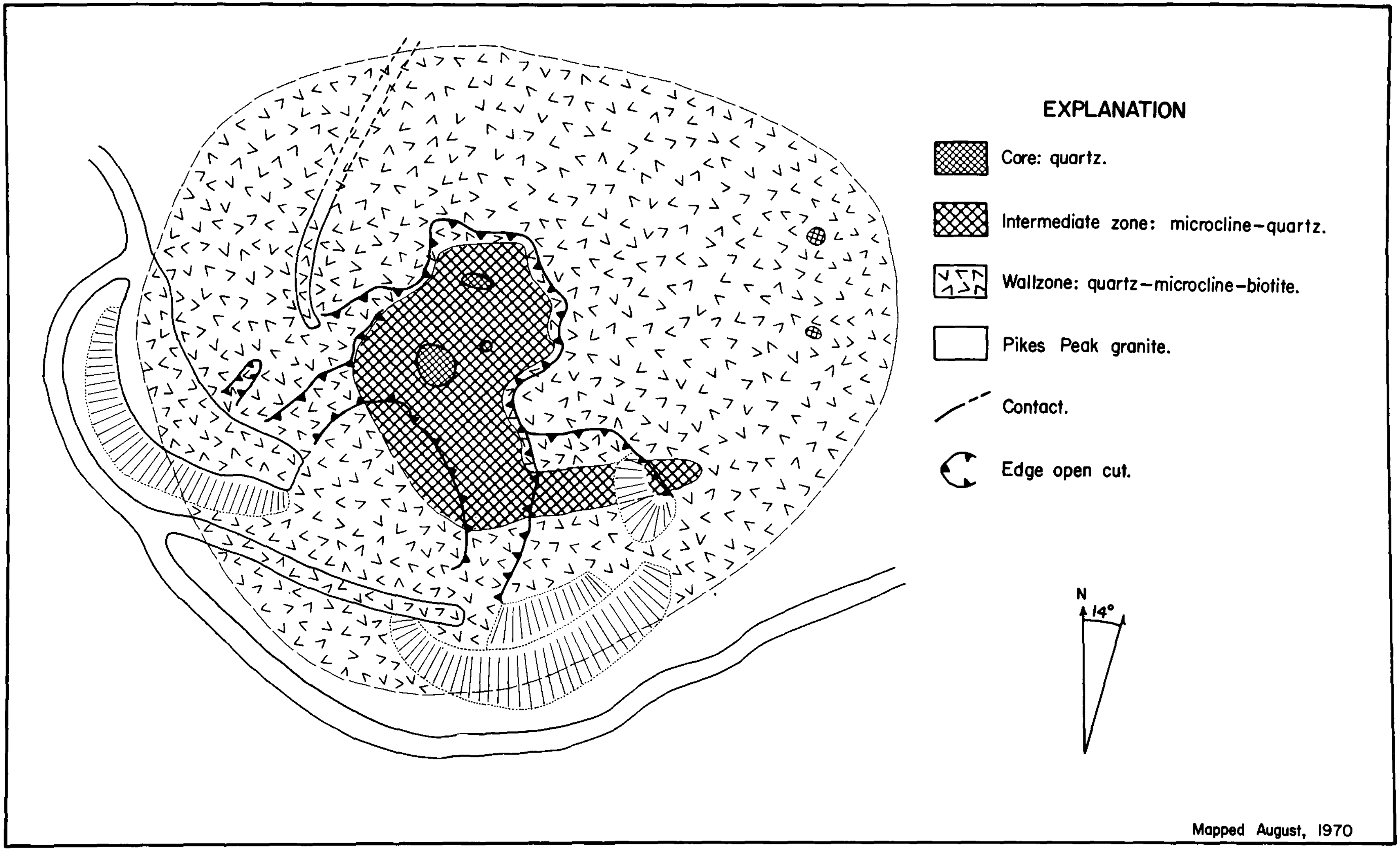
Mapped July 13-14, 1970

GEOLOGIC MAP OF THE McGUIRE PEGMATITE

WELLINGTON LAKE, COLORADO

30 0 30 60 90 Ft.

PLATE 29



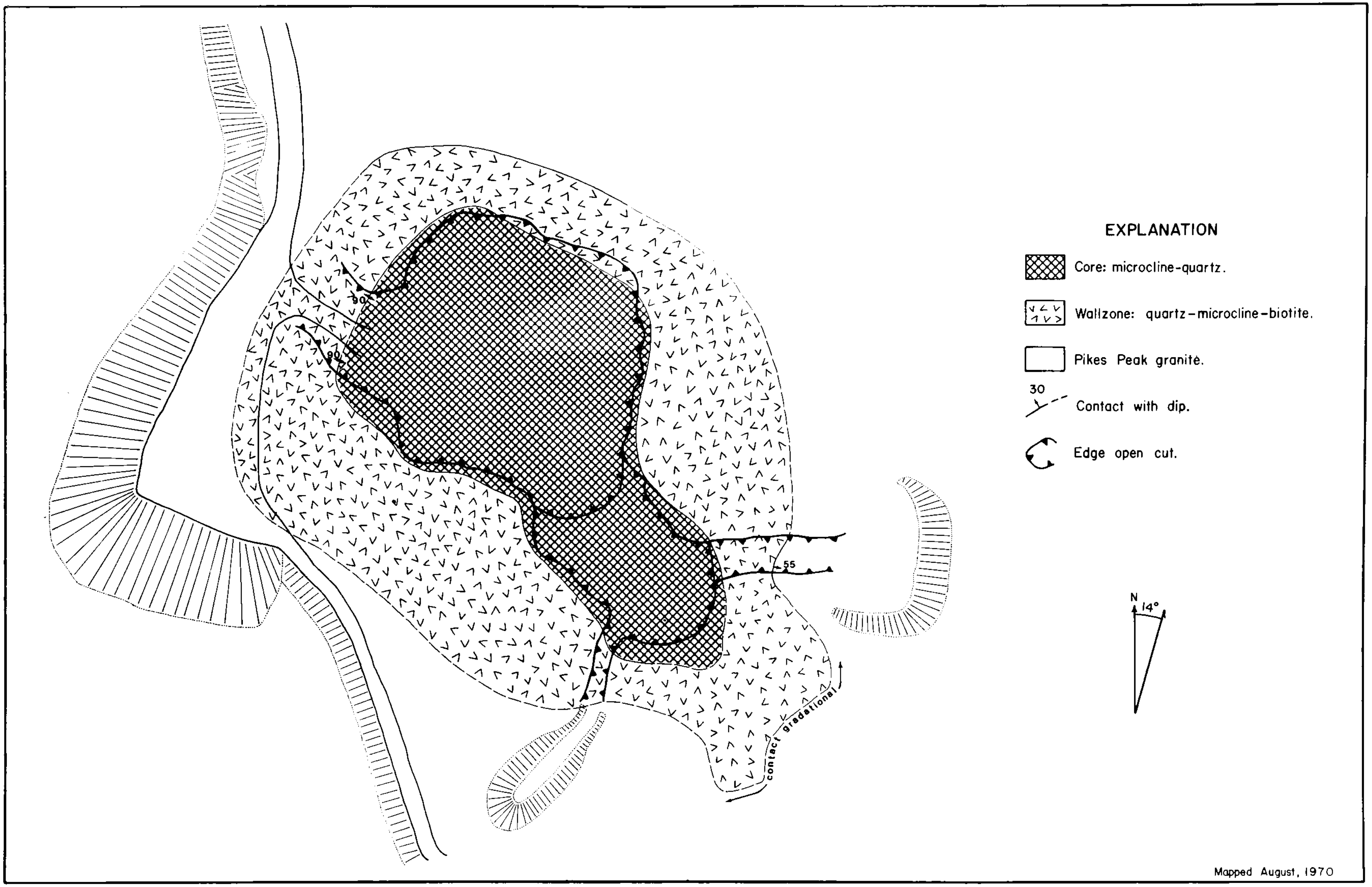
Mapped August, 1970

GEOLOGIC MAP OF THE SNOWFLAKE PEGMATITE

WOODLAND PARK, COLORADO

50 0 50 100 150 Ft.

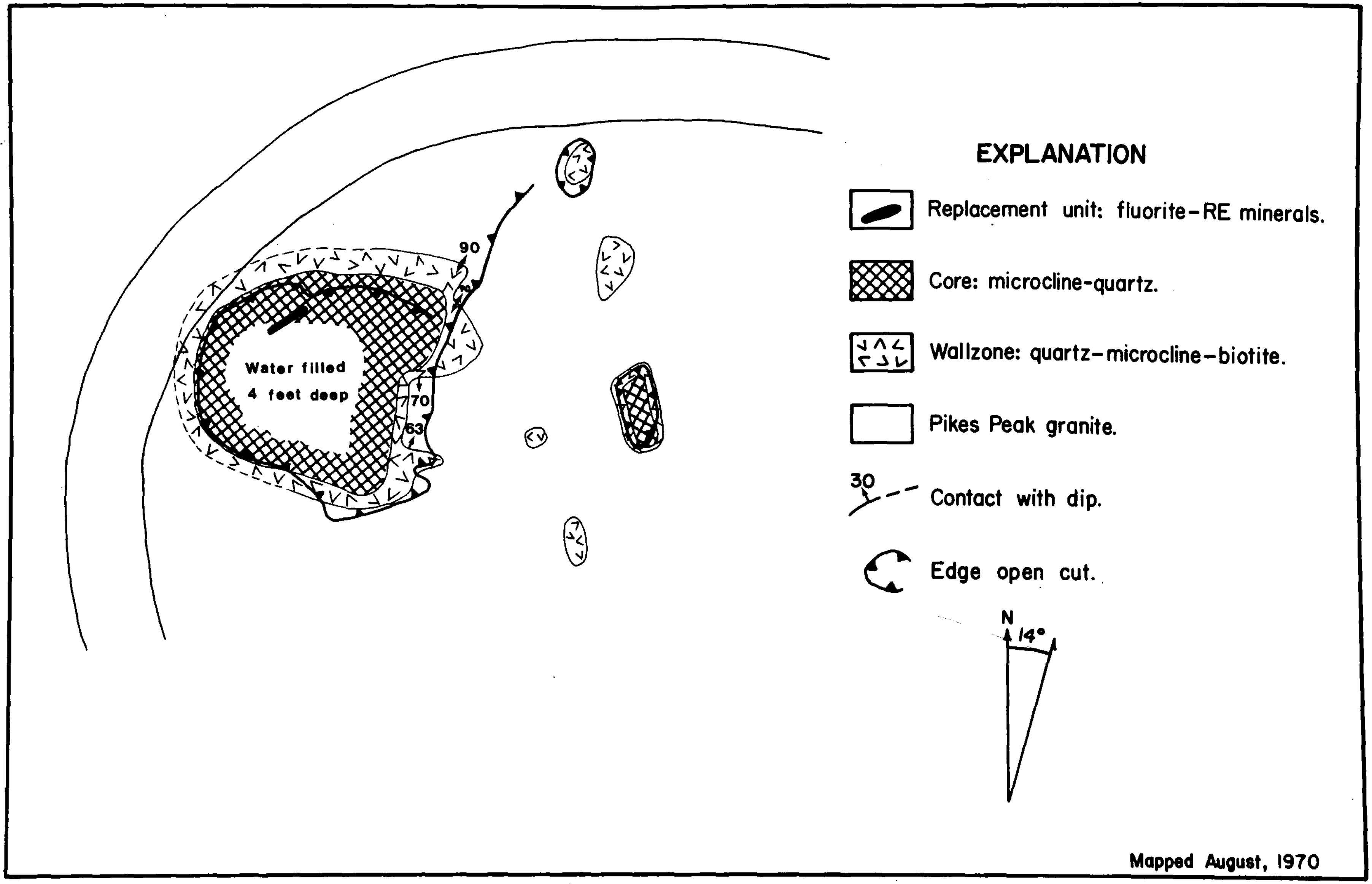
PLATE 30



GEOLOGIC MAP OF THE BLACK CLOUD PEGMATITE

DIVIDE, COLORADO

PLATE 31



GEOLOGIC MAP OF THE TELLER PEGMATITE

LAKE GEORGE, COLORADO

30 0 30 60 90 Ft.

SELECTED PUBLICATIONS OF THE COLORADO GEOLOGICAL SURVEY

GENERAL

BULLETIN 32--*Prairie, Peak and Plateau--A guide to the geology of Colorado*, by John Chronic and Halka Chronic, 1972, 126 p., $4.00.

BULLETIN 37--*Bibliography and index of Colorado geology, 1875 to 1975*, American Geological Institute, 1976, 488 p., 3 figs., softbound, $7.50; hardbound, $10.00.

MAP SEREIS 1--*Geologic, energy and mineral resources maps of Routt County, Colorado*, by John Chronic and Halka Chronic, 1972, 126 p., $4.00.

MAP SERIES 3--*Geologic map of Moffat County, Colorado*, by A. E. Miller, 1977, (scale 1:126,720), $8.00.

MAP SERIES 13--*State lands status map, lands and minerals administered by agencies of the Colorado Department of Natural Resources*, compiled by S. J. Soukup, 1979, 1 pl. (scale 1:500,00), $3.00.

Colorado stratigraphic correlation chart, by R. H. Pearl and D. K. Murray, 1974, 11" x 14", 25 cents./

Energy resources map of Colorado, USGS and CGS, 1977, (scale 1:500,000), $2.00.

Geologic map of Colorado, USGS, Ogden Tweto, 1979, (scale 1:500,000). This is the newly revised colored state geologic map, over-the-counter or mailed folded, $4.00; mailed rolled, $4.50.

Geologic map of Colorado, USGS, 1935 (scale 1:500,000). Reprinted 1975, colored (superseded by 1979 geologic map by Tweto), over-the-counter or mailed folded, $2.00; mailed rolled, $2.50.

MINERAL RESOURCES

MAP SERIES 10--*Metal mining activity map of Colorado excluding uranium and vanadium (with directory)*, by A. L. Hornbaker, 1978, 1 pl. (scale 1:500,000), $3.00.

Fluorspar deposits in Colorado, map showing, by B. T. Brady, 1975 (scale 1:500,000), $1.25.

Minerals in the economy of Colorado, by K. E. Starch, N. R. Blake, and J. W. Rold, U.S. Bureau of Mines, 1979, $1.00.

Tungsten mines of Colorado, by H. S. Cobb, 1960, 78 p., $1.00.

RESOURCE SERIES 2--*Mineral resources survey of Mesa County--A model study*, by S. D. Schwochow, 1978, $12.00.

RESOURCE SERIES 8--*Proceedings of the 15th Forum on Geology of Industrial Minerals*, S. D. Schwochow, ed., (in preparation).

SPECIAL PUBLICATION 5-A--*Sand, gravel, and quarry aggregate resources, Colorado Front Range Counties*, by S. D. Schwochow, R. R. Shroba, and P. C. Wicklein, 1974, 43 p., 11 figs., 3 pls., 2 tables, $3.00.,

SPECIAL PUBLICATION 5-B--*Atlas of sand, gravel, and quarry aggregate resources, Colorado Front Range Counties*, by S. D. Schwochow, R. R. Shroba, and P. C. Wicklein, 1975, 2 figs., 213 pls., $10.00.

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