

STRUCTURE AND PETROLOGY  
OF  
THE  
FOUNTAIN QUARRY GRANITE

by

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STRUCTURE AND PETROLOGY

OF THE

FOUNTAIN QUARRY GRANITE

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## ABSTRACT

The Fountain Quarry Granite is a small, elongate pluton unconformably overlain by Pleistocene sediments at Fountain, on the coastal plain of North Carolina. Petrologic analysis of the rock indicates that it is a fine- to medium-grained peralkaline granite containing riebeckite, aegirine, orthoclase, and nearly pure albite. Chemical analyses of the granite show that it is comparable to other peralkaline granites worldwide. The rock contains a large, fine-grained aplite vein and several small, poorly-developed pegmatites, which occur as riebeckite-bearing quartz veins. The pegmatites also contain small amounts of fluorite, ilmenite, sphalerite, and molybdenite.

Structural features in the granite include a prominent flow foliation defined by mafic minerals and wallrock xenoliths, and well-developed sets of cross joints and longitudinal joints. The two joint sets are roughly perpendicular, and the average strike of the longitudinal joints is parallel to the north-south axis of the pluton. The pluton contains no major faults, although small movements have occurred along joint planes in response to regional tectonism. However, the rock does not appear to have been regionally metamorphosed.

A preliminary Rb-Sr whole-rock age date suggests a late Paleozoic origin for the granite. The high initial  $\text{Sr}^{87}/\text{Sr}^{86}$  ratio (about 0.730) indicates that the partial melting of crustal rocks may have been involved. Peralkaline magmas are characteristically associated with zones of crustal rifting. The preliminary age date calculated for the Fountain Quarry Granite does not coincide well with known periods of rifting along the eastern margin of North America. This suggests that either the rock is older than late Paleozoic, or that zones of tensional tectonics remained near the edge of the continent prior to the collision with Africa about 280 m.y. ago.

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## INTRODUCTION

Fountain Quarry is located approximately 0.8 km (0.5 mi.) southeast of Fountain, North Carolina (figure 1) and is currently operated by Martin Marietta Corporation for the production of crushed stone. Previous work at the quarry has been limited to a paleoecological study (Maggiolo, 1970), a paleontological study of sediments above the granite (Snyder and Katrosh, in press), joint measurements by ECU structural geology classes, and contour mapping of the top of the granite by Martin Marietta prior to quarrying. The rock has been briefly mentioned in three other reports in which it is described as a "granite monadnock" (Brown, 1959) and a "hill or irregularity in basement rock" (Richards, 1950). Councill (1954) describes the rock as a "highly siliceous granite gneiss". However, petrologic differences between this rock and surrounding basement (Denison and others, 1967) would seem to indicate a more complex relationship. This report is an attempt to expand on that relationship through a structural and petrologic analysis of the granite.

Fieldwork was carried out during 1977 and 1978. Photographs were taken during the summer and fall of 1978 and the spring of 1979.

In this report, the rock will be referred to as the Fountain Quarry Granite.

## HISTORY AND BACKGROUND INFORMATION

The Fountain Quarry Granite has been known since the town of Fountain was settled, and attempts have been made to utilize the surface outcrops at least as long ago as the 1930's (Richards, 1950). In 1938, an attempt to quarry the rock as dimension stone met with limited success (Councill, 1954). The granite is exceedingly hard and difficult to break or drill with conventional equipment. It was not until 1961, when Martin Marietta acquired the property, that commercial-scale production could begin. Initial subsurface coring surveys showed the top of the granite to be an elongate dome, with the major axis trending approximately north-south (figure 2). There is a sharp drop-off on all sides.

Quarry operations began in 1963 with the advent of new hard-rock drilling technology that previously had not been available in the U.S. Most of the stone is crushed, cleaned, and used in construction or road-building. According to quarry supervisors, there are no plans to quarry stone from the north, east, or south walls. Removal of stone from the west wall will eventually be limited by encroachment on neighboring properties, probably sometime in the 1980's.

The Fountain Quarry Granite is the easternmost exposure of crystalline rock on the Atlantic coastal plain and is somewhat of an anomaly. It crops out at a place where surrounding basement is buried by overlying sediments to depths of 125-155 m (400-500 ft), and its elevation is unique in this respect (Brown and others, 1972). The granite is an exposure of basement rock, but the geologic details of the surrounding basement area are hidden beneath the sediments.



The term 'basement', as applied to the coastal plain, refers to "assorted igneous and metamorphic rock on which the Mesozoic and Cenozoic sediments were deposited" (Denison and others, 1967). Cores from seven wells show that basement rocks under the coastal plain are comparable to those found in the Piedmont and Blue Ridge. Some basement rocks in the Blue Ridge are believed to be at least as old as late Precambrian, based on stratigraphic relations and on structures that formed during an episode of regional metamorphism about 1100 m.y. ago (Bryant and Reed, 1970). However, cores from basement from several areas near the present shoreline give Rb-Sr age dates of about 600 m.y. (Denison and others, 1967) and some amphibolites on the coastal plain near Columbia, South Carolina have been dated at about 260 m.y. (Secor and Snoke, 1978). Fullagar and Butler (1979) suggest that there may be no basement older than 1000 m.y. beneath the eastern Piedmont. This indicates that past episodes of regional metamorphism may have caused a resetting of radioisotope concentrations in parts of the basement complex, or else sections of the basement indeed are of different ages.

There has been little detailed geologic work done on the Fountain Quarry Granite. The report by Richards (1950) includes photographs of granite boulders (roughly 4.5 x 7.5 m, 15 x 24 ft) at the surface. In this report the pluton was described as "a hill or irregularity in basement rock." Council (1954), in a survey of commercial granites in North Carolina, called the rock a granite gneiss, "highly siliceous, medium-grained, very hard and massive. It contains dark-colored 'gneissic' inclusions and a few widely spaced mineral-filled joints, striking approximately north and east. Joint fillings are mostly milky quartz with a little feldspar." The following estimate of the mineral composition was also listed in Council's

report:

|                                       |                              |
|---------------------------------------|------------------------------|
| Quartz.....36%                        | Biotite + Homblende.....9%   |
| Orthoclase<br>(and Microcline)....47% | Magnetite, Apatite           |
| Plagioclase.....5%                    | Chlorite, and Calcite.....3% |

The exposure was estimated to be about 0.8-1.2 ha (2-3 acres). Brown (1959), in a report on ground water resources in the Greenville area, characterized the basement surface as "very uneven", based on geophysical data and logs of wells drilled in the area. The report also mentions "the granite monadnock surrounded by more than 125 m (400 ft) of sediment at Fountain...".

In the Fountain area, the crystalline rock is overlain by clastic and carbonate sediments that are Pleistocene in age (Snyder and Katrosh, in press). These sediments are separated from the basement by an erosional unconformity. Upon entering the quarry area, an observer first notices that many large, rounded granite boulders are scattered about the rim of the pit, and that several layers of unconsolidated sediment are in contact with the granite. There is no aureole of contact metamorphosed country rock. The boulders have evidently been exposed to a long period of weathering and erosion. The surface of these boulders is a "skin" of intensely weathered granite 0.5-1 cm (0.2-0.4 in) thick, which grades into fresher rock. Many boulders are pock-marked with oval or bean-shaped shallow depressions. These are probably the result of leaching by ground water. The granite mass was apparently exposed to erosion by wave action in a near-shore environment. Therefore, a large portion of the granite and surrounding rocks have long since eroded away.

The isolated nature of the exposure is the chief obstacle in solving

the problem of the deep structure and origin of the Fountain Quarry Granite. Surrounding rocks that normally would contain clues about the intrusive history of the pluton are not exposed at the surface.

## PETROLOGY

### 1. General Description

The Fountain Quarry Granite is an equigranular, fine- to medium-grained, holocrystalline, peralkaline granite characterized by a pervasive flow foliation. The rock is a uniform light gray at all exposures in the quarry. The flow structure is defined by small acicular clusters of aegirine and riebeckite, which appear as dark streaks in any section cut at an angle to the foliation (figure 3). The rock is very hard, perhaps due to the welded nature of the grain contacts. Large joints in the granite are often coated with mixed layers of albite, riebeckite, and quartz with lesser amounts of pyrite and calcite. Small gash veins, cutting the granite at various angles, are usually filled with quartz and albite. Larger veins often contain some subhedral crystals of riebeckite.

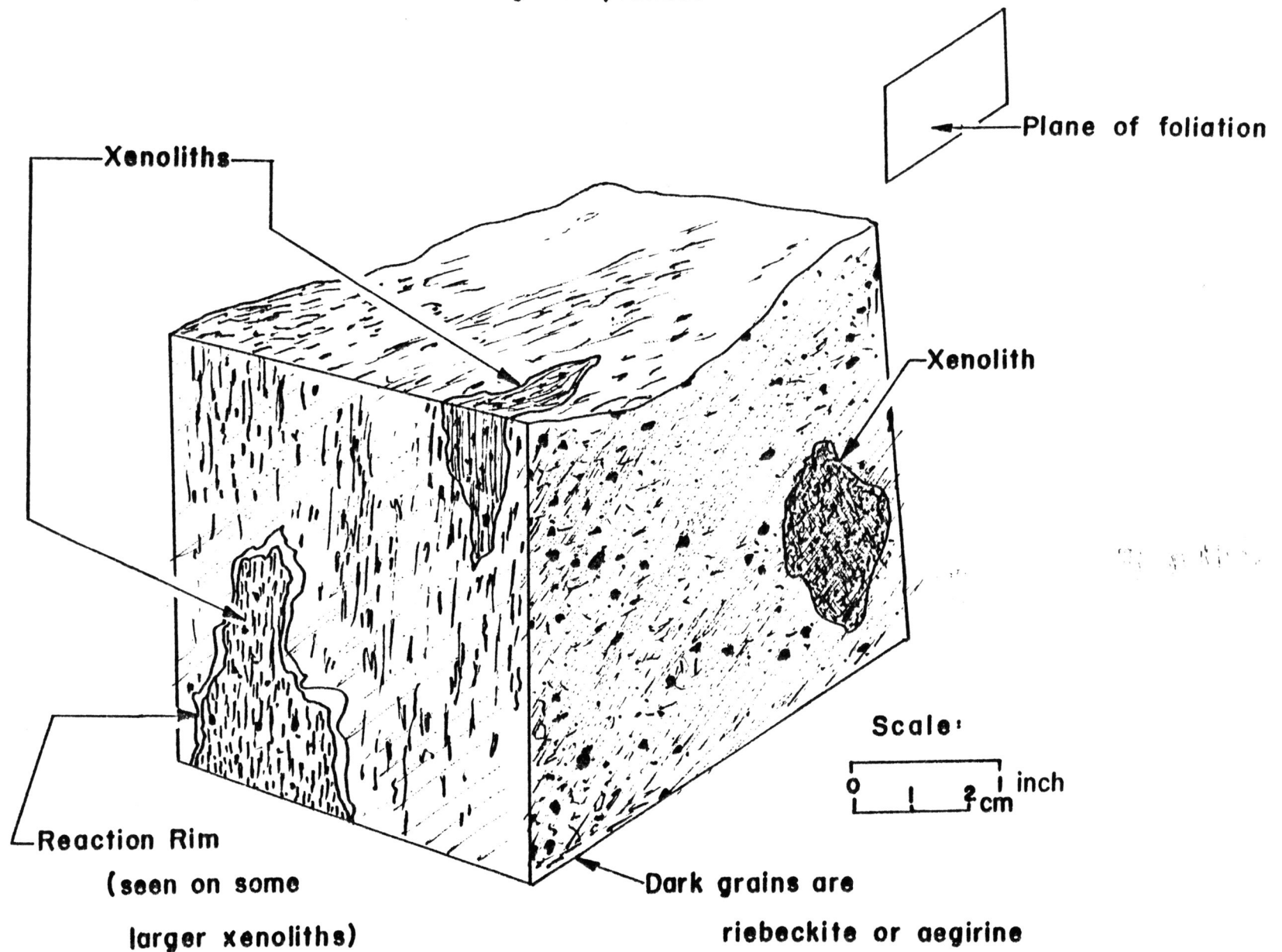
The granite composition is typical of many peralkaline intrusives (Bowden, 1974). Peralkaline rocks by definition have a molecular excess of alkalis over alumina; in the Fountain Quarry granite, the excess sodium has resulted in the formation of sodic pyroxenes and amphiboles. Slabs of granite stained with sodium cobaltinitrite (Hutchison, 1974) show a number of large grains of potassium feldspar. These grains are mostly subhedral, un-twinned, and contain small patches of albite.

### 2. Mineralogy

The major minerals in the granite are albite, quartz, and potassium feldspar, with up to 20 percent aegirine, riebeckite, and opaque minerals. The albite and quartz grains are usually anhedral (some feldspar is subhedral) and are about the same size (0.5-1.5 mm). Grain contacts between

FIGURE 3 : SKETCH OF FLOW FOLIATION IN GRANITE.

Sample cut in three orthogonal planes.



the two are very tight, almost welded together (plate 1). The plagioclase is very sodic albite ( $\text{Ab}_{99.1}\text{Or}_{0.9}$ ) as indicated by electron microprobe analyses. Granite samples collected near large inclusions of wallrock differ from the rest of the granite in that they contain a higher percentage of biotite and calcite, and little or no riebeckite and aegirine. The amphibole in these samples may be hornblende or arfvedsonite. These more calcic samples are spatially very close to the wallrock inclusions, and it seems likely that assimilation of the wallrock is responsible for the differences in composition. Some plagioclase grains appear to be zoned. The extinction band sweeps across the grain in a linear fashion as the thin section is rotated on the microscope stage. The band is usually parallel to a cleavage plane. There are three types of twinning observed in the plagioclase. Polysynthetic albite twinning is seen in 10-20 percent of the grains. A combination of albite and pericline twinning that simulates the cross-hatch pattern common to microcline is seen in 20-30 percent of the grains (plate 2), and 5-10 percent of the grains have closely spaced twin lamellae that interfinger and pinch out near the grain boundaries (plate 3).

Quartz grains in the granite are anhedral and relatively equigranular, except in the vicinity of small veins, where they tend to form an aggregate of very small grains. The tendency for large areas of quartz to appear as small aggregated grains may be explained by the recrystallization behavior of quartz (Spry, 1969). Certain minerals, notably feldspar, quartz, and calcite, show little tendency to form elongate crystals; instead, they break down and form several small equant grains. Regional metamorphism associated with the Alleghenian orogeny may have caused some limited recrystallization along quartz veins, in addition to some mechanical deformation along pre-

existing joints in the quarry. Quartz viewed in thin section exhibits undulatory extinction, and many grains seem to be divided into "sub-grains", or elliptical sections that go extinct across the grain in succession (plate 4). These sub-grains are often aligned with the direction of flow foliation in the thin section, and are more prevalent in quartz grains that are elongated. This alignment may be due to flow movement during the late stages of crystallization, imposing stresses that would result in deformation of crystal grains. The alignment of elliptical grains with the flow foliation would appear to be the result of mechanical orientation during flow, in view of the inclination of quartz not to form elongate grains in response to recrystallization (Spry, 1969).

Potassium feldspar grains are generally large (1.5-4 mm), subhedral, and untwinned. Twinned grains display the typical cross-hatched pattern of microcline. Most K-spar grains have patches or strings of albite (plate 3) that have exsolved during cooling of the granite.

The major mafic minerals are riebeckite and aegirine, and to a lesser extent, sphene and titanomagnetite. The riebeckite is well-crystallized, often subhedral, but aegirine crystals usually appear somewhat corroded and are less abundant (plate 5). The mafic minerals are concentrated in small subparallel patches, which have been flattened and stretched during magma flow. These patches are separated by relatively large expanses of intermixed quartz and feldspar (plate 6). In a section cut perpendicular to the flow foliation, it is not unusual to see "tails" of small opaque grains and epidote stringing out from either end of a patch of aegirine and riebeckite. Also, some of the pyroxene and amphibole grains have very small aggregates of opaque minerals following cleavage planes. These aggregates are enclosed

poikilitically within the grains. It is unclear whether these opaques are the result of concentration during magma flow or chemical replacement. Some of the riebeckite seen in thin section occurs as very small, acicular, euhedral crystals or as fibrous, whisker-like aggregates emanating from small fractures in the rock (plate 7). These are both probably the result of late-stage hydrothermal activity within the pluton.

Sphene has crystallized as anhedral, clear grains roughly 0.05-0.3 mm in diameter, or euhedral to subhedral, light brownish crystals up to 0.5 mm in length. Sphene is intimately associated with the amphibole/pyroxene clusters, and only a few grains are seen elsewhere. The major opaque mineral is low-titanium magnetite. It occurs as rounded to nearly euhedral grains up to 0.5 mm across. As mentioned above, it often is seen stringing out from mafic clusters, and in fine-grained aggregates within amphibole and pyroxene grains.

Calcite and epidote are minor minerals found in nearly all granite samples, and both are probably of secondary origin.

Fluorite was observed in hand samples of granite and pegmatite (quartz and riebeckite veins). Large crystals of ilmenite, as well as small amounts of molybdenite and sphalerite, were seen in the pegmatite. These minerals are not unusual; peralkaline magmas characteristically have high concentrations of niobium, tantalum, molybdenum, zinc, zirconium, yttrium, cadmium, and fluorine (Bowden, 1974; Carmichael and others, 1974).

Granite that is close to a wallrock inclusion, or has a high content of xenoliths, is slightly different from the average granite described above. Usually there is a reduced amount of sodic amphibole and pyroxene in these samples; the amphibole is either hornblende or arfvedsonite. Addition of



potassium to the granite is manifested in the appearance of fibrous, matted aggregates of biotite that occur in and around the mafic clusters (plate 8). These granite samples may also be higher in calcium. Plagioclase extinction angles were not conclusive, since the calculated composition could be either  $An_{25-30}$  or  $An_{0-5}$ . The samples also contain larger calcite grains throughout. In view of the altered chemistry of the rock and the unique location of these samples, it seems likely that assimilation of wall-rock is the cause of the deviation from average granite. It follows, then, that small-scale alteration should be seen in the immediate vicinity of any xenoliths, assuming that they were originally pieces of wallrock. The degree of chemical interchange was extensive enough so that major mineralogic differences between the original xenolith and granite minerals were eliminated as the xenoliths were digested.

### 3. Modal Composition

Point counts of several thin sections give the following modal composition for the granite:

Table 1: Modal Composition of Fountain Quarry Granite (percents)

| <u>Albite</u> | <u>K-spar</u> | <u>Quartz</u> | <u>Riebeckite</u> | <u>Aegirine</u> | <u>Sphene</u> | <u>Opakes</u> | <u>Epidote</u> | <u>Calcite</u> |
|---------------|---------------|---------------|-------------------|-----------------|---------------|---------------|----------------|----------------|
| 42.8          | 27.5          | 19.3          | 5.5               | 3.6             | 1.6           | 2.7           | 1.0            | 0.3            |

-(based on 28 thin sections, 3300 total counts)

The Fountain Quarry Granite shows rough equivalence to several other peralkaline plutonic rocks (Bowden, 1974; table 1A below).

Table 1A: Modal Analyses of Peralkaline Plutonic Rocks (Bowden, 1974)

| <u>Analysis</u> | <u>Alk. Feldspar</u> | <u>Quartz</u> | <u>Riebeckite</u> | <u>Aegirine</u> | <u>Zircon</u> <sup>*</sup> |
|-----------------|----------------------|---------------|-------------------|-----------------|----------------------------|
| 1. Siwala       | 57.0                 | 32.9          | -----8.70-----    |                 | 2.41                       |
| 2. Oslo         | 62.5                 | 31.8          | 0.5               | 3.0             | 2.0                        |
| 3. Corsica      | 50.0                 | 40.0          | 1.0               | 9.0             | trace                      |
| 4. Rockall      | 37.0                 | 25.0          | 25.0              | 9.0             | 4.0                        |
| 5. White Mtn.   | 54.0                 | 39.4          | trace             | 5.5             | 1.1                        |

\* includes astrophyllite, opaques, etc.

To determine the degree of peralkalinity of the Fountain Quarry Granite, normative calculations were done using the analyses in Table 2. The norm, shown below, indicates the presence of acmite, making the granite weakly peralkaline.

Table 1B: Normative Calculation of Fountain Quarry Granite (sample 10-25-5)

|    |       |    |      |
|----|-------|----|------|
| q  | 31.44 | di | 1.16 |
| or | 26.69 | mt | 1.02 |
| ab | 28.30 | il | 0.46 |
| ac | 9.24  | f  | 0.07 |

Where the granite has assimilated some wallrock, there is a slight change in rock chemistry. This is reflected in slight differences from the modal percentages seen in the average granite. Addition of wallrock has caused a reduction in the amount of aegirine and riebeckite (to 1-2 percent total), an increase in the amount of hornblende (or arfvedsonite) (to 5-7 percent), and the appearance of biotite (about 2-3 percent).

#### 4. Texture

The texture of the granite is relatively uniform in all sections of the quarry; however, there may be some slight changes in grain size from one place to another that are made noticeable by the flow structure. The rock may appear to have a larger number of heavy mafic streaks, or fewer, finer streaks, depending on the local concentration of mafic minerals and the degree of grain orientation that took place during flow.

Thin sections were examined under oblique illumination in order to study the textures (plate 9). The elongate aggregates of mafic minerals are in subparallel alignment between comparatively wide zones of quartz and feldspar. The feldspars are arrayed in small groups of a few crystals. Between these groups are long strips or irregular patches of quartz grains. The overall appearance is one of a silica-rich interstitial fluid that has solidified within a feldspar crystal mush. Under crossed nicols, the flow structure is displayed by the mafic streaks and the roughly parallel sub-grains that constitute a majority of the quartz grains. At a few locations around the quarry, hand specimens show red splotches of quartz and feldspar that have been stained by hematite.

Typically, peralkaline intrusive rocks are coarse-grained (Bowden, 1974; Hyndman, 1972; Smith, 1976), in contrast to the fine- to medium-grain size seen at Fountain. The coarse texture is thought to be the result of high volatile pressure, which is also accompanied by the development of pegmatites (Ayrton, 1974). Pegmatites bearing large crystals have not developed at Fountain, but the quartz-riebeckite veins in the quarry might be thought of as small pegmatites. It is possible that the volatile phases were under low pressure during crystallization, or else were lost as the pluton cooled. This appears to be borne out by the presence of a large amount of

aplite along a longitudinal joint at the north end of the quarry (figure 4). In a high pressure system, one would expect the volume of pegmatites developed to exceed the volume of aplite, since the conditions for large crystal formation are maintained for a longer period. The opposite is observed at Fountain, indicating a relatively low-pressure late-stage environment. The fine-grained texture of the Fountain Quarry Granite may also be a reflection of the depth of emplacement. Accurate determination of the emplacement depth is not yet possible. Erosion has removed an unknown amount of granite and country rock, so that one must rely on textural comparisons with other plutons that have known intrusive levels. The granite at Fountain has a prominent vertical planar flow structure that is present even in the interior of the pluton. This is characteristic of a magma that has solidified near the epizonal/ mesozonal border, somewhere between depths of 5 and 10 km (Billings, 1972; Buddington, 1959). However, depths of crystallization that are shallower than this (1-3 km) were hypothesized for a number of African stocks similar in composition to the Fountain Quarry Granite (Balk, 1937).

## 5. Age

Prior to obtaining a preliminary age date for the granite, there was the possibility that the granite could have pre-dated a major regional metamorphic episode, and therefore could have undergone some degree of deformation and alteration. With this in mind, several thin sections were checked for evidence of metamorphism. No unambiguous evidence was found. At the very least, some recrystallization and reorientation of micaceous or fibrous minerals would be expected, even at minimal temperatures and

pressures. However, the only minerals that appear to have a metamorphic origin are those at the contact between the granite and wallrock inclusions.

The Rb-Sr age date for the granite is, at this point, very uncertain (Spruill, pers. comm., 1979) due to the almost uniform concentrations of rubidium and strontium in the samples selected for analysis. The preliminary age date is older than the estimated peak of Alleghenian metamorphism from 290-260 m.y. ago (Fullagar, 1971). Subsequent work (Fullagar and Butler, 1979) seems to indicate that Alleghenian activity east of the Blue Ridge was largely mechanical, and very high temperatures never developed. Thus, if the country rock surrounding Fountain was relatively incompetent, acting as a shock absorber, and any remaining stress on the granite was relieved by movement along pre-existing joints, the granite could have passed almost unchanged through an episode of regional metamorphism.

## 6. X-ray Fluorescence Data

Ten granite samples were analyzed for major elements by X-ray fluorescence (table 2).  $\text{Na}_2\text{O}$  and  $\text{MgO}$  were determined for selected samples by atomic absorption. The amphibole schist wallrock (sample 11-11-2) was run against the granite standards (table 6) and this analysis is only expected to be semi-quantitative.

A complete description of X-ray fluorescence analysis would be beyond the scope of this paper. The reader is referred to complete, exhaustive details given in Allman and Lawrence (1972), Hutchison (1974), Wainerdi and Uken (1971), and Energlyn and Brealy (1971). The analytical methods used in this report are given in Appendix 1.

Analyses of the granite samples are summarized in Table 2. Also, one sample was given a complete analysis by atomic absorption as a check on the

accuracy of the fluorescence determinations. The results are presented in Table 2A.

Table 2: Analyses of Fountain Quarry Granite (percents)

| <u>Sample</u>        | <u>SiO<sub>2</sub></u> | <u>Al<sub>2</sub>O<sub>3</sub></u> | <u>K<sub>2</sub>O</u> | <u>TiO<sub>2</sub></u> | <u>CaO</u> | <u>Fe<sub>2</sub>O<sub>3</sub></u> | <u>Na<sub>2</sub>O</u> | <u>MgO</u> | <u>MnO</u> | <u>F</u> |
|----------------------|------------------------|------------------------------------|-----------------------|------------------------|------------|------------------------------------|------------------------|------------|------------|----------|
| 6-1-2                | 74.40                  | 10.95                              | 4.63                  | 0.19                   | 0.35       | 4.13                               | ND                     | ND         | ND         | ND       |
| 6-1-15               | 74.47                  | 11.57                              | 4.66                  | 0.20                   | 0.47       | 3.75                               | 3.7                    | 0.22       | ND         | 0.036    |
| 6-6-4                | 73.38                  | 11.10                              | 5.21                  | 0.21                   | 0.40       | 4.59                               | ND                     | ND         | ND         | ND       |
| 10-7-6b              | 72.50                  | 11.90                              | 4.68                  | 0.21                   | 0.29       | 3.98                               | ND                     | ND         | ND         | ND       |
| 10-25-3              | 73.35                  | 11.14                              | 4.48                  | 0.21                   | 0.54       | 5.06                               | ND                     | ND         | ND         | ND       |
| 10-25-5              | 73.00                  | 10.39                              | 4.64                  | 0.21                   | 0.27       | 4.70                               | 4.6                    | 0.058      | 0.11       | 0.044    |
| 11-10-3              | 73.85                  | 11.04                              | 4.59                  | 0.20                   | 0.89       | 3.70                               | 4.3                    | 0.16       | 0.12       | 0.034    |
| 11-10-5              | 74.51                  | 10.54                              | 4.29                  | 0.21                   | 0.78       | 4.49                               | 4.8                    | 0.098      | ND         | 0.034    |
| 11-11-1              | 74.27                  | 11.10                              | 4.63                  | 0.193                  | 0.52       | 3.70                               | ND                     | ND         | ND         | ND       |
| 11-11-2 <sup>*</sup> | 58.54                  | 9.73                               | 4.45                  | 2.83                   | 2.87       | 18.76                              | ND                     | ND         | ND         | ND       |
| 11-11-8              | 69.33                  | 12.17                              | 5.61                  | 0.22                   | 0.29       | 5.33                               | ND                     | ND         | ND         | ND       |

\* amphibole schist      ND = not determined

Table 2A: Comparison of X-ray and Commercial Analyses of Sample 10-25-5

|             | <u>SiO<sub>2</sub></u> | <u>Al<sub>2</sub>O<sub>3</sub></u> | <u>K<sub>2</sub>O</u> | <u>TiO<sub>2</sub></u> | <u>CaO</u> | <u>Fe<sub>2</sub>O<sub>3</sub></u> |
|-------------|------------------------|------------------------------------|-----------------------|------------------------|------------|------------------------------------|
| X-ray:      | 73.00                  | 10.39                              | 4.64                  | 0.21                   | 0.27       | 4.70                               |
| Commercial: | 74.9                   | 10.6                               | 3.9                   | 0.21                   | 0.26       | 4.28                               |

During the analysis of the granite samples, a standard (GSP-1) was run at the beginning and end of each batch of three samples. The calculated values for GSP-1 are all within 9 percent of the published analysis, except for

TiO<sub>2</sub>, which is low, and Fe<sub>2</sub>O<sub>3</sub>, which is high.

The analyses (table 1) indicate that all the granite samples, from widely separated sections of the quarry, are chemically very similar. There appears to be little, if any, concentration of elements in one particular area or sample. Thus, chemical effects due to assimilation of wallrock have been mostly homogenized and only the slight mineralogical differences near wallrock inclusions remain.

Comparison of the chemistry of the Fountain Quarry Granite with other peralkaline rocks indicates that the granite is weakly peralkaline (Bailey and MacDonald, 1970). Because of its phaneritic texture, the rock should be correctly classified as a peralkaline granite.

## 7. Aplite

A large vein of aplite was observed in the north end of the quarry (figure 4) emplaced along longitudinal joints. The aplite is very fine-grained and has different fracturing characteristics than the granite. Closely spaced fractures give the aplite a "crackly" appearance. The aplite contains less mafic minerals and more quartz than the granite, probably a reflection of its origin from late-stage magmatic fluids. Also, some epidote was identified in hand sample. Point counts of thin sections give the following modal composition for the aplite (compare table 1).

Table 3: Modal Composition of Aplite in Fountain Quarry Granite (percents)

| <u>Albite</u> | <u>K-spar</u> | <u>Quartz</u> | <u>Sphene</u> | <u>Opagues</u> | <u>Epidote</u> | <u>Calcite</u> |
|---------------|---------------|---------------|---------------|----------------|----------------|----------------|
| 38            | 30            | 28            | trace         | 1              | trace          | 1              |

-(based on 3 samples, 235 total counts)

## 8. Mixed Granite

At places along the contact between the granite and wallrock inclusions, the wallrock was partially melted and became mixed with the granite. Field evidence of this is seen in the multiple, thick, continuous schlieren that lie just outside the granite-wallrock contact. The contact zone itself ranges from less than 2.5 cm to over 15 cm in thickness. The zone typically consists of a matrix of 40 to 50 percent quartz and plagioclase, studded with garnet, sphene, epidote and minor amounts of biotite, opaques and calcite, plus a very few corroded aegirine grains (plate 11). Occasionally the contact zone seems to be segregated into a garnet-calcite-epidote assemblage and an albite-quartz-riebeckite assemblage that show distinct signs of being swirled and molded by magma flow. The structures do not lend themselves to interpretation as late hydrothermal deposits; the deformed, convoluted layers must have originally existed as mushy, semi-solid material. The calcite-garnet-epidote assemblage may be the result of interaction between migrating calcium, aluminum, and other metal ions from partially melted wallrock and silicate or carbonate fluids in the magma.

The thickness of the contact zone roughly corresponds to the size of the wallrock inclusion it envelopes; thinner inclusions are bounded by narrow contact zones with more completely developed schlieren. Perhaps the smaller inclusions had a lower potential for heat absorption from the granite magma, which resulted in increased partial melting.

## 9. Wallrock Outcrops

The long, tabular outcrops of wallrock (figure 4) are composed of dark greenish-black, fine-grained amphibole schist (plates 12 and 13). Hand sam-



ples of this rock do not usually have a noticeable foliation, except in thinner sections, where the foliation layers become very thin and distinct. Occasionally the amphibole schist contains small ( $0.5-1.5 \text{ mm}^3$ ) cubes of pyrite, especially near the contacts with granite. Along the contact zone, several larger  $5-10 \text{ mm}^3$  cubes have been observed in hand specimens.

Thin section analysis of the amphibole schist gives the following approximate modal composition:

Table 4: Modal Composition of Wallrock Outcrops (percents)

| <u>Plagioclase</u> | <u>K-spar</u> <sup>*</sup> | <u>Quartz</u> <sup>*</sup>              | <u>Riebeckite</u> | <u>Hornblende</u> <sup>+</sup> | <u>Sphene</u> | <u>Calcite</u> |
|--------------------|----------------------------|-----------------------------------------|-------------------|--------------------------------|---------------|----------------|
| 16                 | 6.5                        | 6.5                                     | 20                | 40                             | 6             | trace          |
| <u>Epidote</u>     | <u>Pyrite + Opaques</u>    |                                         |                   |                                |               |                |
| 6                  | trace                      | -(based on 3 samples, 300 total counts) |                   |                                |               |                |

\* initially calculated as 13 percent quartz due to similarity in thin section

<sup>+</sup> may include some arfvedsonite

The composition is rather variable since some samples are nearly devoid of quartz and contain up to 20-25 percent biotite. Plagioclase composition appears to be more calcic than in the granite, but extinction angle measurements are inconclusive (the calculated composition could be near  $\text{An}_{30}$  or  $\text{An}_0$ ). Occasionally the amphibole schist will contain a small amount of badly corroded aegirine. Most of the mineral grains in the schist are anhedral, except for a few subhedral epidotes.

The wallrock inclusions remained relatively undisturbed by mechanical deformation during intrusion of the granite. It is possible that small amounts of strain were annealed by heat from the magma. This suggests that the in-

clusions' long dimension was parallel to the direction of magma flow, so that no large horizontal stresses were ever developed.

#### 10. Basalt

The dike that has intruded the granite (figure 4) is a 0.6-1.5 m-wide basalt carrying small (1-2 mm), scattered phenocrysts of olivine. In hand sample it is a dense, gray-black rock that commonly breaks into blocks due to a fairly well-developed columnar jointing. Thin sections (plate 14) show a typical ophitic texture produced by small non-oriented laths of calcic plagioclase ( $An_{55-60}$ ) in a matrix made up of an extremely fine-grained, dark brown pyroxene and possibly some bowlingite. In this respect, the basalt is not very different from the thousands of diabase dikes that were injected along the east coast during late Triassic-Jurassic time. Several larger plagioclase laths have transverse fractures filled with chlorite. These fractures appear to have resulted from differential cooling of the crystals; the fractures occurred as the crystal shrank faster in one direction than another. The olivine phenocrysts, which made up about 10 to 15 percent of the rock, are now bowlingite, an alteration product. They have a crack pattern similar to that seen in olivine phenocrysts. It is clear that the bowlingite is a pseudomorph of olivine.

At two exposures in the quarry, the dike exhibits a 1-3 cm-wide chilled margin. This material originally was basaltic glass, but has since decomposed into saponite. The chilled margin is evidence that the granite must have been fairly cool at the time the dike was injected. Thus the dike is probably late Triassic or Jurassic.

## 11. Magma Genesis and Original Composition

The consistent association of peralkaline magmas with crustal rift zones (Rankin, 1972; Sykes, 1978) suggests a relationship with the upwardly mobile mantle-derived materials common along such zones. Supporting evidence for a strong connection between peralkaline rocks and alkali olivine basalts (Bowden, 1970; Bailey and Schairer, 1966) is seen in the low initial  $\text{Sr}^{87}/\text{Sr}^{86}$  ratios of both types of rock (Weaver, Scoal and Gibson, 1972). There are also inclusions of peralkaline granite in many of the alkalic rhyolite/phonolite lavas (Azores, Ascension Island, Bouvet, St. Helena, Tristan da Cunha, Gough Island) along the southern Mid-Atlantic ridge (Bailey and Schairer, 1966).

There seems to be no reason to count the Fountain Quarry Granite as an exception. However, it has been intruded through a section of continental crust and as Bailey and Schairer note, peralkaline magmas are extremely susceptible to sialic contamination by assimilation of argillaceous rocks. Two possible mechanisms have been suggested that allow a peralkaline magma to rise through the crust without becoming so contaminated that it no longer retains its peralkaline chemistry. These are ascension through a conduit lined with comagmatic material, or generation of the magma from partially melted rocks of the lower crust (Bowden, 1974). The preliminary initial  $\text{Sr}^{87}/\text{Sr}^{86}$  ratio reported for Fountain (R. Spruill, pers. comm., 1979) is relatively high (about 0.730). This suggests that the Fountain granite magma may have been derived from remelted, very old sialic rocks or alkali-rich rocks.

Experimental petrologic work has brought forth many hypothetical methods for obtaining a peralkaline magma at depth (Hyndman, 1972; Carmichael and others, 1974). The two most plausible hypotheses involve partial

melting of an alkali olivine basalt in the deep crust or upper mantle, or partial melting of lower crustal rocks. In view of the isotopic data and rift-zone associations, most researchers favor the former method; of course, some emplacement mechanism must be proposed to avoid contamination by sialic crust. However, the isotopic data from Fountain suggest that it is a product of deep sialic anatexis.

The assemblage actinolite + albite + quartz has been used to experimentally approximate a silica-saturated peralkaline magma. It has been found that this assemblage will exist in equilibrium with a liquid fraction only if the system also contains sodium disilicate (Bailey and Schairer, 1966). In normative calculations of many peralkaline intrusives, sodium disilicate is notably low or absent, whereas it is more abundant in pantellerites and comendites (peralkaline volcanic rocks). It has been suggested that the slow cooling history of a peralkaline pluton allows the boiling-off and subsequent escape of many soluble and volatile components (of which sodium disilicate is one). This appears to be true for the Fountain intrusion, because there may have been sodium metasomatism of the surrounding country rock. There is evidence for this in the amphibole schist; plagioclase in the schist originally was more calcic, but has since been changed to a more sodic variety, perhaps with the accompanying formation of epidote.

Some peralkaline intrusives show evidence of late-stage metasomatic activity (Bowden, 1974). Indeed, some research indicates that crystallization of nearly pure albite, as in the Fountain Quarry Granite, is very unusual (Phillips, 1971), and that deuteric alteration is responsible for such sodic feldspar. The presence of riebeckite and albite coatings on many joint surfaces indicates that sodium-bearing fluids were held inside the

pluton long after low temperatures had been reached. This is contrary to what one might expect, in view of the early fracturing history of the pluton (discussed later).

However, thin section evidence of feldspar alteration is absent. It is more likely that during the slow cooling history of the pluton, extensive subsolidus reactions between the sodium and potassium feldspars were taking place, facilitated by the remaining low-pressure sodium-rich fluids and by shear stresses. The fluids may not be relied upon exclusively to explain the nearly complete segregation of potassium feldspar and albite, since the separation is so uniform and pervasive throughout the granite. Therefore, subsolidus reaction during cooling must have been a major factor in the generation of two nearly pure feldspars in the granite.

## STRUCTURE

### 1. General Shape: Outcrop and Core Data

The shape of the granite pluton was not delineated until 1963, when Martin Marietta Corp. embarked on a test drilling program to determine if economic amounts of the granite were accessible. The resulting isopach map (figure 2) showing depth from surface to the top of the granite, indicates a roughly elliptical body (1130 x 460 m, 3700 x 1500 ft at the -20 m, -65 ft contour) upon which are superimposed a number of ridges and troughs. The ridges and troughs are parallel to the major axis of the granite body, approximately north-south, and also are parallel to one of the major joint sets. Thus the troughs formed by preferential erosion along joints, leaving the ridges on either side.

Below the -30 m (-100 ft) contour, the sides of the pluton drop off rapidly down to about 122 m (400 ft) deep, where the bedrock is granite gneiss. The surface of the gneiss is comparatively flat (Bonini and Woolard, 1960). Unfortunately, the test drilling by Martin Marietta did not go deeper than 25m (80 ft) and there are few wells in Fountain that are deeper than about 90 m (295 ft) (Brown, 1959). However, the town's water supply wells are finished in the granite gneiss at depths slightly greater than 120 m (395 ft).

### 2. Flow Structure

The Fountain Quarry Granite has a well-developed flow foliation which is visible in hand specimen as dark parallel streaks of aegirine, riebeckite, and scattered pancake-shaped schlieren composed of riebeckite-enriched rock. This structure is pervasive; it occurs in all exposures in the quarry and there is only minor variation in attitude from one area to the next.

Viewed at an exposure that presents three orthogonal surfaces, the flow foliation and schlieren lie in a nearly vertical plane approximately parallel to one of the major joint sets. The strike of this plane is almost constant, for it diverges only a few degrees from an average direction of N11°E (figure 4). The dip is more variable, ranging from 70°E to 82°W. The dip can change rather markedly within a few centimeters, and the maximum variation occurs where the flow foliation wraps around the riebeckite-enriched schlieren. The schlieren are widespread throughout the granite and are seen as dark-colored, elongate bodies with their shortest dimension perpendicular to the local flow layers. The schlieren differ from the granite in mineral percentages; they are richer in riebeckite and sphene, and they are more fine-grained than the granite. The schlieren could be classified as mineral segregations, but a number of factors suggest that they were originally xenoliths. The schlieren appear to have retained a definite boundary even though they have been stretched and deformed, whereas a segregation might be expected to have more diffuse boundaries.

There has been a high degree of chemical interchange between the magma and the xenoliths, as evidenced by the similar mineralogy in smaller inclusions. Some larger xenoliths are surrounded by a small reaction rim, mostly albite, with quartz and garnet. The reaction rim indicates an initial disequilibrium between the magma and the xenoliths which would not be expected if they were some sort of magmatic segregation. Based on evidence from thin sections and hand samples, it seems likely that the xenoliths are remnants of amphibole schist wallrock that were incorporated into and metamorphosed by the granite magma.

### 3. Joint System

The granite body at Fountain has a well-developed joint system and since quarry operations have exposed near-vertical walls at different orientations, the joints are quite prominent and easily studied.

The extreme hardness of the granite has dictated the method used to remove rock from the quarry. Vertical holes, usually parallel to one of the major joint sets, are drilled and blasted, producing a mound of shattered rock (figure 5). This rock is then removed to be processed. Unfortunately, the drilling and blasting have introduced many short, irregular fractures at odd angles. These artificial joints must be recognized and omitted from the interpretation of the original joint pattern. The criteria for recognition of natural joints and or artificially induced fractures are listed in Table 5.

Table 5: Criteria for Distinction Between Natural Joints and Artificial Fractures

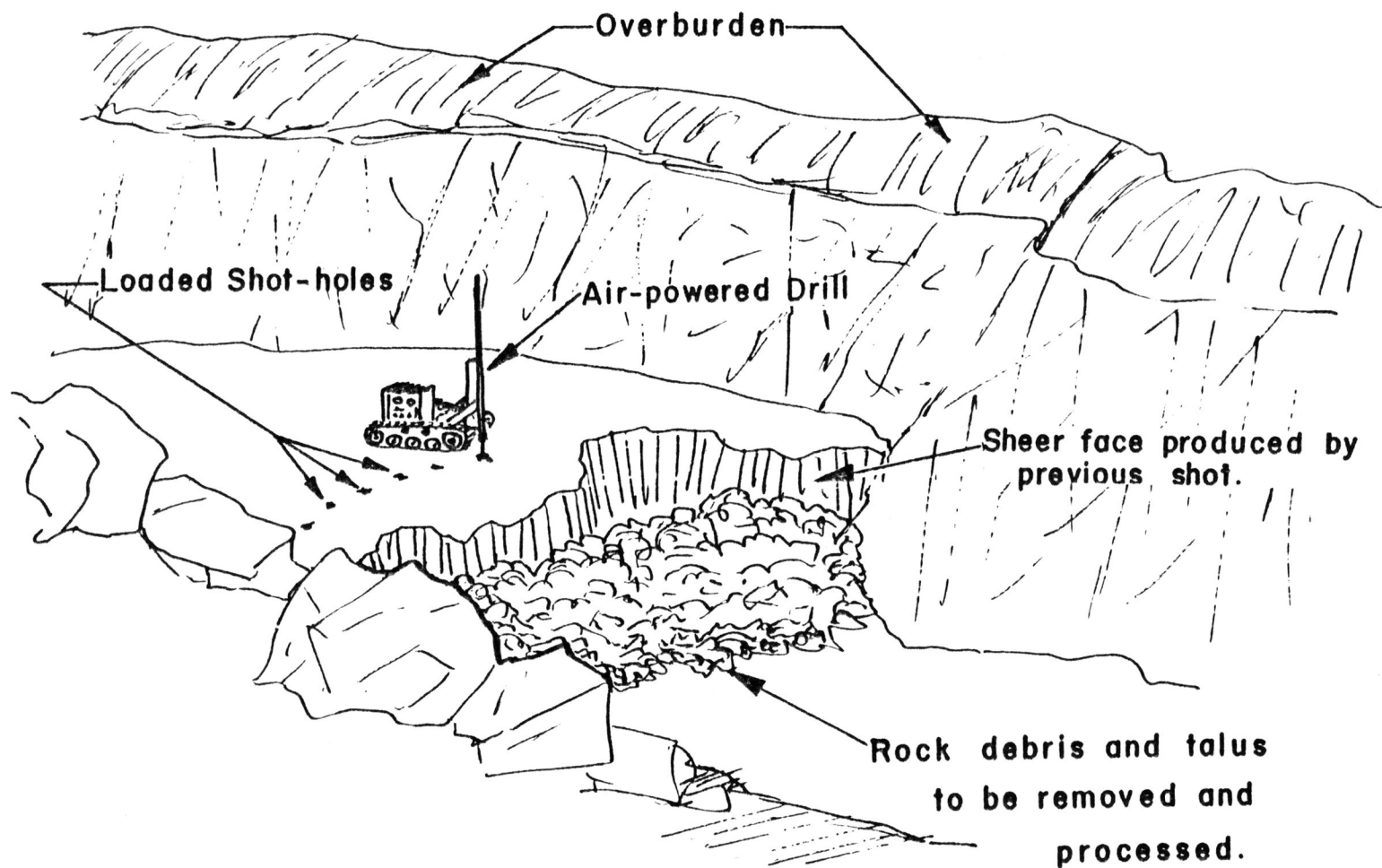
| <u>Joint type</u> | <u>Mineralization</u> <sup>*</sup> | <u>Trend</u>        | <u>Proximity</u> <sup>+</sup> |
|-------------------|------------------------------------|---------------------|-------------------------------|
| Original          | similar to granite                 | relatively straight | removed                       |
| Explosive-induced | none                               | very irregular      | usually within 3 m (10 ft)    |

\* the coating of minerals that may be found on the joint surface

<sup>+</sup> the distance between the joint and the shatter zone marking the detonation point of the explosive

A total of 358 joints, selected by the above criteria, were mapped and analyzed (figure 6). Two major joint sets are apparent. Both consist of long, very smooth joints, many with an extensive coating of epidote,





**FIGURE 5: Typical procedure for removal of rock at Fountain Quarry  
(view from central haul road looking southwest).**

riebeckite, or quartz in addition to various oxides, sulfides, and sulfates that have been deposited after being carried down in solution from the overburden.

The major trends are easily seen on pi-diagrams (figures 7 and 7A). The average strikes of the two major sets are N12°E and N89°E, and dips are mostly within 10 to 20 degrees of vertical. Also, there is a third, less well-defined joint set, with variable strikes and dips of 25 to 30 degrees. These shallow-dipping joints are also very long; some extend for 20 m (65 ft) or more, but the surfaces are not as smooth as the vertically-dipping joints. Along the quarry walls, the nearly horizontal joint traces can best be described as undulatory, rather than straight. Mineralization is rarely present along these fractures.

#### 4. Analysis

The set of joints striking N12°E is nearly parallel with the flow foliation in the granite, and detailed measurements (figure 6) indicate that the joints change direction slightly, following small changes in the direction of the foliation. This characteristic, plus the widespread occurrence of mineral veneers on the joint surfaces, the extremely smooth surface, and the steep dip, all fit the description by Balk (1937) of longitudinal joints. In many igneous bodies, the early age of these joints is indicated by the aplites, basic dikes, and quartz veins that follow them. There are several basalt dikes and quartz-riebeckite veins that follow the north-south-trending joints exclusively. Also, a large aplite vein, intruded along the trend of these joints, was observed at the north end of the quarry. Well-developed pegmatites are not seen at Fountain. However, some of the thick quartz-riebeckite veins contain small amounts of ilmenite, fluorite,

sphalerite, and molybdenite, and could be construed to be pegmatites. This is good evidence that the joints should be classified as longitudinal.

The origin of these joints is not well-known, according to Balk (1937). Several hypotheses have been suggested, including the effect of mineral parallelism, cooling and contraction of the granite, or further injection of magma from beneath the solidified portion of the intrusion.

The second major set of joints (figure 7) strikes approximately at right angles to the first set, and consequently these joints are perpendicular to the foliation. The joints are also very long, extremely smooth, and show mineral coatings similar to the longitudinal joints. However, only a few riebeckite-quartz veins wider than 3-5 mm (0.1-0.2 in) follow these joints, and basalt dikes are conspicuously absent. These characteristics closely fit the description (Balk, 1937) of cross joints, which are considered to be among the earliest fractures to form in a solidifying pluton. Even though the basalt has been intruded only along longitudinal joints, there is no reason to suppose that the cross joints formed after the time of basalt injection. Possibly the cross joints were under compression when the basalt was intruded, and the injection pressure of the basalt was insufficient to force the cross joints apart.

Cross joints have been interpreted as forming in semi-solid rock due to the continuing stresses imposed by magma upwelling and by confinement by country rock (Balk, 1937). The development of cross joints has the same mechanical effect that viscous flow had in earlier stages of intrusion. The semi-solid rock mass is lengthened in the direction of the least compressive stress. As the magma slowly congeals, its mechanical behavior changes from that of a viscous liquid to a brittle solid, and the stress release is accomplished by fracture.

FIGURE 7

Equal Area Projection of  
Poles to Joints

Combined Data from  
Entire Quarry

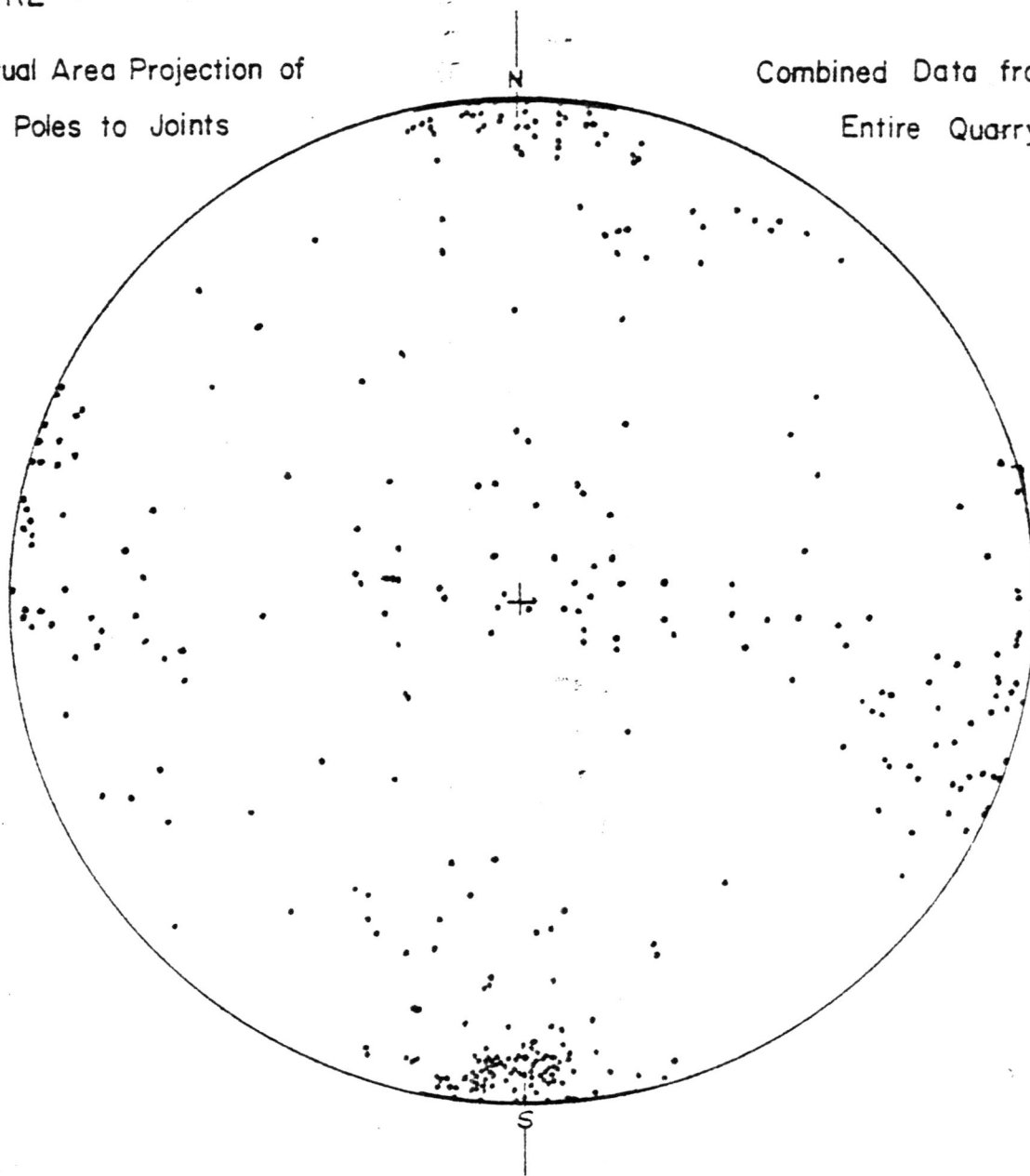
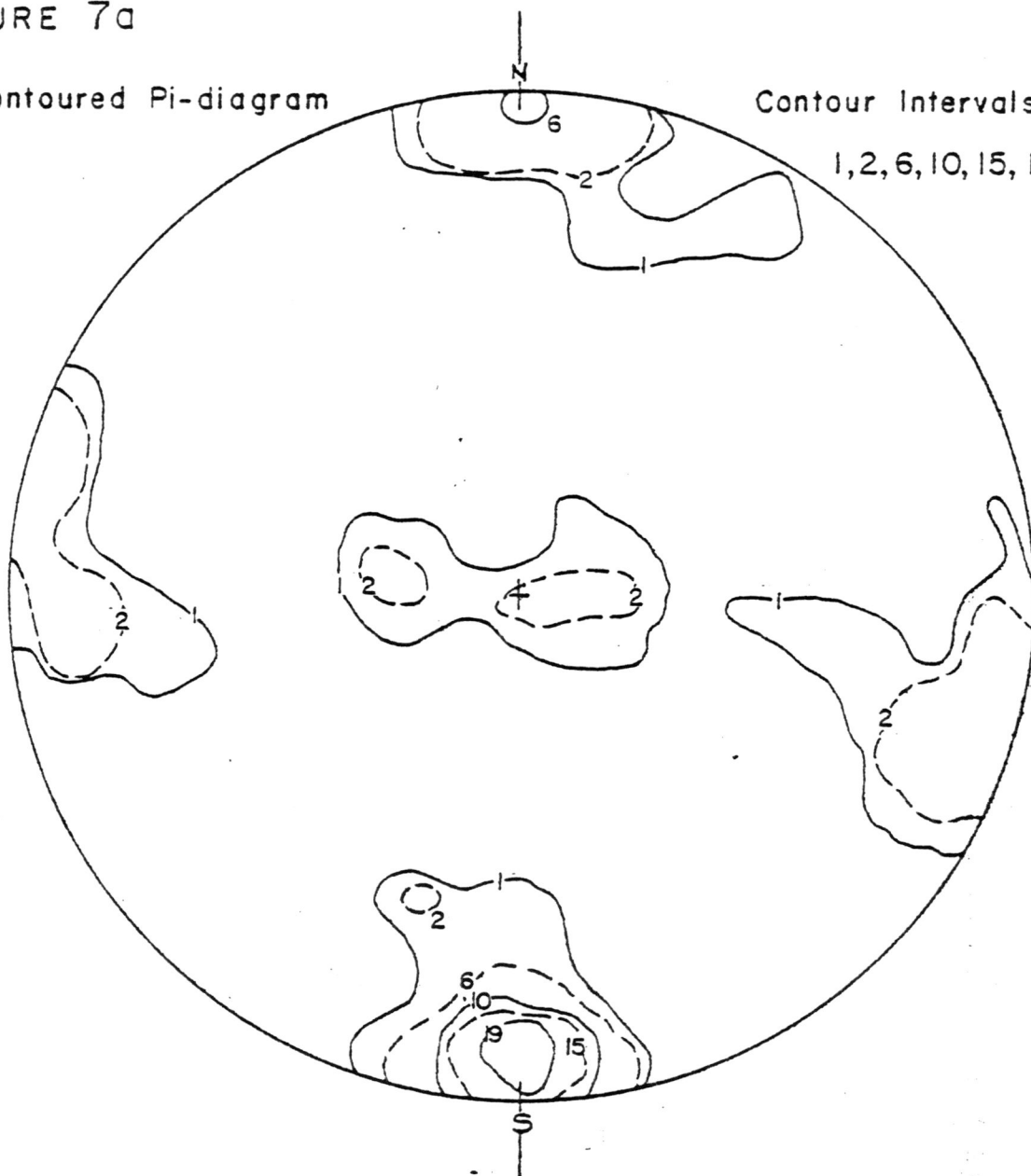


FIGURE 7a

Contoured Pi-diagram

Contour Intervals:

1, 2, 6, 10, 15, 19 %



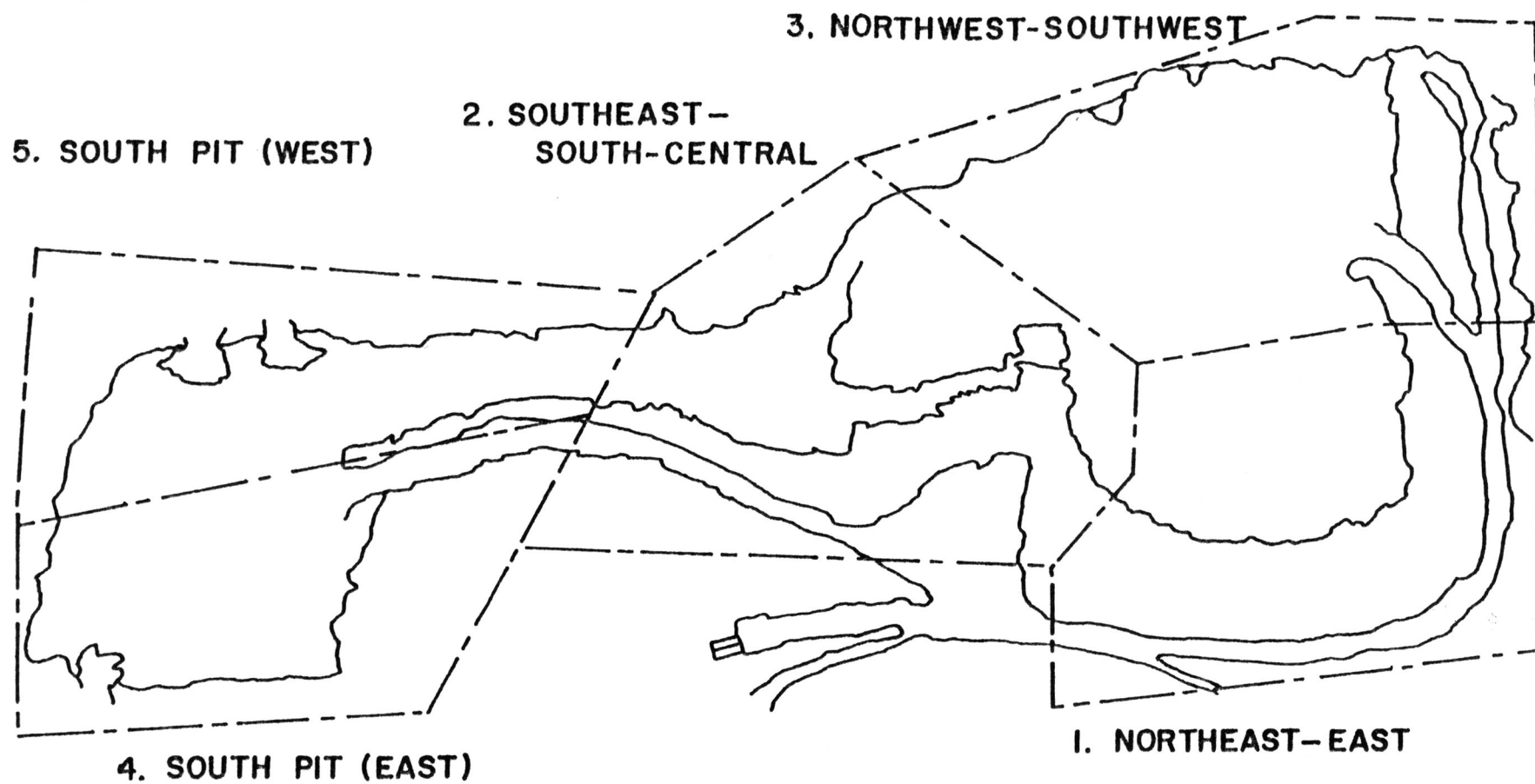
The set of flat-lying joints, seen as a concentration of poles around the center of the composite pi-diagram (figure 7A), is not as well-defined as the other two sets. Although some of these fractures are very extensive, they are less numerous than the cross and longitudinal joints. The poles plot about a horizontal line approximately parallel to the long north-south dimension of the granite body, and dips are at low angles to either side. The joint surfaces are generally undulatory or rarely even, and there is a general absence of mineral coatings. These factors suggest that this set of fractures formed later, perhaps due to the unloading of confining stresses by erosion of the overlying country rock. The orientation of these joints may have been modified and controlled to some extent by the shape of the pluton. Joints that form roughly parallel to the land surface in response to the release of hydrostatic stresses are common in granitic rocks (Billings, 1972). Such joints are sometimes called unloading or release fractures.

In summary, both major joint sets are considered to be primary structures, formed during or just after intrusion of the granite. The two sets are classed as cross joints and longitudinal joints. The flat-lying set of joints is considered to be secondary and post-dates the cooling of the granite. These joints are probably release fractures formed in response to unloading of confining pressure.

## 5. Local Differences in Joint Sets

The longitudinal and cross joints are easily visible in all sections of the quarry and their density and general orientation are fairly constant. However, the possibility exists that domains, or locally unique sets of joints,

**FIGURE 8 : SECTION LOCATION MAP FOR JOINT DATA**



**Note: Numbers refer to order of reference in text.**

are present. These domains may form due to different stress conditions or they may indicate small displacements and rotations of original joints at a later time.

The joint data were divided into groups according to their positions in the quarry (figure 8). Joints in the larger, northern part of the pit were divided into three groups: 1) those from the northeastern-most exposures, the east wall and one-half of the south wall; 2) those from the bench walls (south-center) and southwest wall; 3) and those from the northwestern-most wall and west wall of the pit. Joint measurements from the southeastern section of the southern pit and the central section along the haul road constitute a fourth group. The fifth group comprises joints in the southwestern section of the south pit.

Comparison of the five groups indicates some slight differences. It should be noted that the general direction of the pit walls has been partly controlled by fracture orientation. Thus, a wall or section that is parallel to one of the major joint sets will show comparatively fewer joints of that group because the wall does not intersect those particular joint planes as frequently. This accounts for the low number of measured longitudinal joints in the southeast--south-central section (figures 9 and 9A) where most of the quarry walls are parallel to this joint set. Cross joint orientation undergoes a slight shift, from nearly N88°W in the northeast (figures 10 and 10A) to N86°E in the southwest (figures 11 and 11A). Longitudinal joints are best represented in areas where the walls trend east-west. There is little change from the average orientation of N12°E between the northern and southern sections of the quarry. However, in the west (figures 12 and 12A) there is a reduction in dip such that the longitudinal joints approximate a weakly developed conjugate shear, with a principal stress axis



FIGURE 9

Equal Area Projection of  
Poles to Joints

Southeast/South Section  
(66 pts.)

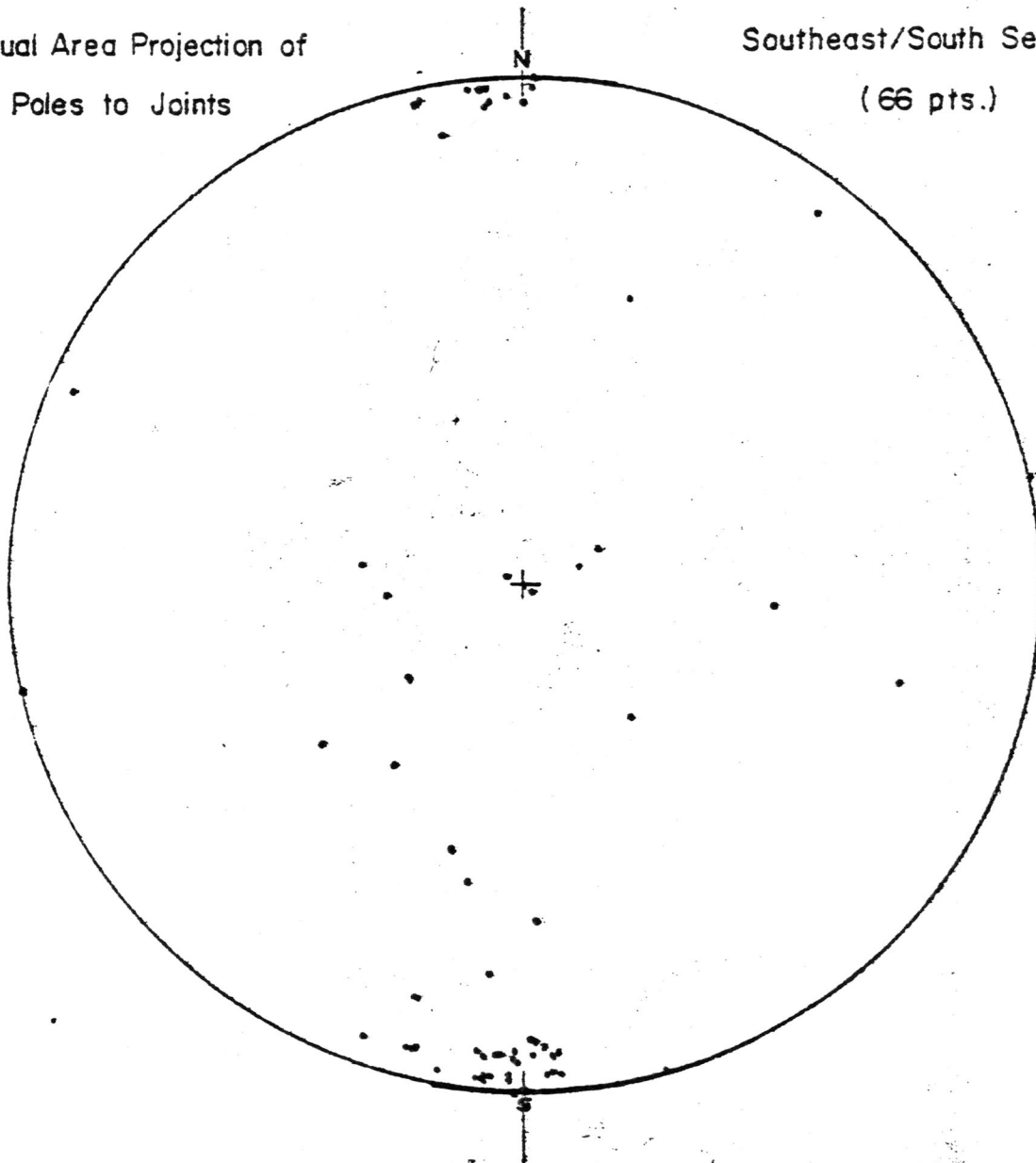


FIGURE 9a

Contoured Pi-diagram

Contour Intervals:

2, 6, 10, 15, 19, 25, 35 %

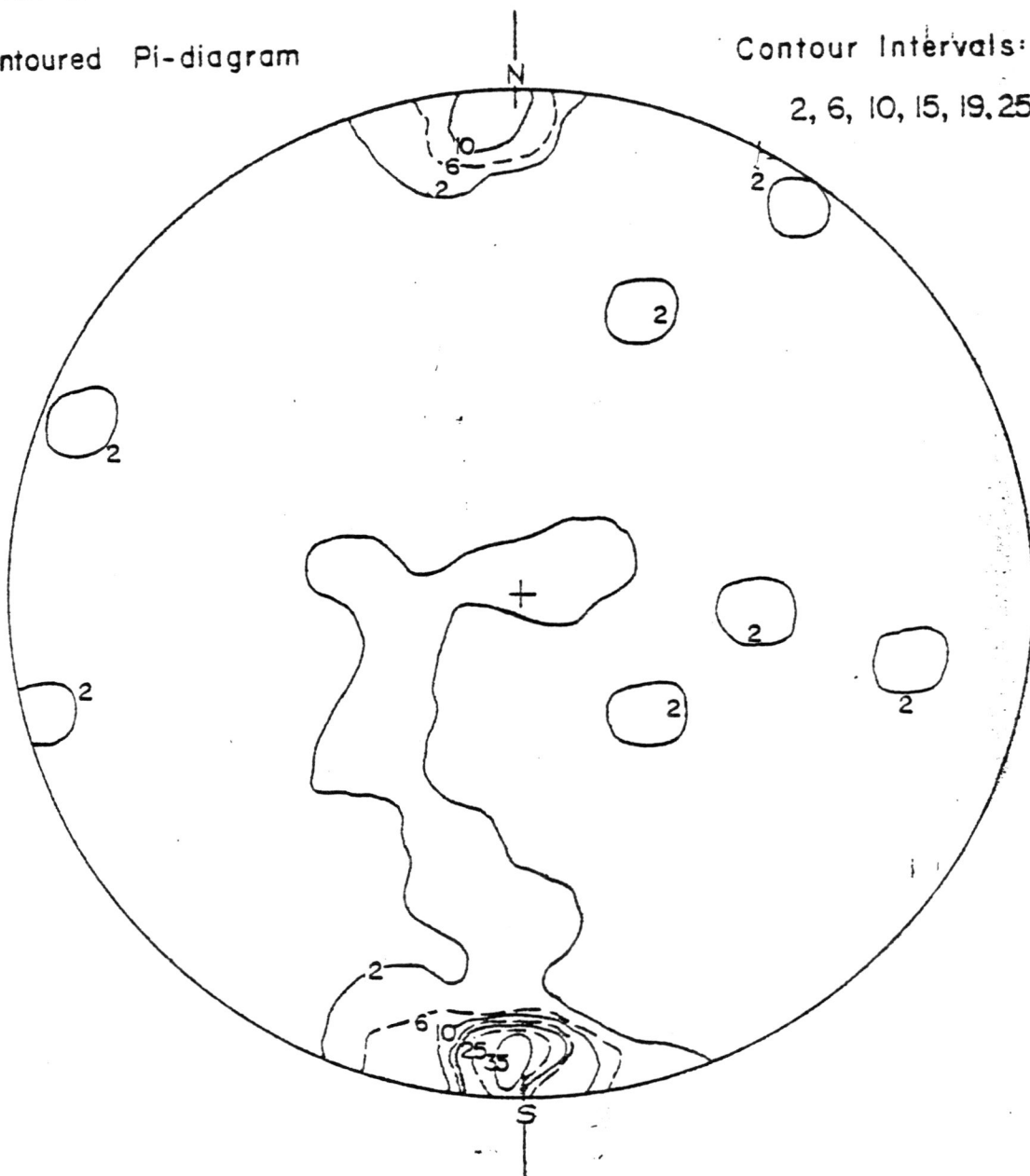


FIGURE 10

Equal Area Projection of  
Poles to Joints

Northeast/East Section  
(66 pts.)

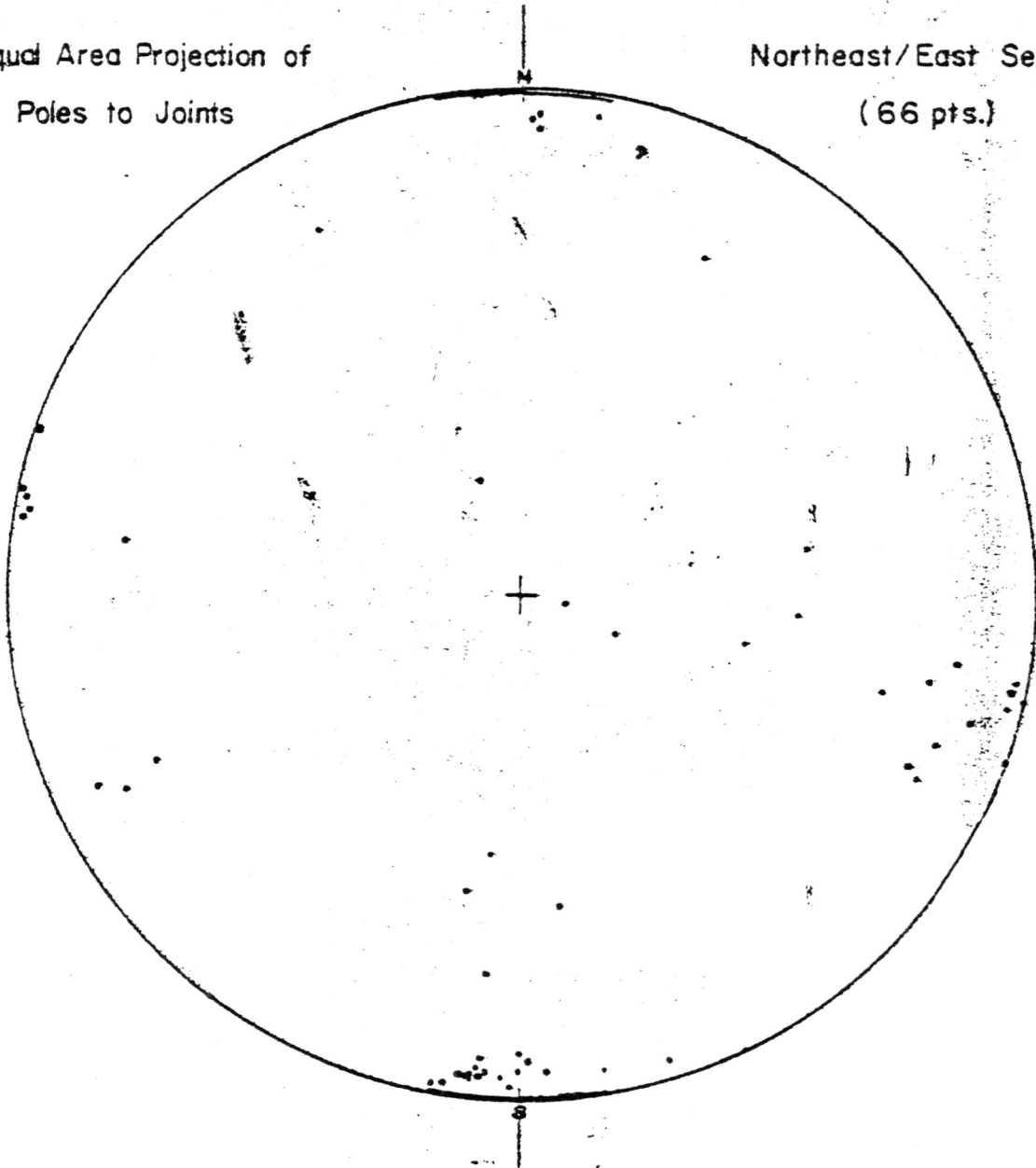


FIGURE 10a

Contoured Pi-diagram

Contour Intervals:

2, 6, 10, 15, 19 %

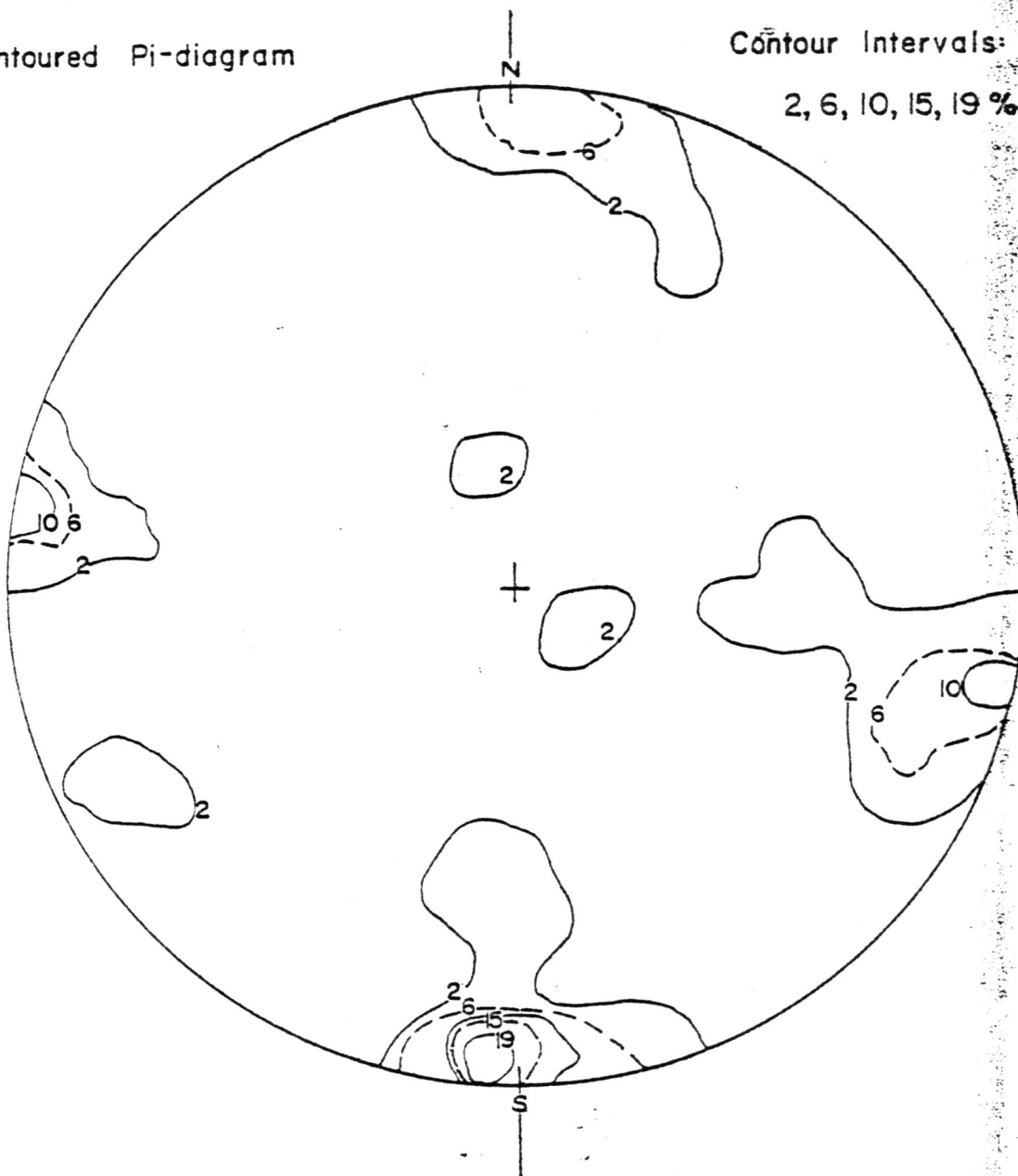


FIGURE 11

Equal Area Projection of  
Poles to Joints

South Pit-West Section  
(95 pts.)

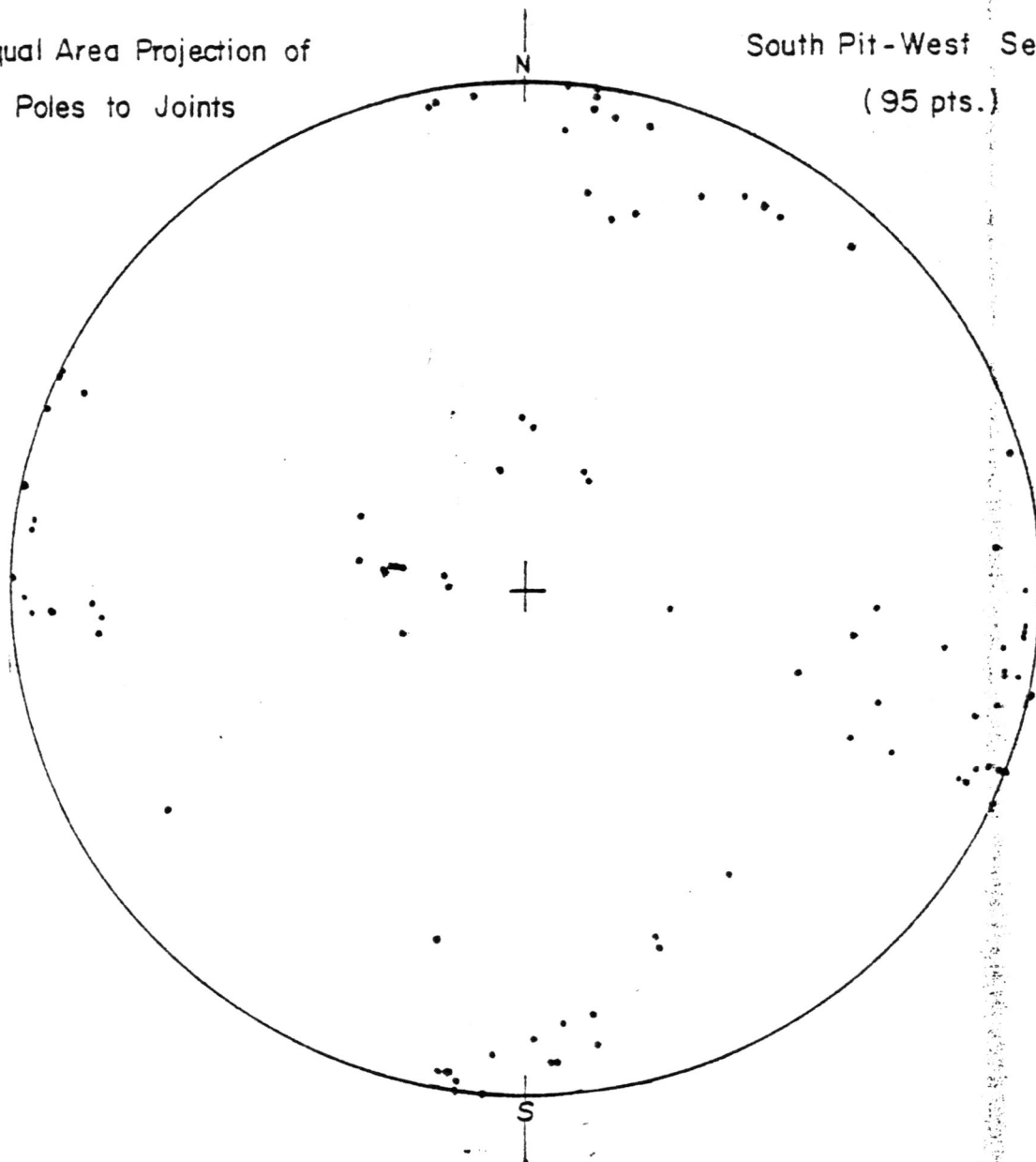


FIGURE 11 a

Contoured Pi-diagram

Contour Intervals:

2, 6, 10, 15, 19 %

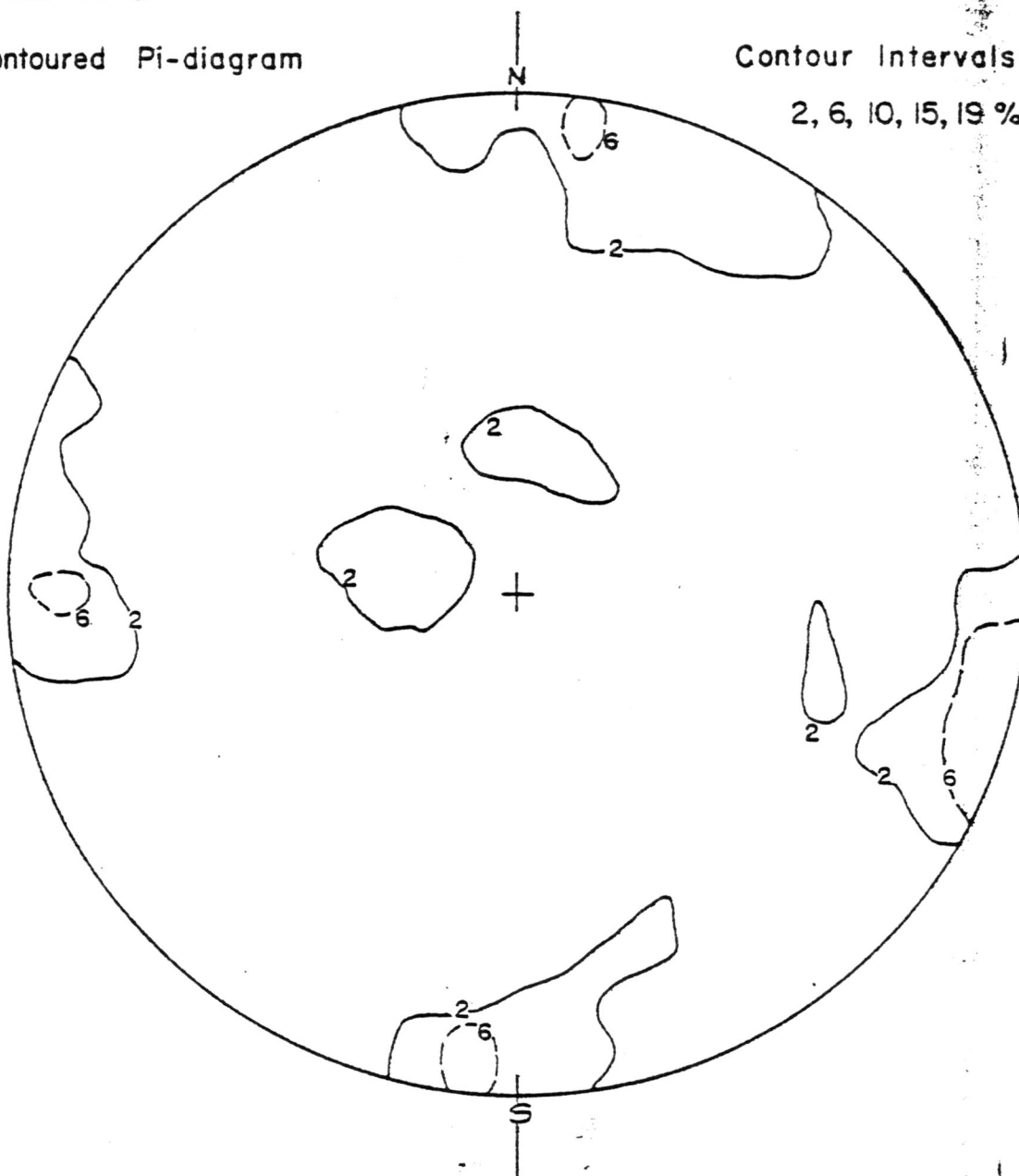


FIGURE 12

Equal Area Projection of  
Poles to Joints

Northwest/Southwest Section  
(65 pts.)

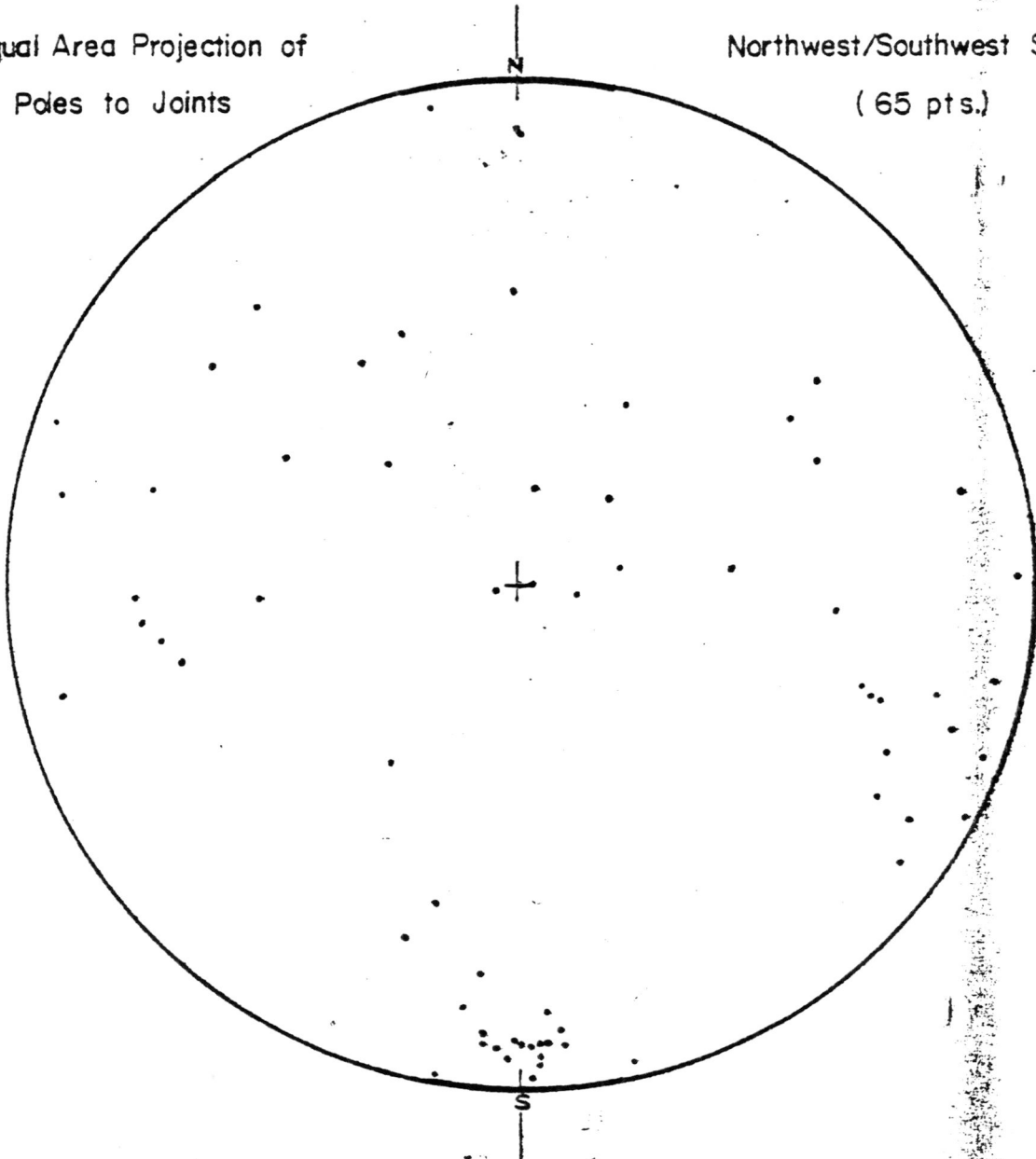


FIGURE 12a

Contoured Pi-diagram

Contour Intervals:  
2, 6, 10, 15, 19 %





FIGURE 13

Equal Area Projection of  
Poles to Joints

South Pit- East Section  
( 66 pts.)

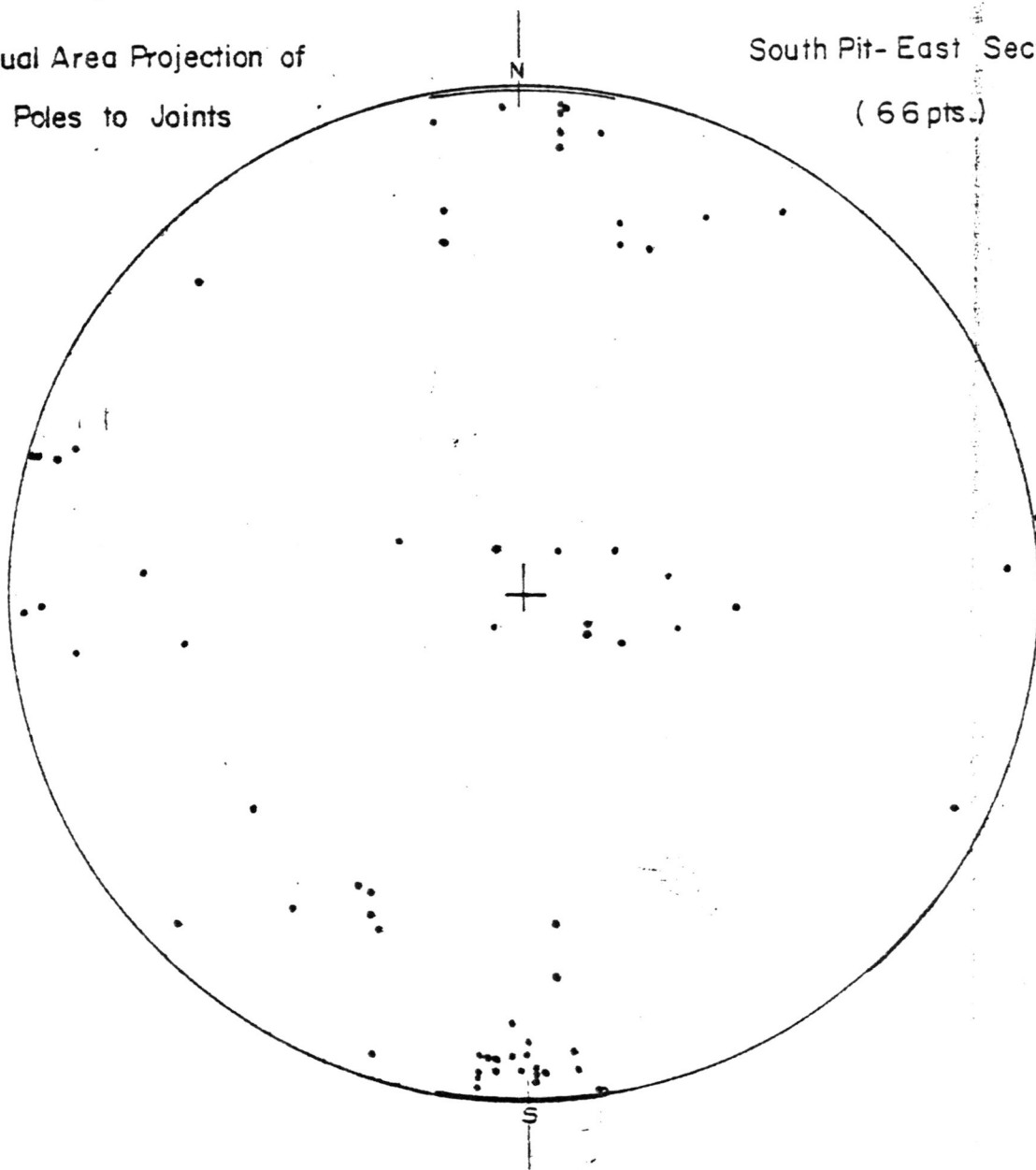
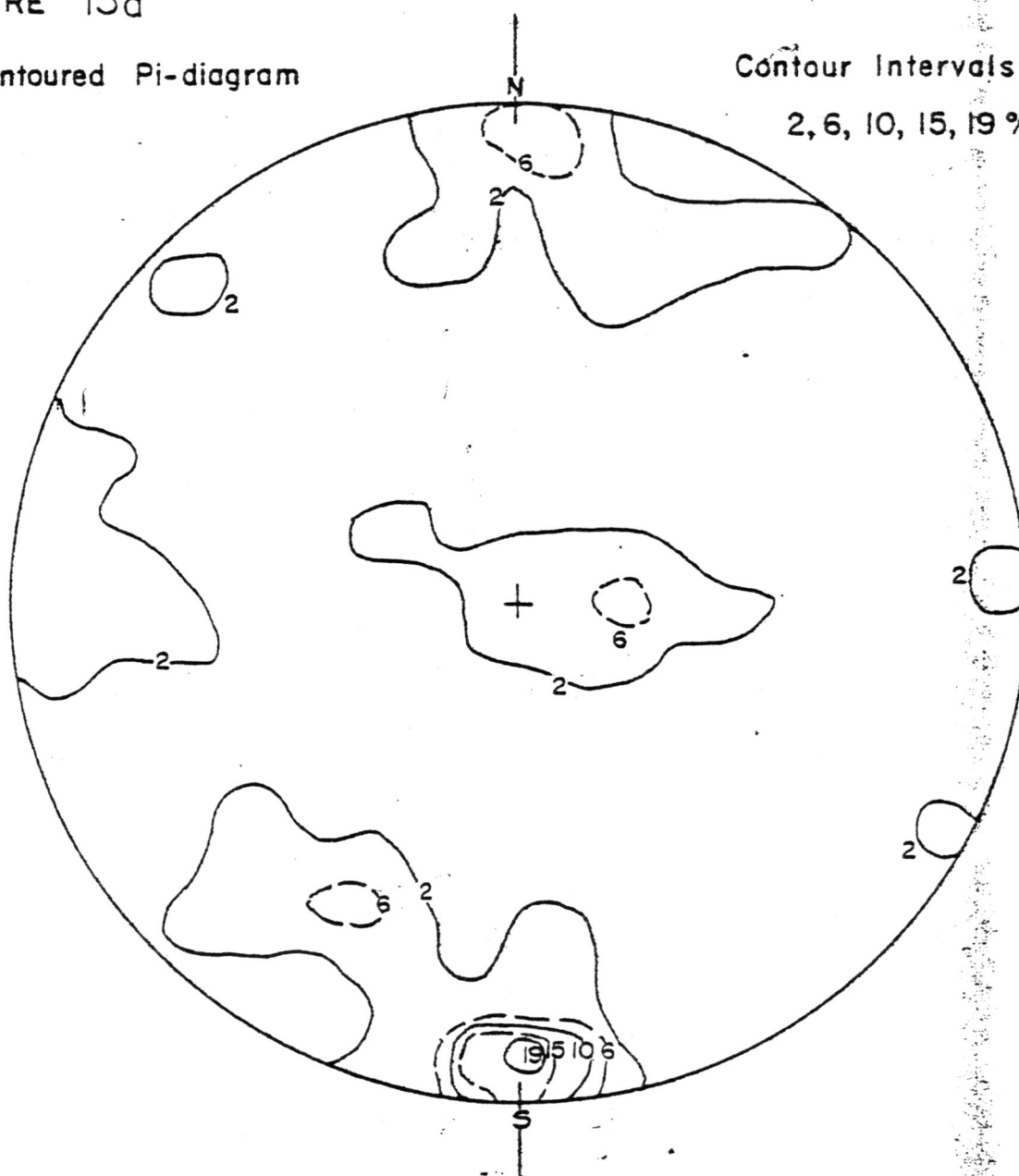


FIGURE 13a

Contoured Pi-diagram

Contour Intervals:

2, 6, 10, 15, 19 %



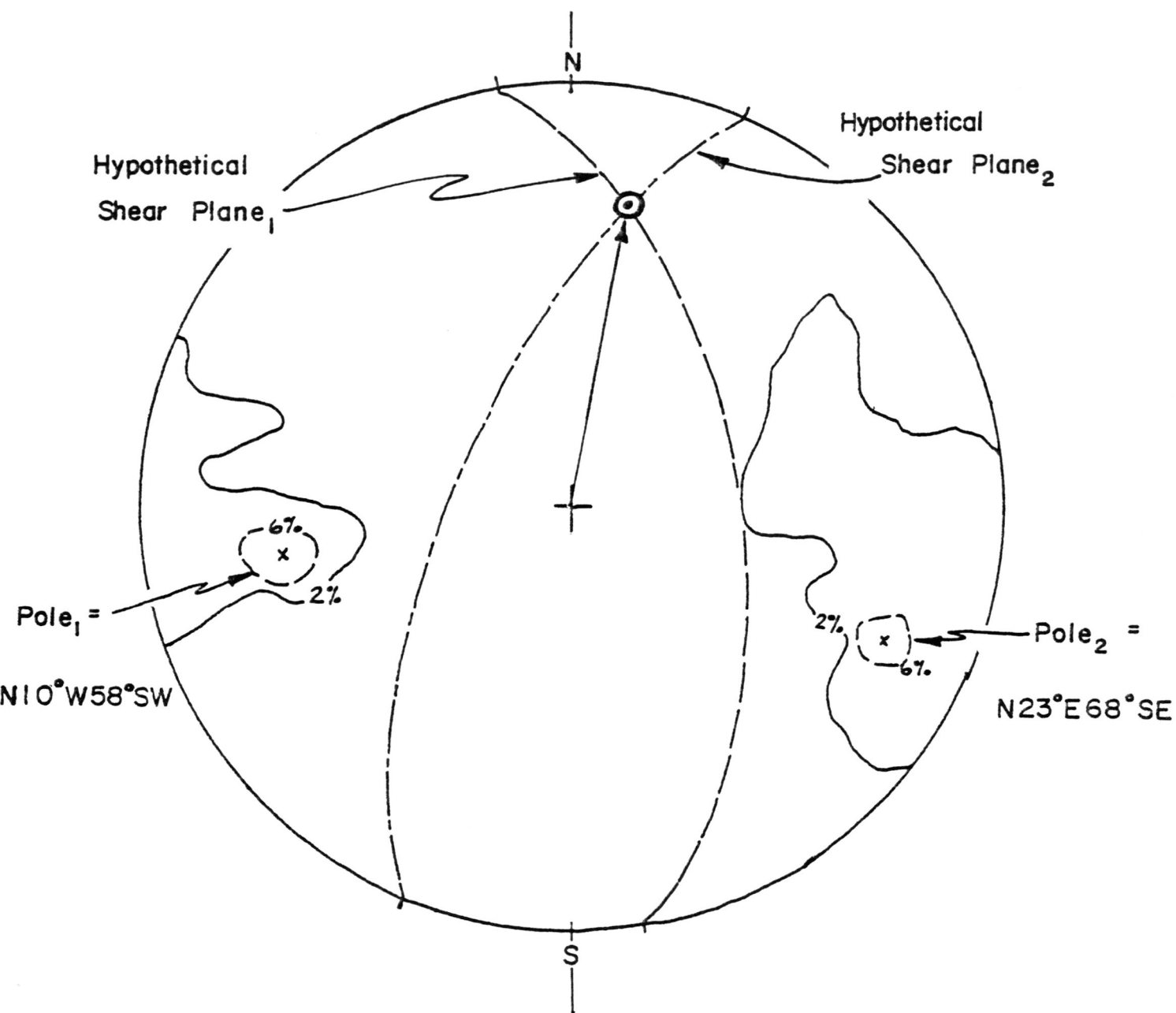


FIGURE 14: Conjugate shear developed by longitudinal joints from the west wall (see fig. 11a). ⊙ = intersection of shear planes (stress axis) at N10°E 28° NE.

trending N10°E and plunging 62°SW (figure 14). These weakly developed shears are confined to the northwestern part of the quarry and their relation to the rest of the joint system is not understood.

Release fractures are present in all areas and are seen as a concentration of points near the center of the equal area nets. Their orientation is variable and only faint similarities exist between the different sections. In the central area of the quarry, joint strikes generally trend northeasterly (figures 9, 12, 13 and 9A, 12A, 13A). The variable strikes are to be expected in view of the low dip angles.

In some granite plutons, the joint systems are the result of regional tectonic activity following solidification of the granite. A primary origin for the cross and longitudinal joints in the Fountain Quarry Granite is suggested by the mineral coatings on joint surfaces. The mineral coatings are very similar in composition to the granite.

## 6. Wallrock Outcrops

Several outcrops of vertically foliated mafic rock are exposed in the quarry. These are mainly amphibole schist with lesser amounts of biotite-riebeckite-chlorite schist. In places, the amphibole schist is intruded by basalt dikes that are easily distinguished after close study.

The schist bodies are variable in size and shape. Some occur as mere slivers of rock that seemingly have been 'emplaced' along vertical joints, while others are massive blocks that the granite has flowed into and around. Where they are in contact with granite, these mafic bodies are bounded by a contact metamorphic zone characterized by a garnet-sphene-albite-calcite assemblage. In the granite outside the contact, there are usually several thick layers of mafic minerals that are parallel to the boundary.

In some exposures, the schist and granite appear to be intimately mixed, somewhat like a migmatite, with large quantities of albite and riebeckite in the granite. The thinner mafic bodies have a strongly defined schistosity, while the large blocks are weakly foliated. This is strong evidence to suggest that these mafic bodies are wallrocks that were enveloped by the magma. These wallrock 'screens', or septa, originally may have been iron-rich sediments or tuffaceous material. The screens may have been metamorphosed to their present greenschist grade before the time of the granite intrusion.

Most of the screens are thin compared to their vertical height, and they extend horizontally for a few tens of meters (figure 4). Considering this, it is surprising that the screens remained relatively undisturbed mechanically by the magma. Because the magma was intruded vertically, as seen from the flow structure, it is probable that little horizontal stress was imposed on the wallrock screens.

There are two reasons that suggest that the many pancake-shaped schlieren in the granite originated as chunks broken from these mafic screens. First, the reaction rims seen around the screens are identical to those surrounding some larger xenoliths; second, xenoliths are slightly more prevalent in sections of the quarry that contain a screen. However, the distribution of xenoliths has been modified greatly by magma flow. Because most of the xenoliths were relatively small, they were digested and made over into inclusions with granitic mineralogy; the only difference is the higher concentration of riebeckite and sphene in the inclusions. During magma flow, the small xenoliths must have been stretched, flattened, and hydrodynamically aligned into their present configuration.

## 7. Basalt Dikes

At some time after consolidation of the granite, thin basalt dikes were intruded along longitudinal joints. The granite must have been relatively cool at this time, because there are thin, glassy chill zones bounding the dikes at several exposures in the quarry. The dikes were emplaced along zones of weakness in the granite, and the nearly constant association of basalt with amphibole schist/ granite contacts suggests that the contact zone may have operated as a structural control during injection of the basalt. The dikes are not continuous across the quarry, as can be seen from figure 4. At the present quarry level, two main dikes are exposed. These dikes may pinch out along strike, or they may be connected as a single dike at a deeper level.

The apparent offset of the dikes is not due to faulting but results from structural control of magma intrusion by the joint system and by the amphibole schist septa. Reaction of basalt with the granite and amphibole schist is limited; there is no discernible zone of alteration at the contact. Perhaps this is to be expected, in view of the very small volume of basalt that was intruded.

The basalt possesses rudimentary columnar joints that strike perpendicularly to the basalt-granite contacts. This columnar jointing is the major difference, in outcrop, between an amphibole schist screen and a dike. These relationships are best observed in two outcrops near the center of the quarry. In one exposure, the basalt has been intruded along vertical joints between granite and a screen (figure 15). Upon careful inspection, one can contrast the schistose nature of the screen with the weakly developed columnar jointing in the basalt. In the other exposure, the basalt has been injected around a large block of schist, forming a 20-25 cm-thick shell (figure 16). The

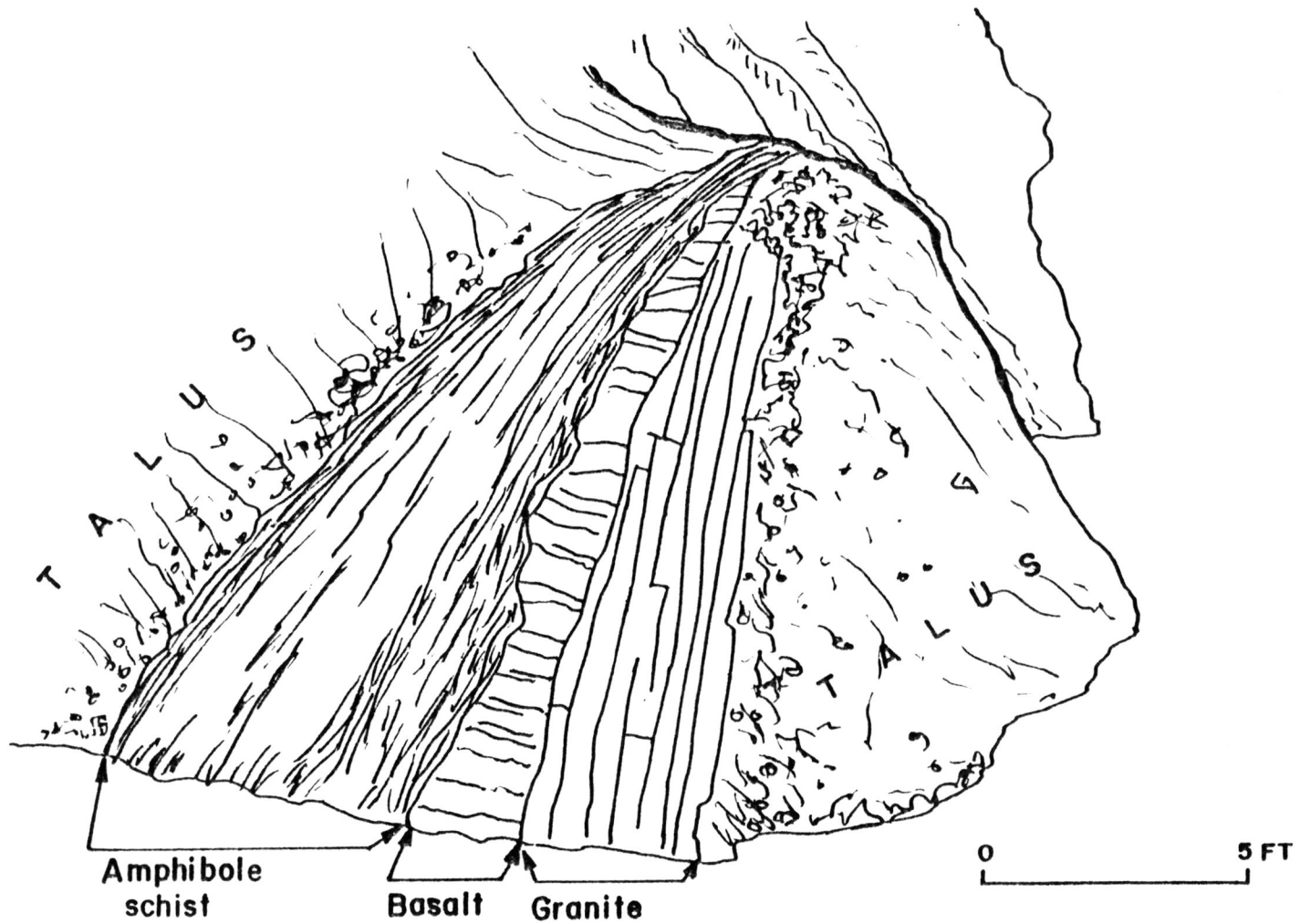
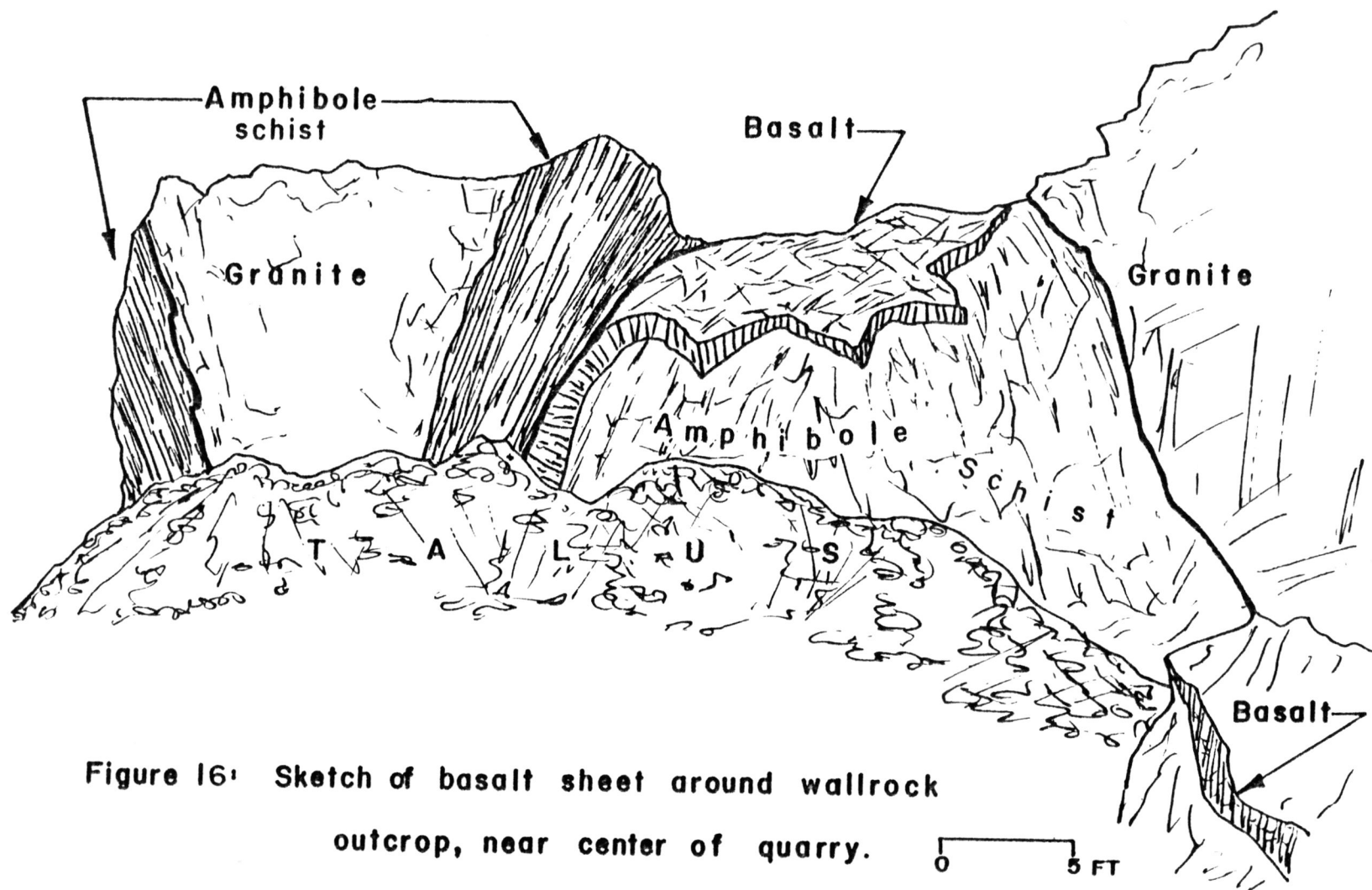


Figure 15: Sketch of basalt and wallrock in granite, near quarry center.





different surfaces displayed by the dike as it wraps around the block of schist cause it to appear as an additional, badly weathered layer of the schist.

## 8. Faults

Evidence of major faults in the quarry is absent. Partitioning of the joint data (figure 8) indicates that there are no marked differences between sections of the quarry. Inspection of the quarry walls showed no mylonitic zones or other typical fault plane artifacts, and the apparent offsets in the basalt dike may be ascribed to structural control of intrusion. This is because the two apparently offset ends have been emplaced into altogether different surroundings (figure 4) and the required displacement (90-105 m, 300-350 ft along a plane roughly N60°W, 5-15°NE, assuming purely dip-slip movement) does not fit in with the joint orientations in the quarry (figure 6).

Some minor faulting has occurred along pre-existing joints. This is indicated by the streaked-out coatings of albite, riebeckite, and calcite seen on virtually all slip surfaces; the coatings must have been in place, i.e., along a longitudinal or cross joint, prior to displacement. Displacements of about 0.3-0.9 m (1-3 ft) are indicated by offset portions of small quartz-filled gash veins. The slickensides show movement in various directions and there is no preferred direction of movement. It may be that these faults are late features that formed in response to the relief of hydrostatic stress as a result of erosion. A more likely possibility, in view of the regional compression that was occurring during the Alleghenian orogeny (290-260 m.y.), is that joint-bounded granite blocks experienced small movements between themselves, resulting in shear along the joints. Also, small, irregular quartz veins cut the flow foliation at all angles, and appear to be the result of

shear failure within the individual granite blocks.

## CONCLUSIONS

The Fountain Quarry Granite is a small peralkaline pluton that was intruded into basement rocks of the coastal plain of North Carolina during the late Paleozoic era. Some of the basement rocks were incorporated into and metamorphosed by the granite magma. In the quarry, these basement rocks crop out as large blocks and slivers of amphibole schist.

Structural features in the granite include long, smooth longitudinal and cross joints, and a flow foliation displayed by streaks of needlelike riebeckite and aegirine and highly metamorphosed inclusions of wallrock. The joint system is a result of stresses induced shortly after solidification of the pluton, perhaps due to further magma injection at a deeper level. Structural analysis of the joint system shows consistent development and orientation in all sections of the quarry, with no evidence of major faulting.

The average strike and dip of the flow foliation describes a vertical plane, indicating that the magma was injected straight up, perhaps along vertical tension cracks in the country rock.

Chemical analyses of the granite by X-ray fluorescence indicate that the rock is uniform in composition throughout, and that it compares closely to other peralkaline granites worldwide. Thin section analysis indicates that the granite has not been regionally metamorphosed. Thus the granite seems to have remained relatively undisturbed by the latest sequence of Appalachian metamorphism. The rock does show evidence of mechanical deformation, manifested by small gash veins and slickensides on mineral-coated joints.

Due to the isolated exposure of the Fountain Quarry Granite, interpretation in a regional geologic framework is highly speculative. The granite is

chemically distinct from the linear belt of plutons in the eastern slate belt, approximately 40 miles to the west. That a granite pluton, much less a peralkaline one, should exist on the coastal plain is extremely peculiar. However, it may be slightly less unexpected if it is considered with the regional geologic history in mind.

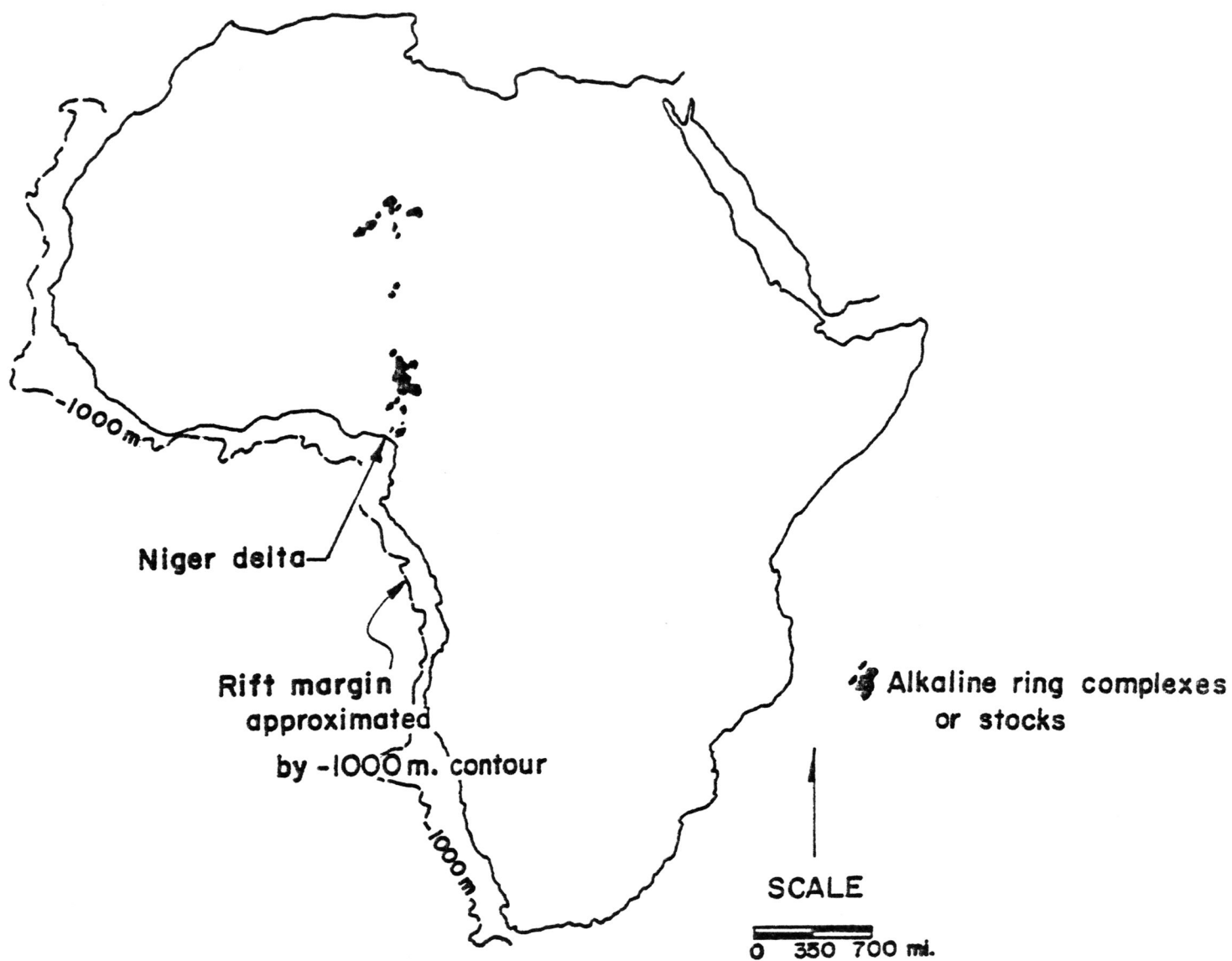
The pre-Cretaceous geologic history of the Atlantic coastal plain is not well known, especially with regard to plate tectonics. Although the major orogenic events that have deformed the inner continental margin are fairly well-documented (Fullagar and Butler, 1979; Fullagar, 1971), the compressional forces behind each episode of folding and uplift can only be tentatively related to the collision or rifting of lithospheric plates (Gass and others, 1971).

Studies of worldwide peralkaline rocks have led to recognition of a few general characteristics associated with this type of magmatism. Peralkaline magmas are common in continental areas undergoing epeirogenic doming. This doming is frequently a precursor to active rifting (Ayrton, 1974). The rift zone may or may not eventually evolve further into an oceanic basin. Plutons are frequently emplaced as subvolcanic ring structures beneath areas of peralkaline lavas such as pantellerites (Bowden, 1974), and the magmas can rise quickly through the lower crust (Smith, 1976). The occurrence of peralkaline granite xenoliths in pantellerite flows over actively spreading ridges (Bowden, 1974, 1970; Bailey and Schairer, 1966) indicates that peralkaline magmatism may be a minor, but important early event in formation of tensional tectonic zones.

The most extensively studied peralkaline ring complexes are those in Nigeria and in the Niger Republic (Bowden, 1970; Hyndman, 1972). They are situated along a roughly straight line trending north from the late Triassic-

Jurassic rift zone that opened between central Africa and the western continents (figure 17). Just south of this line of plutons is one of the many fracture zones that cross the Atlantic and offset the Mid-Atlantic rift. The presence of a fracture zone at this point indicates that rifting followed zones of weakness along the continental shelf, rather than splitting open the African continental crust. The age of the ring complexes, about 190 m.y., coincides well with the supposed age of rifting. Field evidence indicates that the emplacement of these complexes may have been dependent upon the existence of a large, persistent, shallow heat source, such as would exist in a very young rift zone (Bowden, 1970). Sykes (1979) has indicated that zones of alkaline magmatism are related to rifts that did not open into full ocean basins or form due to tectonic effects at the end of major ocean transform faults. Thus, there appears to be a strong connection between the Nigerian peralkaline plutons and an incipient (but never completed) rift zone in the African lithospheric plate.

On the west side of the Atlantic, the late Precambrian (850-700 m.y.) 'proto-Atlantic' ocean opened along a zone somewhere between the Blue Ridge and the Carolina slate belt (Odom and Fullagar, 1973; Bird and Dewey, 1970; Wilson, 1966). The emplacement of the Crossnore peralkaline series (about 820 m.y. old) in western North Carolina is related to the tensional tectonics surrounding this event (Rankin, 1972). However, at the time of emplacement of the Fountain Quarry Granite (late Paleozoic, based on a preliminary whole-rock Rb-Sr isotopic age) (Spruill, pers. comm., 1979) the structural regime for the eastern margin of North America was mainly compressional. Following the closing of the proto-Atlantic in middle Ordovician time, subduction of an oceanic crustal plate beneath the North American continental edge resulted in an offshore island arc system (Odom and Fullagar, 1973; Bird and Dewey, 1970).



**FIGURE 17: Coincident trends of Nigerian alkaline rocks and Mid-Atlantic rift zone south of the Niger delta (after Sykes, 1978).**

These conditions prevailed until the collision with Africa resulted in the formation of the super-continent Pangea, about 280 m.y. ago (Wilson, 1966).

However, recent work in New Guinea (Smith, 1976) seems to indicate that the compressional regime created by subduction will migrate toward the back-arc regions. It is possible that the tensional tectonics of the early Paleozoic were gradually replaced by compression, but not before small amounts of granite magma were emplaced in the Piedmont and coastal plain (Fullagar and Butler, 1979). Fullagar and Butler also mention a peralkaline granite of Pennsylvanian age that intruded a zone of weakness in Newfoundland. The tectonic setting and possibly the age coincide with those of the Fountain Quarry Granite.

Sykes (1978) has shown that major continental fracture zones (zones of weakness) become nearly adjacent when the continents are moved back to their pre-drift (Permian) positions. When this is done, the area surrounding Fountain becomes aligned between the Canary and Cape Verde Islands, both of which contain peralkaline volcanic rocks as least as old as 180 m.y. Thus, it is also possible that as North America and Africa began drifting apart nearly 200 m.y. ago, small sections of the continental margin were broken off by the opening rift. One of these small sections, containing an old peralkaline intrusion, became submerged by coastal plain sediments along the North American continental margin.

## APPENDIX 1: X-RAY FLUORESCENCE ANALYSIS TECHNIQUE

The following techniques were used for analyzing samples of Fountain Quarry Granite for major elements. X-ray fluorescence is based on the fact that atoms of a certain element will emit a characteristic radiation when they are bombarded by a beam of X-rays. The intensity of the emitted radiation, or fluorescence, is theoretically proportional to the concentration of that element in the sample. All other parameters, such as intensity of the beam, must be held constant. Because the fluorescence of a particular element has a characteristic wavelength, radiation from all the different elements in a sample can be separated by an analyzing crystal, much as white light can be separated into its components by refracting it through a prism. Radiation from a particular element is then selected by placing the counting apparatus at a given angular position calculated from Bragg's Law.

A graph of intensity vs. concentration can be constructed, using analyzed standard reference materials. The points on this graph are described by a straight line; thus, for any unknown sample, once the intensity of the fluorescence is obtained, the corresponding concentration can be calculated from the graph.

Sample preparation is relatively simple; a small (5-15 g) amount of the rock is powdered and pressed into pellets. Two to three grams of powder were used in this analysis, and the pellets were pressed to  $3 \times 10^5$  lbs/in<sup>2</sup>. This technique usually requires the addition of a small amount of inert material to act as a binder; in this case, 10 percent methyl cellulose was ground with the rock powder before pressing.

The pellets were analyzed on a General Electric XRD-6 fluorescence

spectrometer. Either tungsten or chromium radiation was used to excite the sample. Counting was accomplished with a flow-proportional counter utilizing P-10, a gas composed of 90 percent argon and 10 percent methane. The counter tube output is fed through a pulse height selector to eliminate unwanted radiation that may be close to the wavelength being analyzed. The fluorescence radiation from a particular element is emitted at slightly different wavelengths about a mean value. The pulse height selector is used to reject pulses that are too high or too low (too far below or above the mean wavelength, respectively). The counter is run for 10 seconds, and the digital readout automatically determines the count rate in counts-per-second (cps).

The counter tube output is dependent upon the rate of gas flow through the tube and the electric potential between the cathode and anode in the tube. In all analyses, gas flow was held at a constant value. The counter tube response exhibits a plateau at a certain range of potentials, making it insensitive to small fluctuations in voltages. For all analyses, the potential was set within the plateau range to minimize changes in counter tube response. To optimize counting characteristics, the best settings were determined for each element prior to analysis. A list of the various settings for each element is given in Table 6.

Table 6: List of Parameters Used for Analysis

| Element | 2 $\theta$ | Counter Tube   | X-ray Tube   | Pulse Height Selector* |             | Exciting Radiation | Analyzing Crystal | Amplifier Gain |
|---------|------------|----------------|--------------|------------------------|-------------|--------------------|-------------------|----------------|
|         |            | Potential (kV) | Current (mA) | Lower limit            | Upper limit |                    |                   |                |
| Si      | 108.70°    | 1.700          | 8            | 75                     | 250         | Cr                 | PET               | 1              |
| Al      | 144.80°    | 1.720          | 8            | 100                    | 285         | Cr                 | PET               | 1              |
| K       | 136.85°    | 1.680          | 4            | 85                     | 300         | W                  | LiF               | 1              |
| Ti      | 86.32°     | 1.690          | 10           | 125                    | 350         | W                  | LiF               | 1              |
| Ca      | 113.23°    | 1.685          | 8            | 105                    | 340         | Cr                 | LiF               | 1              |
| Fe      | 57.65°     | 1.370          | 8            | 140                    | 280         | W                  | LiF               | 16             |

\* units are Volts x 100

-Note: X-ray tube run at 45 kV for all analyses.



Before the count rates can be related to concentration, there are three corrections that must be made to the raw data. The first correction is for counter dead time. This reflects the small but finite amount of time needed by the counter tube gas to 'recover' from an incoming X-ray. Dead time results in a count rate that is lower than it should be, and it becomes more and more important with higher count rates. The formula for dead time correction is:

$$N_o = N_o' / (1 - N_o' t)$$

where  $N_o$  is the true count rate,  $N_o'$  is the measured count rate, and  $t$  is the counter recovery time (equal to  $3.5 \times 10^{-6}$  sec).

The correction for background radiation is measured by taking a count rate a few degrees above or below the  $2\theta$  used for each element and subtracting this from the peak count rate after correction for dead time. Background only becomes significant when a) the count rates are very low, or b) the average background is high (more than 10 percent of the average count rate). Background corrections were made for all Fountain samples to insure uniform treatment.

The third correction is an adjustment of the count rate that takes into account the pellet holder used at the time the sample was analyzed. There are four pellet holders in the XRD-6, and each has a slightly different effect on the measured count rate. Analyses using pellets of the same material in all four holders show the following results:

Table 7: Adjustment of Count Rate with Holder Position

| <u>Holder</u> | <u>Adjustment Factor</u> | <u>Holder</u> | <u>Adjustment Factor</u> |
|---------------|--------------------------|---------------|--------------------------|
| #1            | 1.0545                   | #3            | 0.9989                   |
| #2            | (1.000)                  | #4            | 0.9963                   |

After applying these corrections, analysis of the standard reference materials (table 8) gave the following results:

Table 8: Analysis of Standard Reference Materials

| Standard | percent<br>SiO <sub>2</sub> cps |      | percent<br>Al <sub>2</sub> O <sub>3</sub> cps |     | percent<br>K <sub>2</sub> O cps |       | percent<br>TiO <sub>2</sub> cps |      | percent<br>CaO cps |       | percent<br>Fe <sub>2</sub> O <sub>3</sub> cps |      |
|----------|---------------------------------|------|-----------------------------------------------|-----|---------------------------------|-------|---------------------------------|------|--------------------|-------|-----------------------------------------------|------|
| GSP-1    | 67.38                           | 3111 | 15.25                                         | 779 | 5.53                            | 24475 | 0.66                            | 5503 | 2.02               | 9789  | 4.33                                          | 8776 |
| G-2      | 69.11                           | 3132 | 15.54                                         | 798 | 4.51                            | 18812 | 0.50                            | 4172 | 1.94               | 9458  | 2.65                                          | 5459 |
| Nancy GH | 75.80                           | 4063 | 12.50                                         | 672 | 4.76                            | 20679 | 0.08                            | 570  | 0.69               | 3299  | 1.34                                          | 2819 |
| Nancy GA | 69.90                           | 3409 | 14.50                                         | 766 | 4.03                            | 17489 | 0.38                            | 2988 | 2.45               | 12468 | 2.83                                          | 5603 |
| Q-108    | 75.05                           | 3991 | 11.65                                         | 605 | 5.28                            | 22881 | 0.24                            | 1747 | 0.12               | 853   | 3.03                                          | 5826 |
| SUNY I   | 67.20                           | 2933 | 15.80                                         | 866 | 4.56                            | 19165 | 0.51                            | 4167 | 2.57               | 13184 | 4.56                                          | 9189 |
| SUNY II  | 83.60                           | 4843 | 7.90                                          | 420 | 3.28                            | 13322 | 0.20                            | 1598 | 0.42               | 2040  | 1.79                                          | 3165 |
| Q-182B   | 75.25                           | 3916 | 10.40                                         | 530 | 4.71                            | 19280 | 0.22                            | 1620 | 0.14               | 994   | 4.41                                          | 9528 |
| NIST-G   | 75.59                           | 3934 | 12.08                                         | 666 | 4.98                            | 21622 | 0.09                            | 715  | 0.80               | 3700  | 2.02                                          | 4230 |

Note: Concentration (percent) is published value for standard. Does not reflect addition of 10 percent methyl cellulose to pellet.

2. Intensity is average value of 10 runs, after all corrections. Units are counts-per-second.

The values in Table 8 were used as the basis for calculation of a straight-line equation, utilizing a linear regression program furnished with the TI-58 calculator. Subsequent entry of measured and corrected intensity of the Fountain samples allows direct readout of the elemental concentrations. Several samples of Fountain Quarry Granite were submitted to a commercial laboratory for analysis of Na<sub>2</sub>O and MgO, which the XRD-6 fluorescence unit cannot accurately record. These analyses are presented in Tables 2 and 2A in the text.

Plate 1: Photomicrograph of Fountain Quarry Granite, 25X, crossed nicols.

Large grain (A) is aegirine, somewhat corroded. Smaller grains in matrix are quartz and albite. Many plagioclase grains exhibit albite twinning (T). Fine-grained texture is typical of section cut normal to flow foliation.

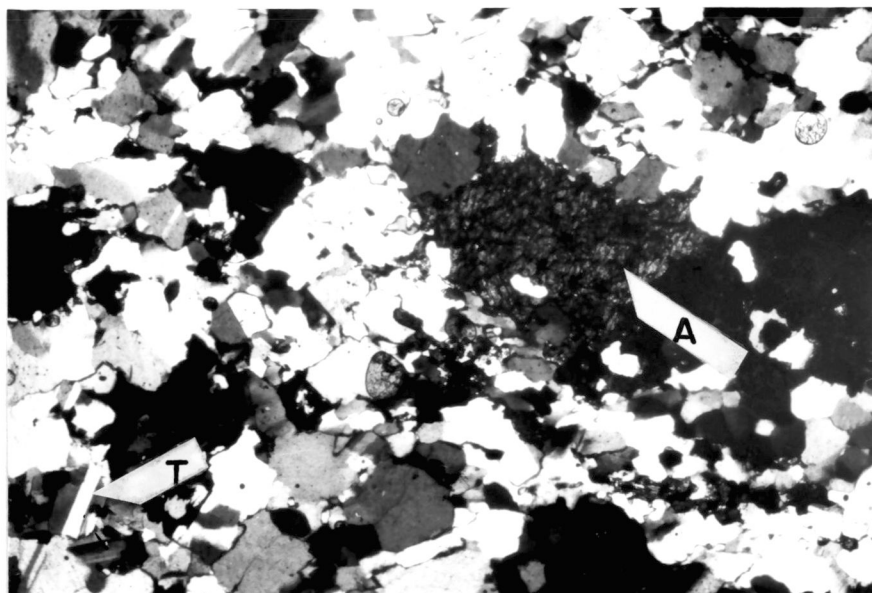
Plate 2: Photomicrograph of large plagioclase grain, 63X, crossed nicols.

Twinning is a combination of albite and pericline, giving the characteristic cross-hatched appearance. Microprobe analysis indicates that the grain is albite ( $\text{Ab}_{99.1}\text{Or}_{0.9}$ ).

Plate 3: Photomicrograph of orthoclase grain, 63X, crossed nicols. Grain

shows perthitic texture caused by small exsolved patches of albite (A). Small dark grains (M) are magnetite. Also visible in the lower left corner is a grain of riebeckite (R), and near the center, epidote (E).

Plate 1



0.3 mm



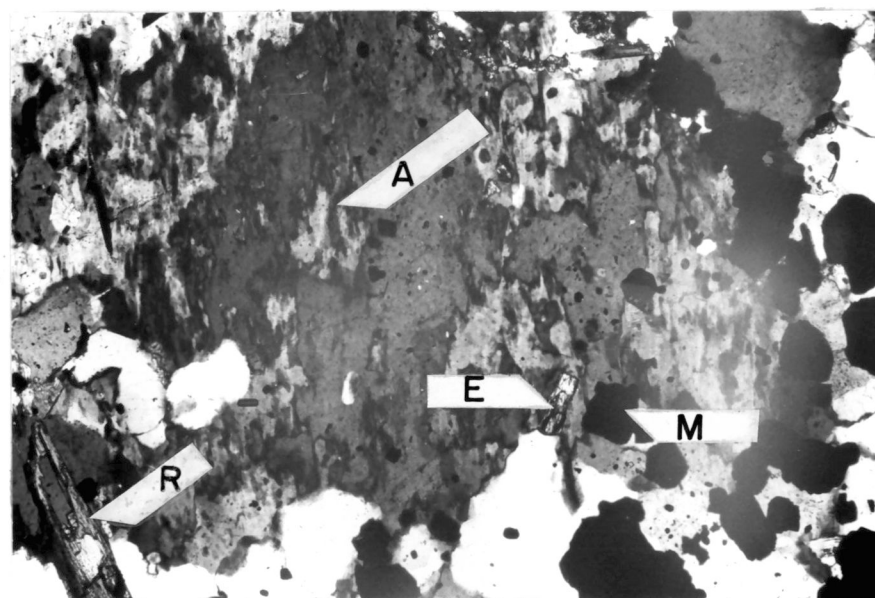
Plate 2



0.1 mm



Plate 3



0.1 mm

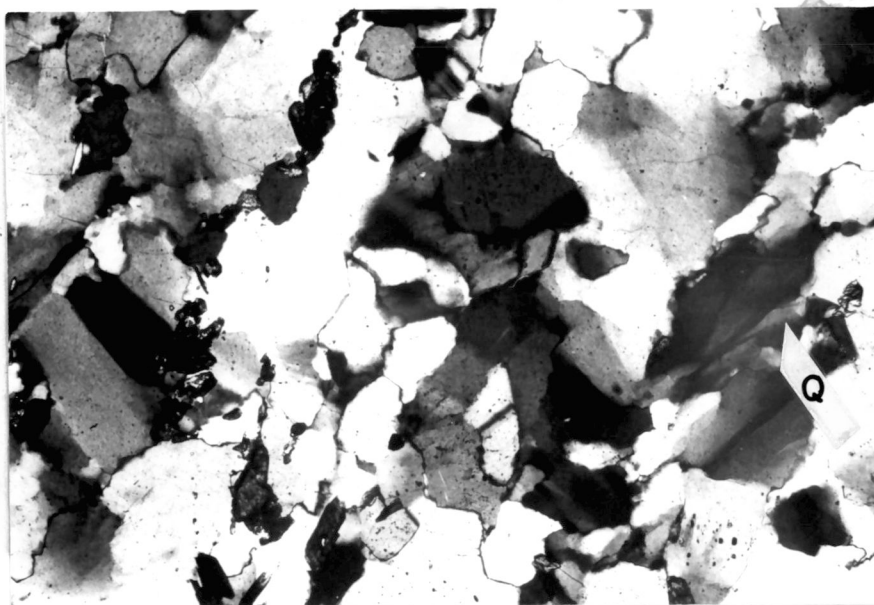


Plate 4: Photomicrograph showing typical section of granite, 63X, crossed nicols. Quartz grains (Q) show small, subparallel sections that go extinct sequentially. In the left-center is a string of mafic minerals, mostly aegirine and riebeckite, that define the flow foliation in the rock.

Plate 5: Photomicrograph of riebeckite-aegirine cluster in granite, 63X, crossed nicols. Amphibole (R) shows characteristic cleavage and crystal faces. Pyroxene (A) is somewhat corroded and appears slightly glassy. Other grains are quartz and albite.

Plate 6: Photomicrograph of granite cut parallel to flow foliation, 25X, crossed nicols. Dark mafic streak (M) showing flow structure is mostly riebeckite. Surrounding grains are quartz and some feldspar that has twinning like that shown in Plates 1 and 2 (T).

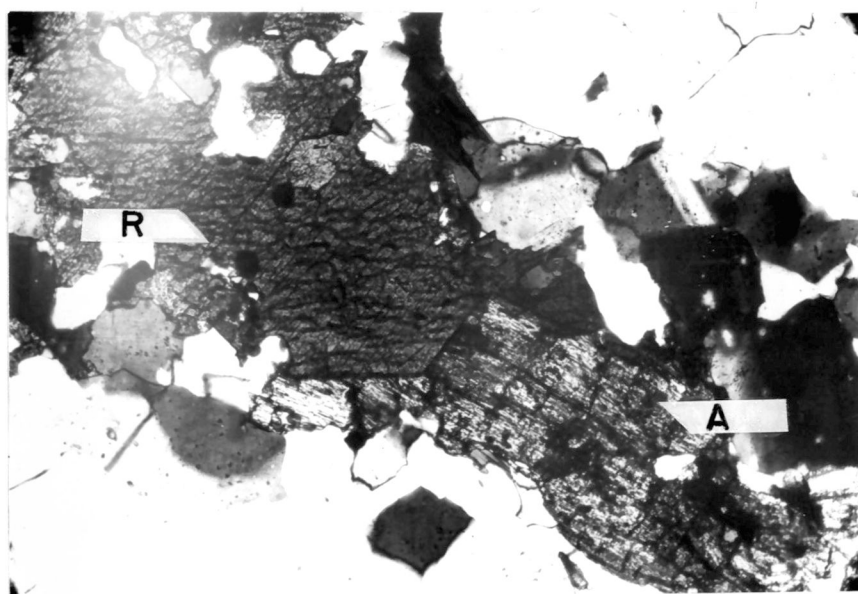
Plate 4



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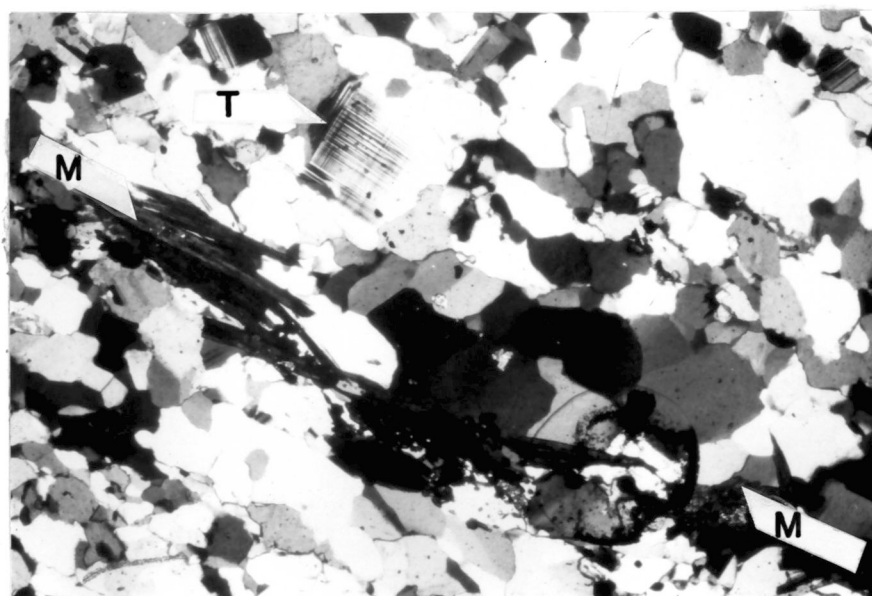
Plate 5



0.1 mm



Plate 6



0.3 mm

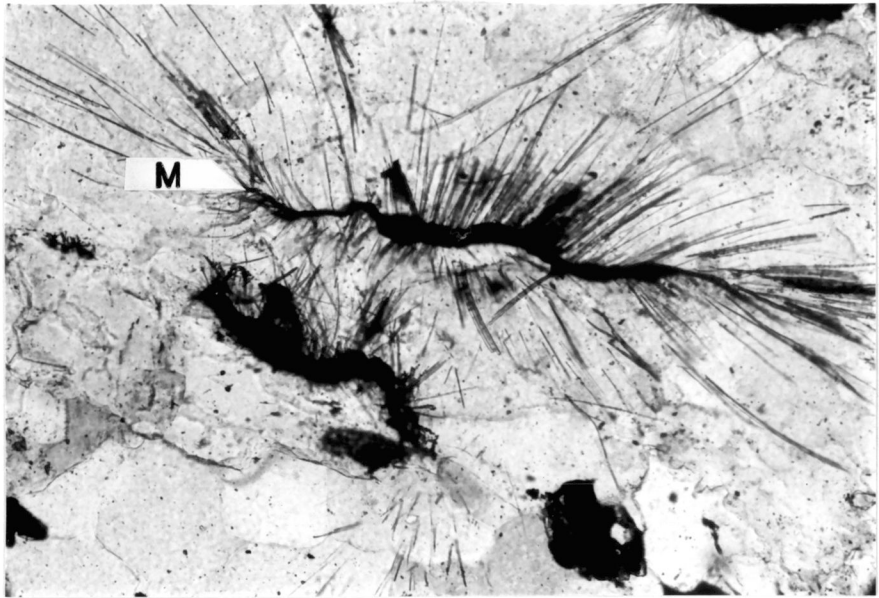


Plate 7: Photomicrograph of granite, 63X, plane light. Shows small, needle-like crystals of riebeckite radiating from two microcracks in the granite (M).

Plate 8: Photomicrograph of granite from close to a wallrock screen. The granite shows effects of wallrock assimilation. Note the aggregates of biotite (B) around mafic mineral clusters, and a few scattered grains of epidote (E). 63X, crossed nicols.

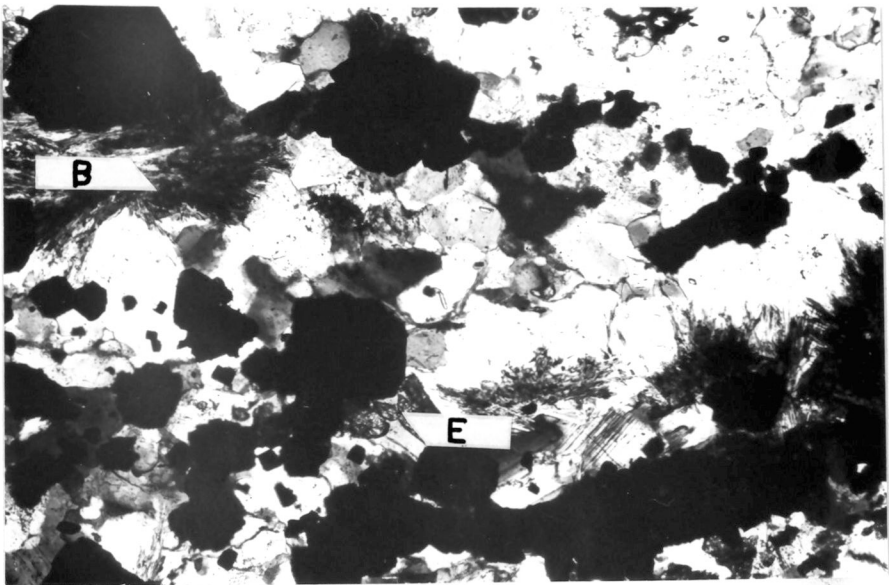
Plate 9: Photomicrograph of granite, 25X, plane light, oblique illumination. Dark streak (flow foliation) is riebeckite (R), aegirine, and some small grains of magnetite (M). Glassy-looking material around riebeckite is calcite (C). The white to gray grains are albite (P) and quartz (Q).

Plate 7



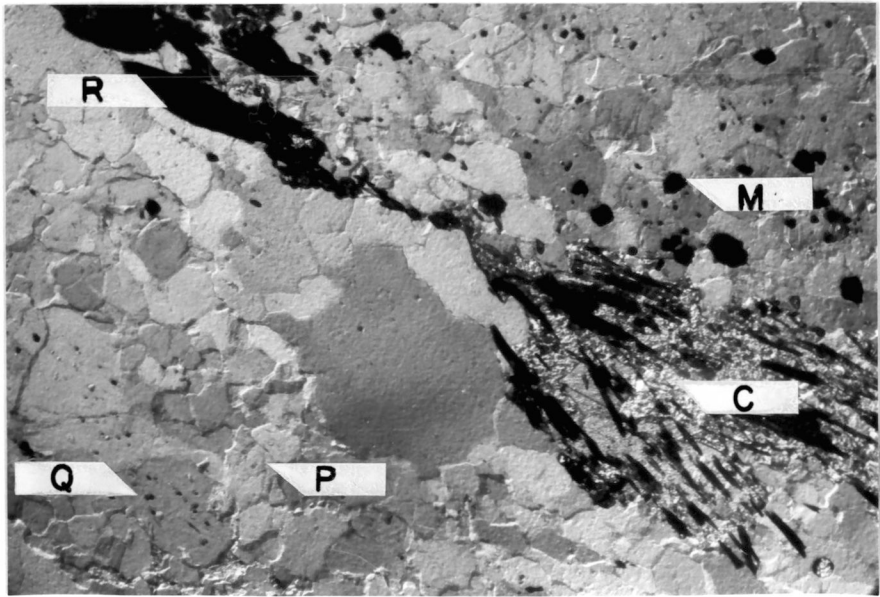
0.1 mm  
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Plate 8



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Plate 9



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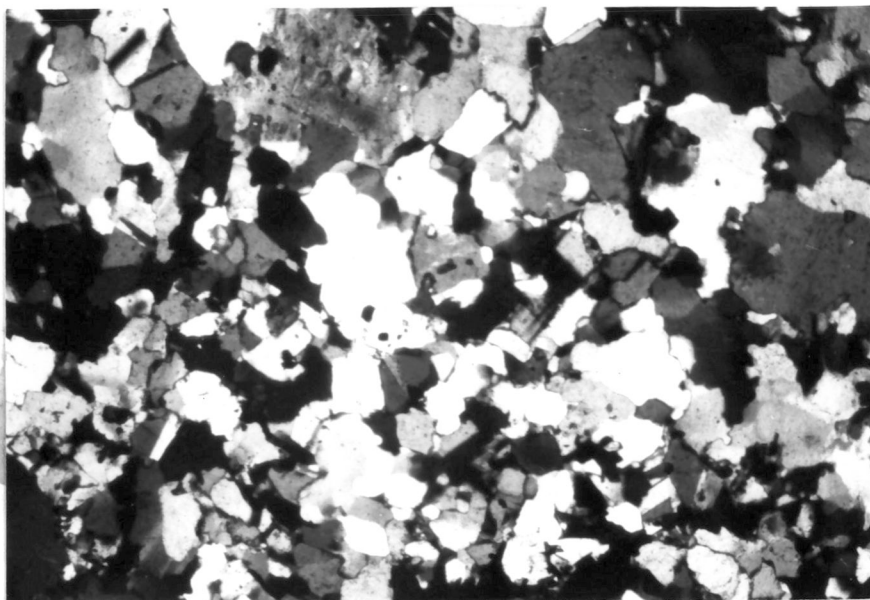


Plate 10: Photomicrograph of the contact zone between granite and a xenolith, 25X, crossed nicols. Xenolith is the finer-grained material in the lower portion of the photo. Mineral grains are mostly plagioclase and quartz, with scattered grains of riebeckite. Note similar mineralogy between xenolith and granite.

Plate 11: Photomicrograph of 'mixed' granite, 25X, plane light. Large grains with glassy appearance are garnet (G). Matrix material is mostly quartz and albite. Square opaque grain in corner is probably magnetite, but could be pyrite. Euhedral pyrite cubes are common in the contact zone, and are easily seen in hand sample.

Plate 12: Photomicrograph of amphibole schist, 25X, plane light. Rectilinear grains (A) are sodium-rich amphibole, possibly arfvedsonite. Small glassy grains (S) are sphene; remainder of the matrix is quartz and feldspar. The slide has been cut approximately normal to the foliation plane, which passes across the photo horizontally.

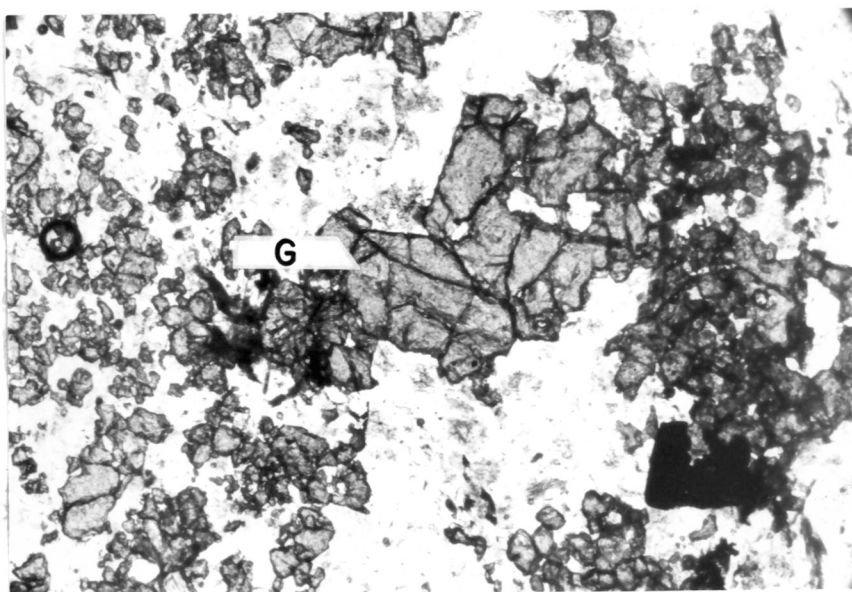
Plate 10



0.3 mm



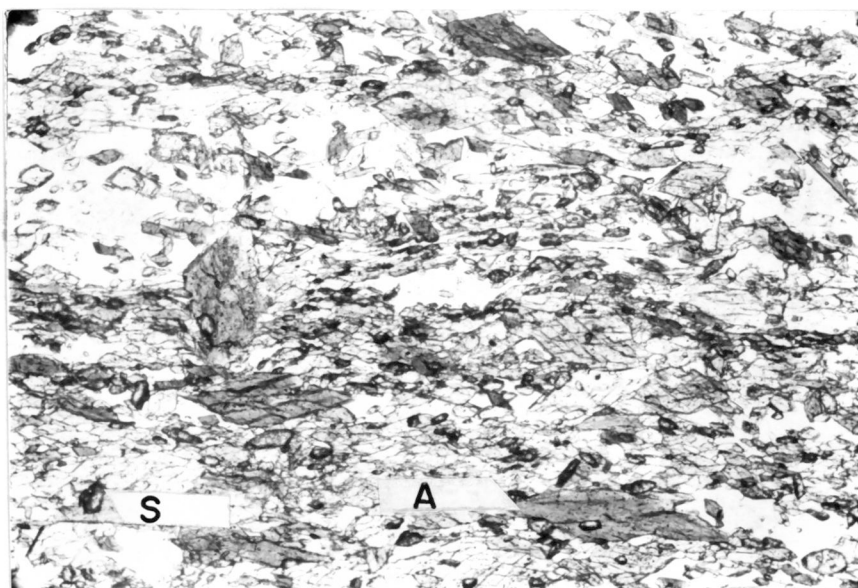
Plate 11



0.3 mm



Plate 12



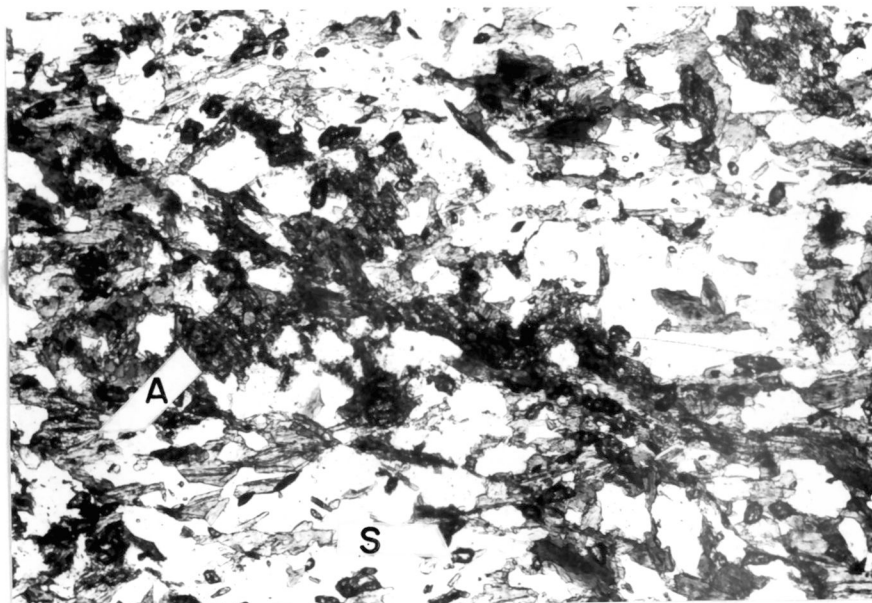
0.3 mm



Plate 13: Photomicrograph of amphibole schist, 25X, plane light. This sample was cut from a rock collected about 1 m (3 ft) farther away from the contact zone than the sample in Plate 12. Amphibole grains (A) still predominate, but the rock is less foliated than the sample in Plate 12. Also visible are grains of sphene (S) and a matrix of quartz and feldspar. This rock is typical of most amphibole schist found in the quarry.

Plate 14: Photomicrograph of basalt, 25X, crossed nicols. Sample shows typical ophitic texture formed by small laths of plagioclase. Large lath-shaped crystals are also plagioclase (P). Phenocryst in upper center (B) is bowlingite, pseudomorphous after olivine. The groundmass is mostly bowlingite after olivine, augite, and plagioclase.

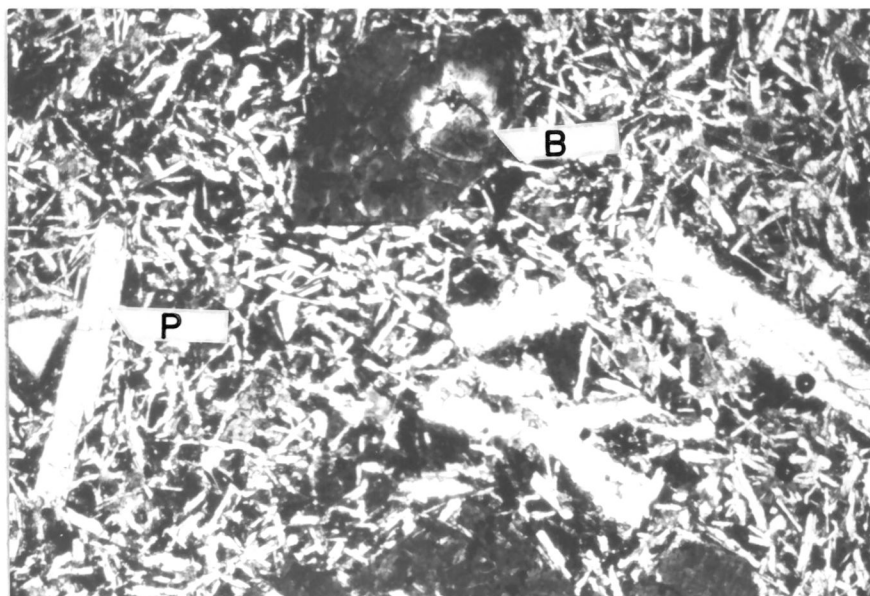
Plate 13



0.3 mm



Plate 14



0.3 mm



## References

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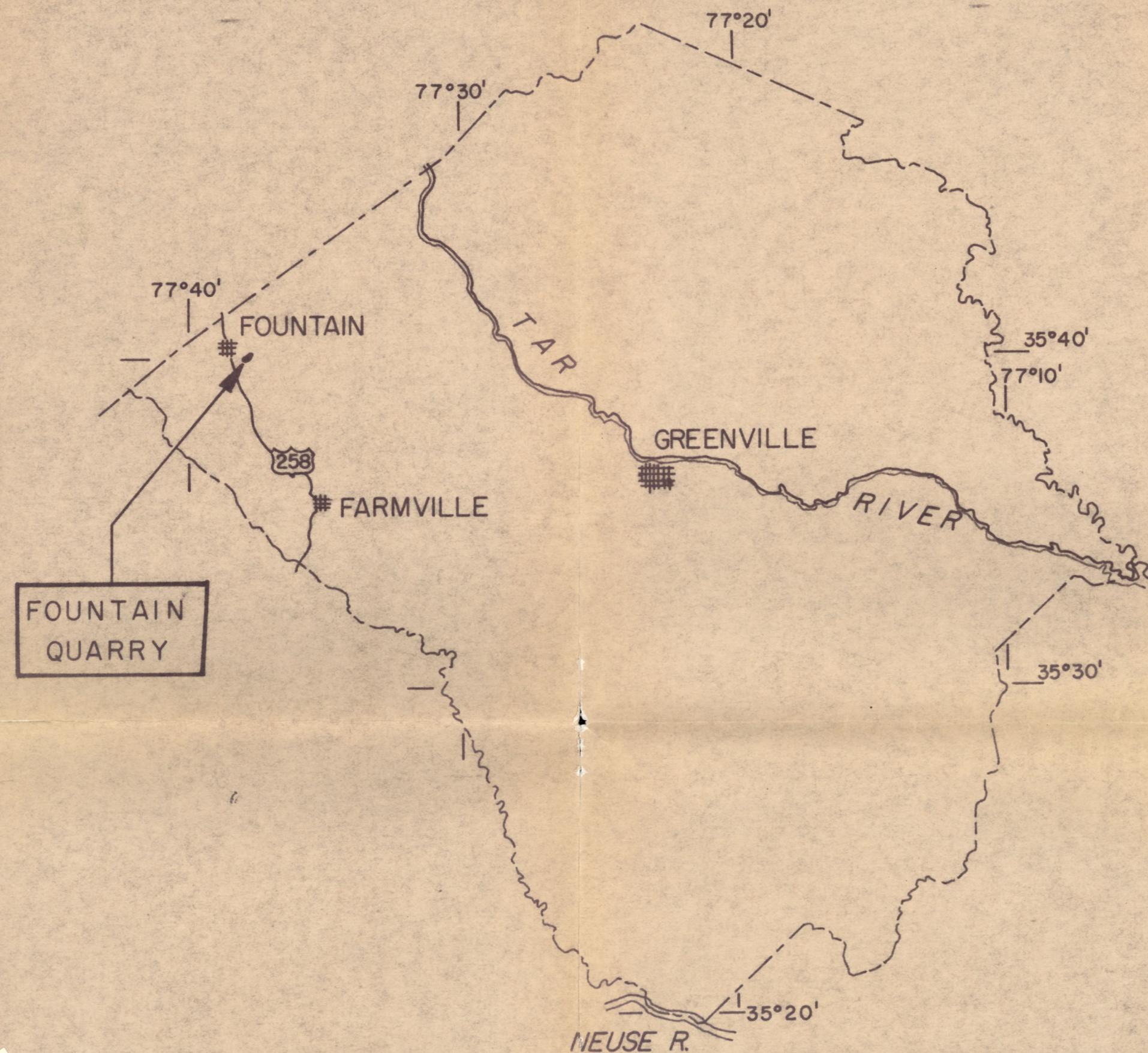
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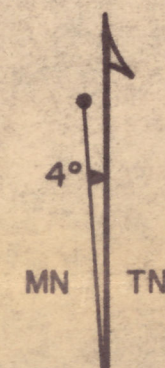
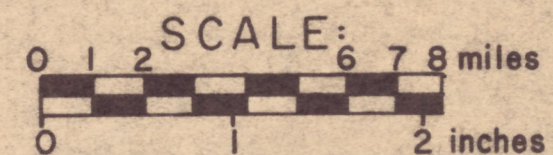


FIGURE 1



LOCATION MAP OF FOUNTAIN QUARRY

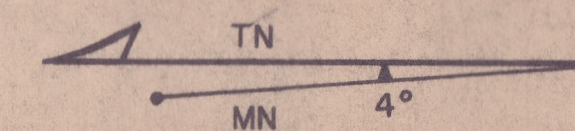
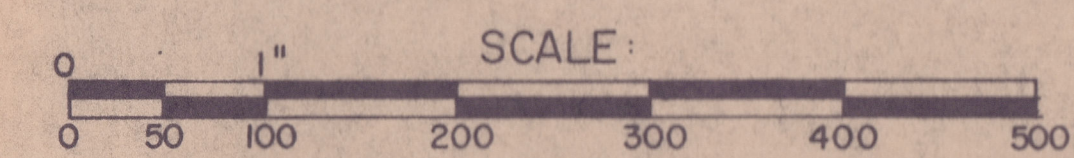
*Pitt County, North Carolina*



Location of Pitt County in  
North Carolina



SHOWING CONTOUR OF GRANITE PRIOR TO QUARRYING (BEGUN 1963).



Drafted by Michael T. Christopher

October 1, 1978

Contour of granite surface expressed as  
feet of overburden (C.I. = 10') :

Location of present haul roads:

Data from 1963 core-hole map and 1970 test-  
drilling map supplied by Martin Marietta Corp.

FARMVILLE

TO 

OUTCROP—

FOUNTAIN



FIGURE 4

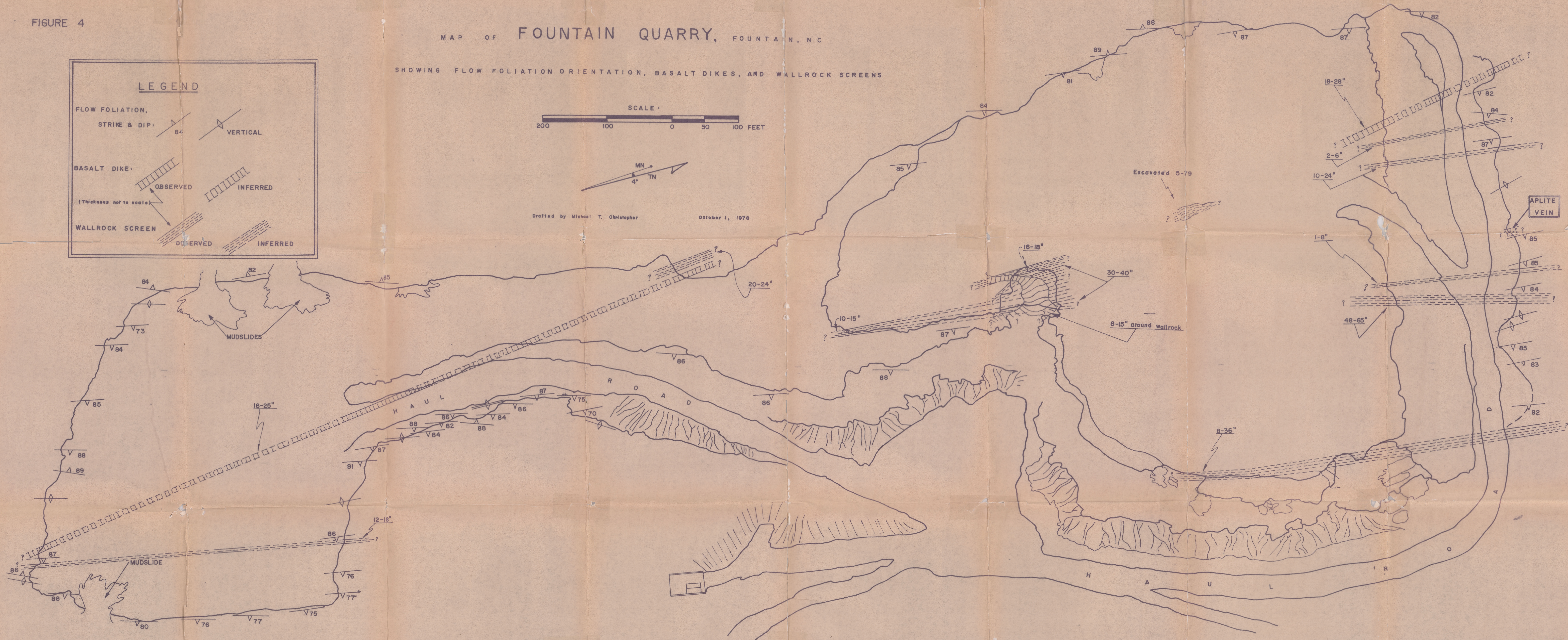


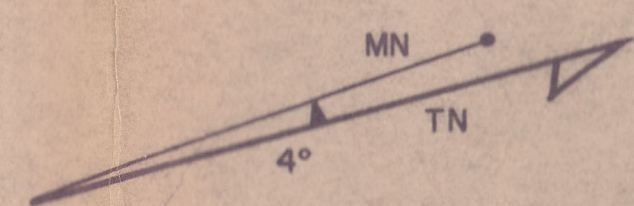


FIGURE 6

# MAP OF FOUNTAIN QUARRY, FOUNTAIN, NC

SHOWING ORIENTATION OF JOINT SURFACES.

SCALE: 0 1 2 INCHES  
200 100 0 50 100 FEET



Drafted by Michael T. Christopher

October 1, 1978

**LEGEND**

JOINT SURFACE, STRIKE & DIP: 80

MULTIPLE JOINTS, CLOSE SPACING: 87

LENGTH OF JOINT (4 ranges):

- < 5 feet: [Symbol]
- 5-15 feet: [Symbol]
- 15-30 feet: [Symbol]
- > 30 feet: [Symbol]

-QUARRY WALL OUTLINE FROM 1963 AERIAL PHOTOGRAPH (NORTH PIT) and 1978 PLANE-TABLE SURVEY (CENTER & SOUTH PIT)

