ANALYSIS OF JOINTING AND FAULTING AT THE SOUTHERN END OF THE EASTERN BORDER FAULT, CONNECTICUT

BY ROBERT G. PIEPUL

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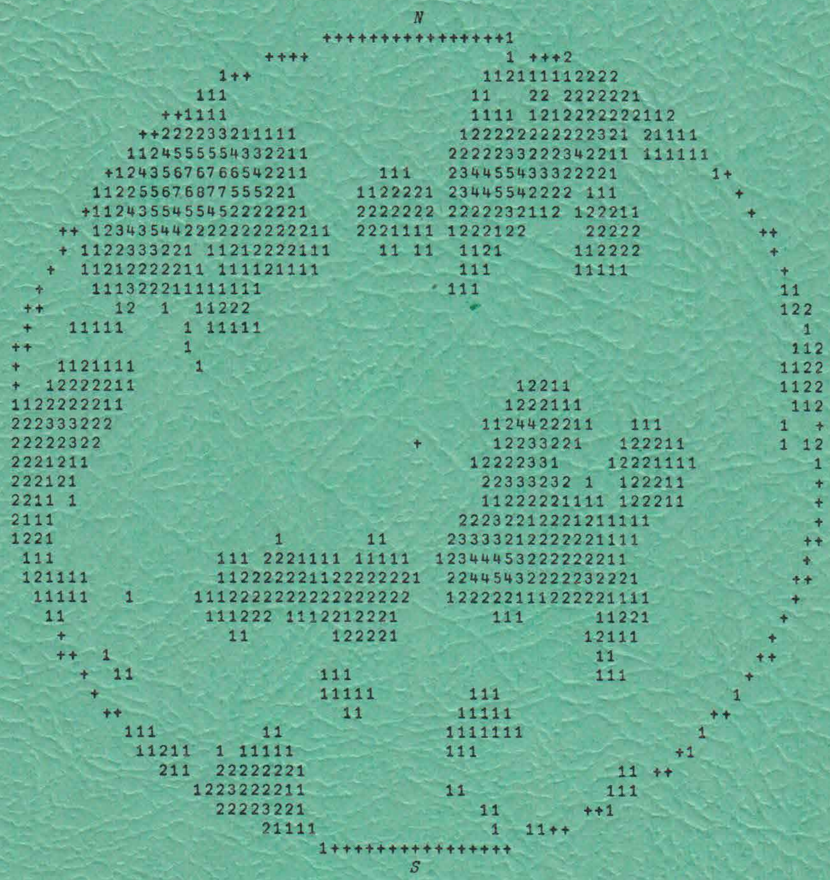

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GEOLOGY DEPARTMENT
UNIVERSITY OF MASSACHUSETTS
AMHERST, MASSACHUSETTS

ANALYSIS OF JOINTING AND FAULTING AT THE SOUTHERN END OF THE EASTERN BORDER FAULT, CONNECTICUT

by

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Contribution No. 23

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TABLE OF CONTENTS

ILLUSTRATIONS

ABSTRACT

A computer-based data collection, storage, and retrieval system was used to separate the brittle fracture elements at the southeastern end of the Connecticut Valley. The relatively undeformed strata of the Connecticut Mesozoic Basin and adjacent pre-Mesozoic basement to the east yield fracture patterns with both similar and contrasting elements.

Common joints, nearly vertical in the pre-Mesozoic basement, have scattered orientations between N75E and N50W but show weak maxima at N30E and N15W. Smoothly polished joints, a sub-class of common joints, are represented by maxima which are nearly vertical and strike N29E, N10W, and N45W.

The pre-Mesozoic terrain also contains two consistently oriented classes of fractures, possibly related to inherent planes of weakness that pre-date the Mesozoic fracturing. Microjoints (sets of sub-parallel fractures with 1-4mm. spacing) and headings (.5-2m. wide zones of parallel, closely spaced, nearly vertical joints) are similarly oriented, forming approximately orthogonal sets at N75E and N15W. Headings also display a strong N30E set.

The pattern of Paleozoic pegmatite dikes shows some resemblance to the patterns of the various fracture elements in the crystallines. Fractures occurring along the centers and parallel to the edges of siliceous dikes strike N18-55E and dip 65° SE. These and quartz-filled fractures (N22-50E 65SE) may represent a NE structural weakness that existed prior to the Mesozoic.

The symmetry of the common joint pattern in the Mesozoic rocks is unlike that in the pre-Mesozoics. Two vertical sets, N40E and N50W, are essentially orthogonal. Weak maxima appear for E-W vertical joints and variably dipping NE striking joints. Mineralized fractures in the Mesozoic rocks are predominantly coated with calcite and mainly strike NE, dipping NW, SE, and vertical. Zeolite and chlorite are also present on joints striking NE and dipping moderately to the NW. Within the pre-Mesozoic terrain, chloritized joints are similar in orientation to fractures in the Mesozoic strata, indicating the effect of a tectonic overprint.

Fault orientation patterns in the Mesozoic and pre-Mesozoic rocks show many resemblances, suggesting origin under similar stress orientation. The majority of minor faults displays normal dip-slip motion. Conjugate NW and SE dipping faults indicate NW-SE extension. Less prominent sets of NE and SW dipping faults, interpreted to be conjugate, suggest that NE-SW extension was also present. Vertically dipping strike-slip faults (rakes of net slip less than 30°) occur on planes oriented N55E, N90E, and N50W and constitute less than 10% of the fault population.

The study shows that Mesozoic rocks contain a number of fracture elements recognizable as an overprint on an ancient tectonic fabric in the older crystalline rocks.

INTRODUCTION TO PROBLEM AND METHODS

Purpose

The orientations of over 2500 joints, faults, and other fracture elements were recorded in the pre-Mesozoic basement complex and adjacent Mesozoic sequence at the southern end of the Eastern Border Fault, east of New Haven, Connecticut. The purpose of this study was to compare fracturing in pre-Mesozoic metamorphic rocks and relatively undeformed Mesozoic strata and to provide information on the history of fracturing in the Connecticut Valley.

A secondary purpose was to develop and experiment with a computer-based information system for fracture data. The large amount of fracture data recorded in this study was placed in computer storage. The computer performs the function of searching through the data much the same as a geologist looks through his notebook. In this way, particular types of data are easily extracted. The system also provided programs for plotting and contouring data on equal-area nets. By using these programs a geologist can easily isolate and analyze separately significant brittle fracture elements. This system greatly reduces the amount of time in presenting the data.

General Geology

The study area is located at the southeastern corner of the Connecticut Valley, east of New Haven, Connecticut (Figure 1). The field area straddles the Eastern Border Fault, which disrupted the pre-Mesozoic rocks and caused the sedimentation that formed the

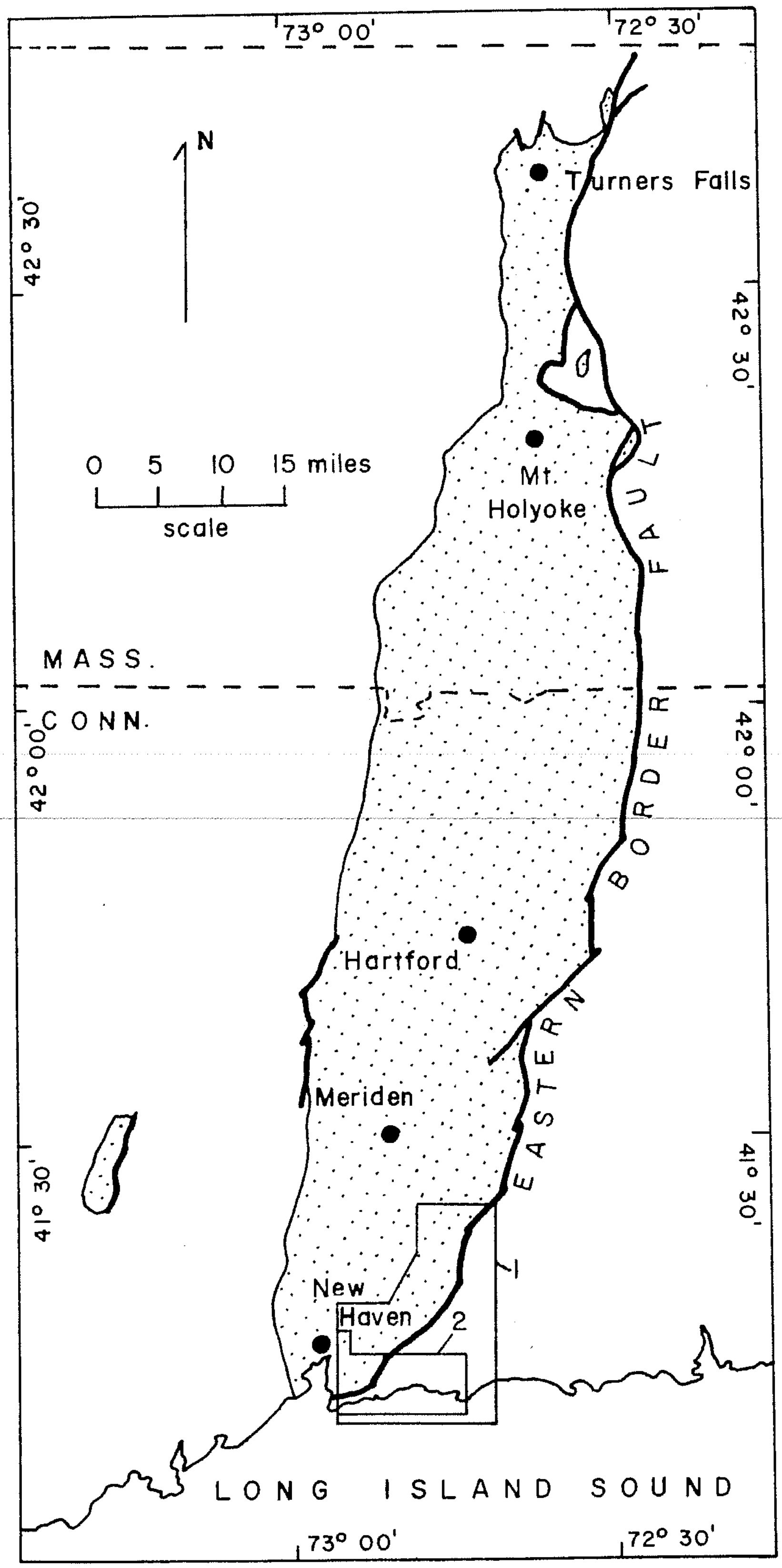


Figure 1. Generalized geologic map of central Connecticut and Massachusetts. (1) indicates location of geologic map in Figure 2. (2) indicates location of study area.

Connecticut Basin during the Triassic and Jurassic (Barrell, 1915; Foye, 1922; Russell, 1922).

Pre-Mesozoic rocks. The major geologic structure of the pre-Mesozoic in this region is the Killingworth Dome (Lundgren, 1968; Lundgren and Thurrell, 1973; Goldsmith and Dixon, 1968), which contains several systems of folds and has a complex tectonic history.

The Stony Creek Granite (Figure 2), the oldest rock unit in the study area, is considered to be Late Precambrian and interpreted to be the result of remobilization or partial remelting of Avalonian acidic volcanic or granitic rocks during Paleozoic metamorphism (Bernold, 1962; Hills and Dasch, 1969). The Stony Creek Granite forms the core of an antiform with an axis trending north-northwest. The geologic maps (Figures 2, 3) show that it is surrounded by the Plainfield Quartzite which is stratigraphically above the granite body. The map pattern suggests that the quartzite is concordant with the granite. Locally, however, the Stony Creek Granite intrudes the quartzite.

Above the rocks of the Stony Creek Dome is the Monson Gneiss which is overlain by the Middletown Gneiss (Figure 2). These gneisses are considered to represent Ordovician volcanics. Younger than the gneisses is the Brimfield Schist (Figure 2) which represents Ordovician sediments.

Refer to Bernold (1962), Lundgren and Thurrell (1973), Lundgren (1968), Dixon and Lundgren (1968), Goldsmith and Dixon (1968), and Mikami and Digman (1957) for more detail on the structure, stratigraphy, and petrography of the rocks east of the Eastern Border Fault.

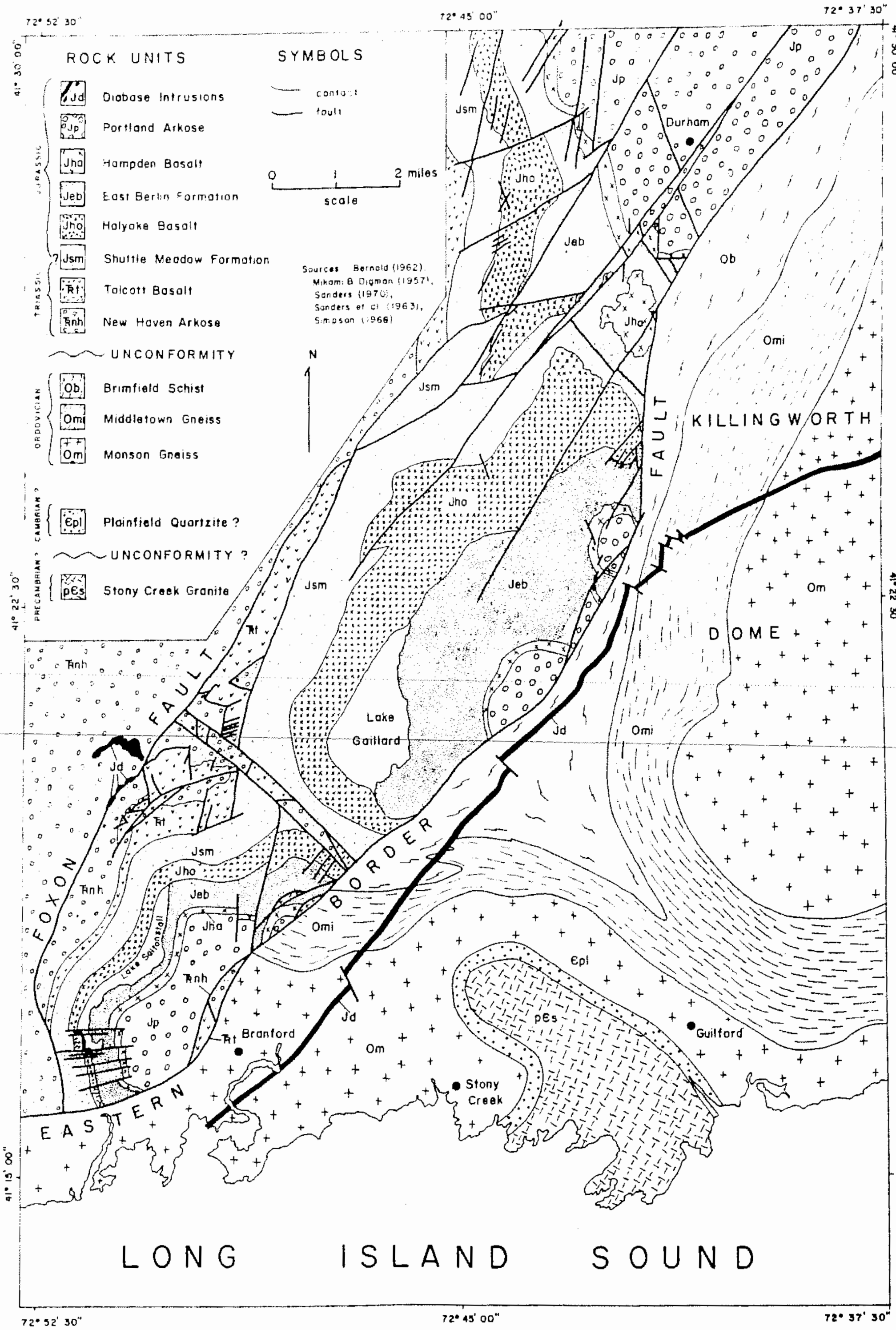


Figure 2. Geologic map showing Gaillard Graben and adjacent crystalline highlands at the southern end of the Eastern Border Fault.

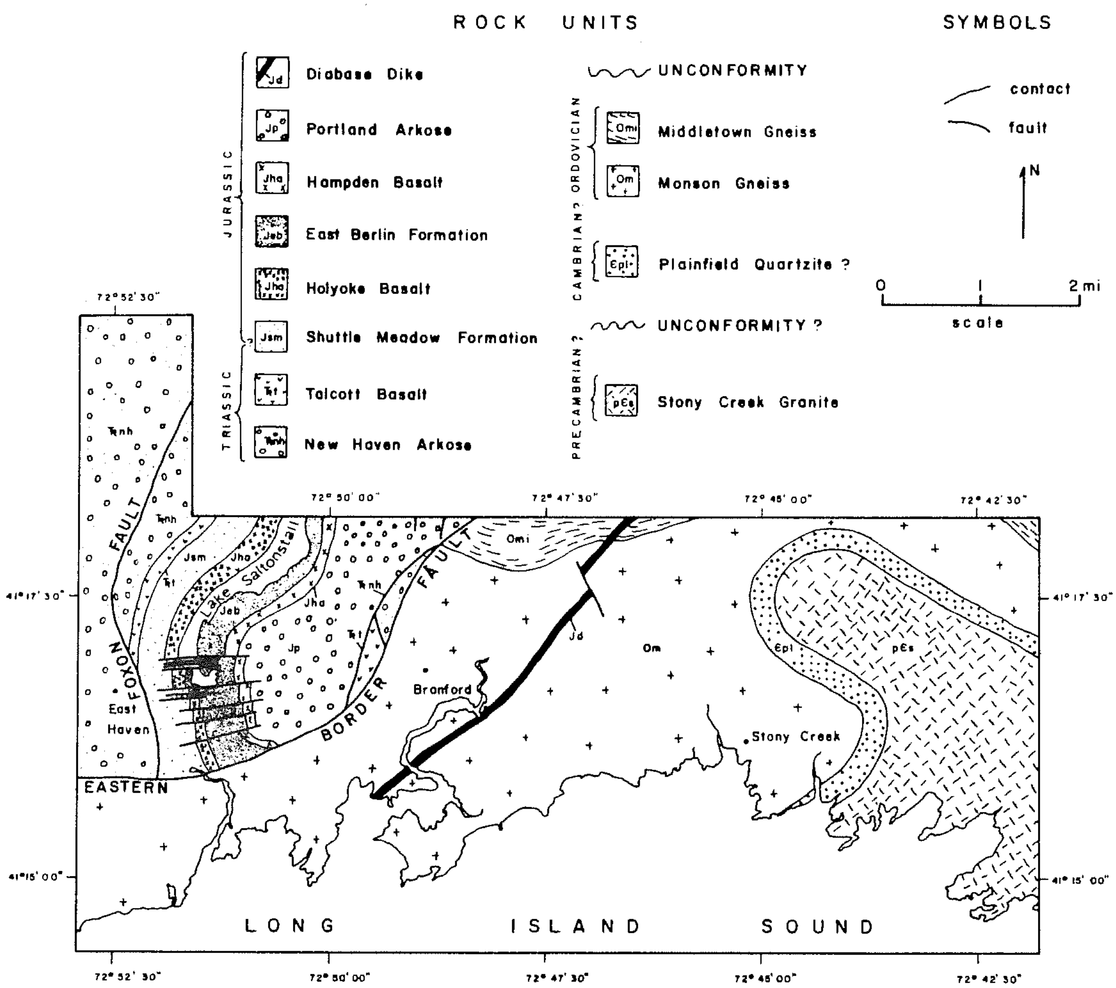


Figure 3. Geologic map of study area.

In this study, fracture stations in pre-Mesozoic units are confined to the Stony Creek Granite and Monson Gneiss located at the southwestern flank of the Killingworth Dome, adjacent to the Eastern Border Fault (Figure 4). In the outcrops sampled, these rocks are generally faintly foliated, although they are moderately foliated at some localities.

Mesozoic rocks. Mesozoic sedimentary and volcanic rocks of the Newark Group lie west of the Eastern Border Fault, in the lowlands of the Connecticut Valley (Figure 2). Although these rocks have been considered to be Triassic, recent evidence from fossil spores and pollen indicates an early Jurassic age for the upper part of the Newark Group (Shuttle Meadow Formation and younger; Cornet et al., 1973). In addition, Armstrong and Besancon (1970) have shown that there is no reliable isotopic dating horizon that would determine the absolute age of the Jurassic-Triassic boundary. In this study, the Jurassic is considered to begin at the base of the Shuttle Meadow Formation (Figure 2).

The main structural feature in the Mesozoic rocks in the vicinity of the study area is the Gaillard Graben (Sanders et al., 1963; Sanders, 1970) bordered on the northwest by the Foxon Fault and on the southeast by the Eastern Border Fault (Figures 2, 3). With the exception of the basal New Haven Arkose and the upper Portland Arkose, the complete Jura-Triassic sequence is exposed on the Gaillard Graben. Figure 2 shows the complete sedimentary and volcanic sequence as exposed in southern Connecticut. Mesozoic stratigraphy has been

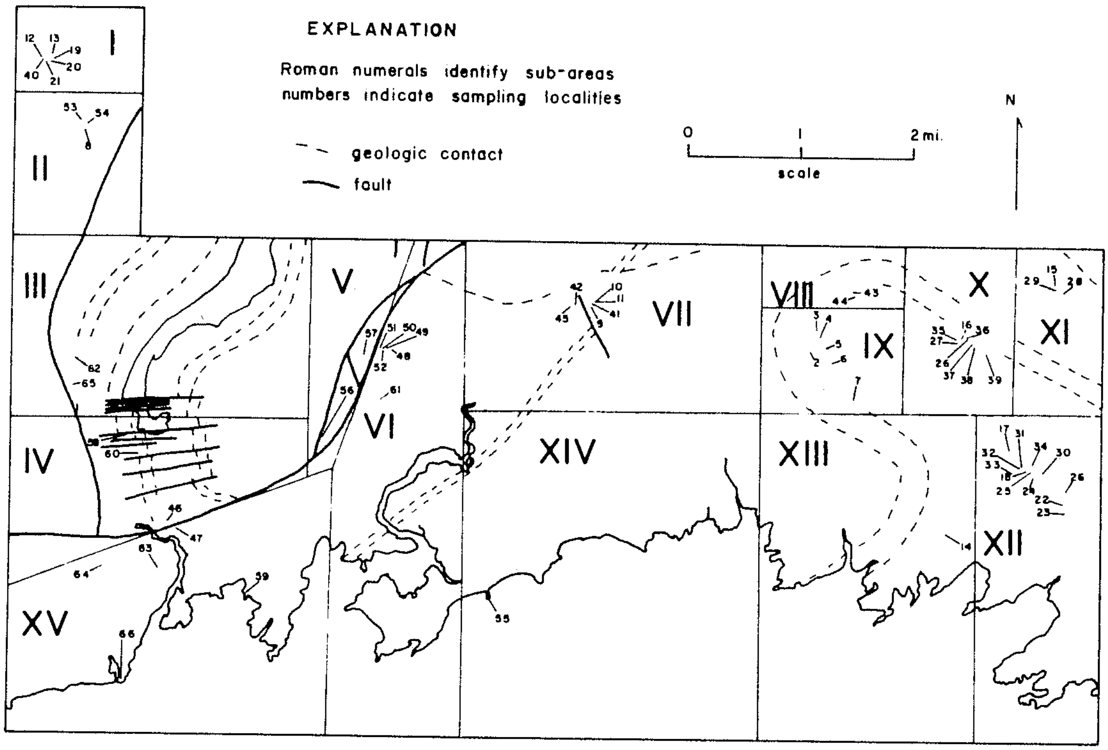


Figure 4. Map of study area with geologic units showing locations of fracture stations and sub-areas.

discussed in more detail by Sanders et al. (1963), Sanders (1970), and Klein (1968). The petrology of the sedimentary rocks has been covered in considerable detail by Krynine (1950).

The sequence has been broadly warped into transverse folds with axes trending perpendicular to the Eastern Border Fault as indicated by the crescent-shaped outcrop patterns of the three lava flows (Figure 2). These folds presumably formed when the hanging wall was dropped along the irregular Eastern Border Fault (Wheeler, 1939). Numerous subsidiary faults in the folded Mesozoic strata trend predominantly N30E. Northwest trending faults are also present (Figure 2). At the southern extremity of the Gaillard Graben, east-west trending strike-slip faults offset the basalt ridges (Figures 2, 3). The primary evidence for these faults is stratigraphic and topographic offset (Sanders, 1970).

Diabase dikes have been shown on geologic maps prepared by earlier workers (Davis, 1898; Mikami and Digman, 1957; Sanders et al., 1963; Wheeler, 1937) studying this region. One in particular intrudes pre-Mesozoic crystalline rocks and parallels the Eastern Border Fault striking N40E. On a geologic map (Figure 2) the dike appears to be offset in several locations by northwest trending faults. The existence of these faults is questionable since the map pattern can also be explained by an en echelon arrangement of discontinuous dikes. In addition to this major dike, many diabase dikes of lesser extent have been mapped immediately west of the Gaillard Graben. One dike is present along a short segment of the Foxon Fault (Sanders et al., 1963).

In this study, fracture stations in Mesozoic rocks are located west of the Foxon Fault and on the southern portion of the Gaillard Graben. The map in Figure 4 shows the locations of all sampling sites in the Mesozoic and pre-Mesozoic rocks.

Previous Fracture Studies

There are several well-known papers dealing with jointing in areas of the United States. Spencer (1959) measured the orientations of 25,000 joints in the Beartooth Mountains of Montana. Wise (1964) related microjoints in the Precambrian basement rocks of Montana and Wyoming with fluid inclusions. Other fracture studies have been done by Hodgson (1965) and Pincus (1961).

The earliest study of fractures in the crystalline rocks in this area was done by Dale and Gregory (1911) who primarily investigated the economic aspects of the granites of Connecticut. They did, however, record the actual attitudes of individual sets of fractures in the granite quarries of the Guilford-Branford area. They observed many types of brittle features and attempted to account for their origin.

In mapping the Guilford 15-minute quadrangle, Mikami and Digman (1957) also measured the orientations of joints in both the pre-Mesozoic and Mesozoic rocks. They attempted to relate mineralized joints in the granitic rocks with an intrusive episode, but were unsuccessful in recognizing any meaningful pattern in the mineralized joints. Also, the number of clean or unmineralized joints measured within small domains was insufficient to show any recurring trend in the data that could be correlated with the regional fracture fabric.

In Mesozoic rocks, Longwell (1922) reports several normal faults displacing the sedimentary beds in an aqueduct tunnel through the basalt ridge which is parallel to and west of Lake Saltonstall. This information is presented in his paper only as a range of strikes and dips of the fault planes.

No detailed investigation of jointing and faulting of the intensity of this study has been made in this region. Recently, however, similar studies have been carried out in other parts of the Connecticut Valley. Detailed work has been done in the vicinities of Meriden, Connecticut (Wise et al., 1975), Mt. Holyoke, Massachusetts (Naso, 1975), and Turners Falls, Massachusetts (Goldstein, 1975).

Field Methods

Sampling techniques. Whenever possible, large outcrops were chosen so that a sample of fractures representing the true rock fabric could be taken. Where feasible, at least 100 joint orientations were measured. Wise (1964), in his study of microjointing in the basement rocks of Montana and Wyoming, lists precautions when sampling fracture orientations from an outcrop:

1. Most outcrops have some sort of planar orientation and those fractures that occur parallel to the trend of the exposure are frequently overlooked. For instance, joints with the same attitude as the wall of a roadcut are generally not noticed. Also, horizontal joints are not revealed on flat outcrops. Planes that strike at an angle to the outcrop surface, however, are more likely to be noticed.

2. In traversing an area there is a strong tendency to select a plane that is sub-parallel to the last one measured, and to ignore those fractures which strike parallel to the direction of traverse. On a flat exposure, these difficulties can be minimized by the observer moving in a broad circle. Vertical

> exposures present more of a problem and the above factors should be considered in the collection and analysis of data.

In the present study, the orientation of each feature was plotted on an equal-area net as it was measured. In this way, strong maxima that are the result of the angular relation between outcrop surface and fracture plane can be minimized, giving a more representative sample of fracture orientations.

Recording data. All the information gathered was recorded on data forms to preserve the necessary details associated with each fracture. The data forms, originally designed by Pferd (1975) as an alternative to the conventional field notebook to provide a systematic method for recording metamorphic structural data, were revised to accommodate the more specialized information collected in a fracture study.

Three types of data forms were used to record the information from this study:

1. Planar elements data sheet for surfaces.
2. Linear elements data sheet for those features whose orientations can be measured as an axis.
3. General data sheet for comments and any information that cannot be recorded on the linear or planar data sheets.

A more complete discussion of the description and use of the data forms is included in Appendix I.

The data forms provide an ideal method for recording several types of information associated with each individual fracture. Information such as fracture length, surface features, and rock type can be easily recorded as codes for every fracture.

Fracture length refers to the maximum dimension of a fracture as seen in the outcrop surface. This means that the total length of a fracture extending beyond the limits of an exposure will not be recorded. It is only intended that this information be recorded in order to distinguish between fractures that are different in size by an order of magnitude.

Surface features include type of mineralization found on fracture planes and such terms as "smooth", "rough", "weathered", and "altered". Smooth and mineralized joints are significant elements of this study and will be discussed later in the text.

By using such a data collection system, information can be methodically and unambiguously recorded, improving the legibility of the field notes.

Computerizing the data. To facilitate the analysis of information, the data forms can be transcribed to computer cards by keypunch and then transfered to a storage device within a computer system. To have access to the data, a computer program was written to extract any information recorded and stored in the computer system. In this way, features of interest can be displayed graphically on equal-area nets or numerical analyses can be performed.

The system proved to be extremely valuable in that it obviously reduces the amount of time spent in preparing contoured equal-area net plots, commonly used in fracture studies. More importantly, the computer rapidly performs the same function as a geologist who searches through his notebook for a particular feature, whose orientation is to be plotted. This permits the geologist to extract particular information which would not be analyzed if a computer were not used because of the amount of time involved.

A description and discussion of this data collection, storage, and retrieval system is presented in Appendix I of this thesis.

Acknowledgements

This research was aided by a grant from Sigma Xi. The computer facilities at the University of Massachusetts, Amherst, were used. I thank Dr. Oswald C. Farquhar who provided the stimulus for beginning and carrying out this project. Sincere appreciation is expressed to Dr. Donald U. Wise who reviewed this manuscript and made many valuable suggestions during the course of the study. I also thank Dr. Leo M. Hall for reviewing the manuscript.

ANALYSIS OF JOINTING

The joints in the pre-Mesozoic and Mesozoic terrains have been analyzed independently because each displays a different fracture pattern. Figures 5A and 6A show all the common joints in the crystalline and Mesozoic rocks of the study area. Possible similarities in the fracture pattern of the two plots exist especially in the northeast striking, steeply dipping joints represented by the areas within the 3% contour lines. In the pre-Mesozoic rocks (Figure 5A) this set strikes N30E while a similarly oriented set in the Mesozoics (Figure 6A) trends N40E.

The basement rocks contain a poorly developed, nearly vertical set trending N45W which is essentially parallel with a steeply dipping set in the Mesozoics which strikes N50W.

The plots of joints in the pre-Mesozoic and Mesozoic rocks also show variability of dips of northeast striking planes, especially by the northwest dipping joints in the Mesozoic rocks.

The pre-Mesozoic and Mesozoic rocks also display dissimilar joint sets. A well-developed, nearly vertical set strikes N10W in the older rock units, but is not displayed by the plot of common joints in the Mesozoic rocks. Conversely, steeply inclined east-west striking joint sets in the Mesozoics do not occur in the pre-Mesozoics. Nearly horizontal joints are well-represented in the crystallines and are attributed to the well-developed sheeting in the granitic rocks.

There appear, then to be similar and contrasting fracture patterns in the basement rocks compared with the overlying strata. In this

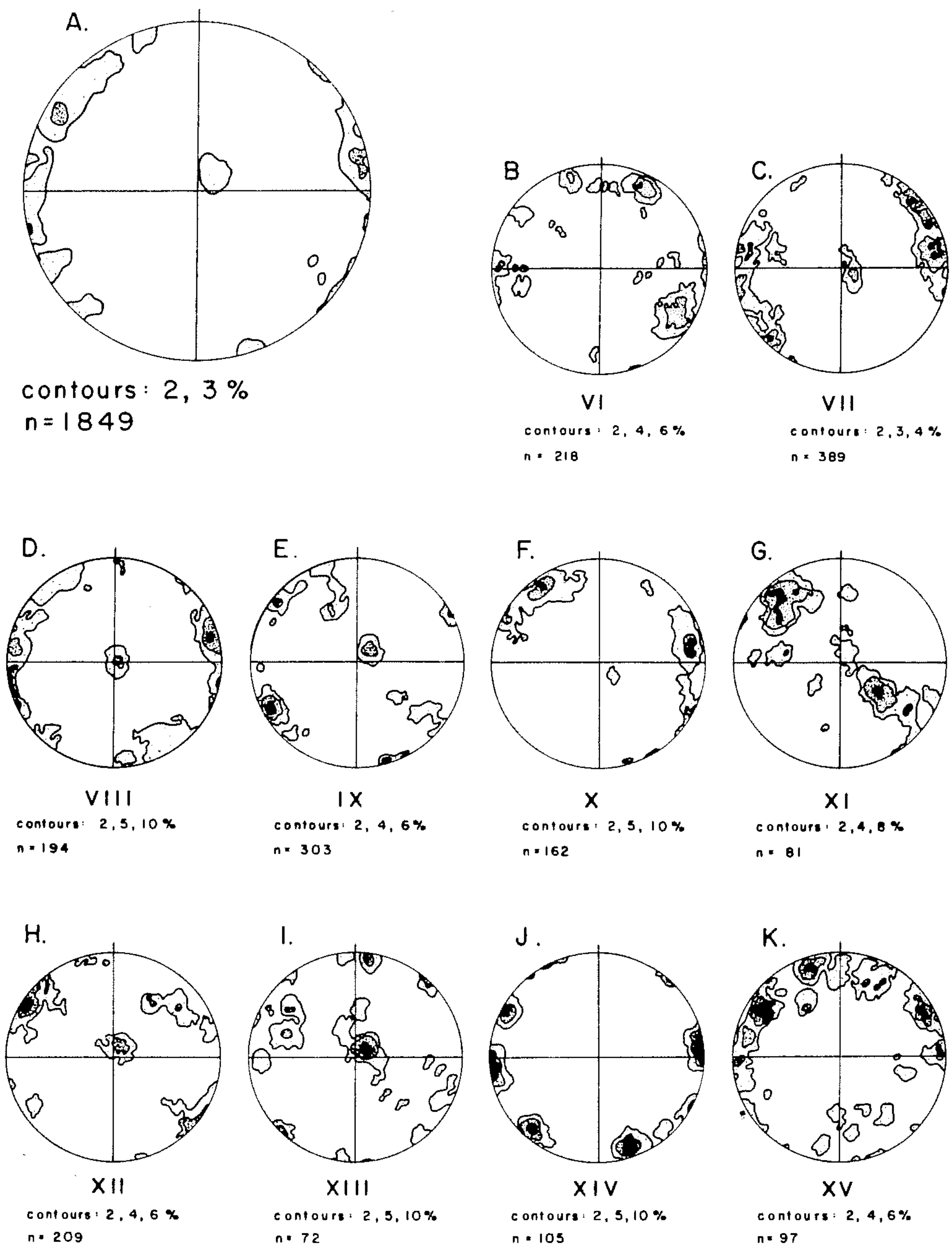


Figure 5. Pole diagrams of common joints in pre-Mesozoic basement rocks. A. All common joints. B-K. Common joints in sub-areas. Roman numerals refer to sub-area locations on map in Figure 4.

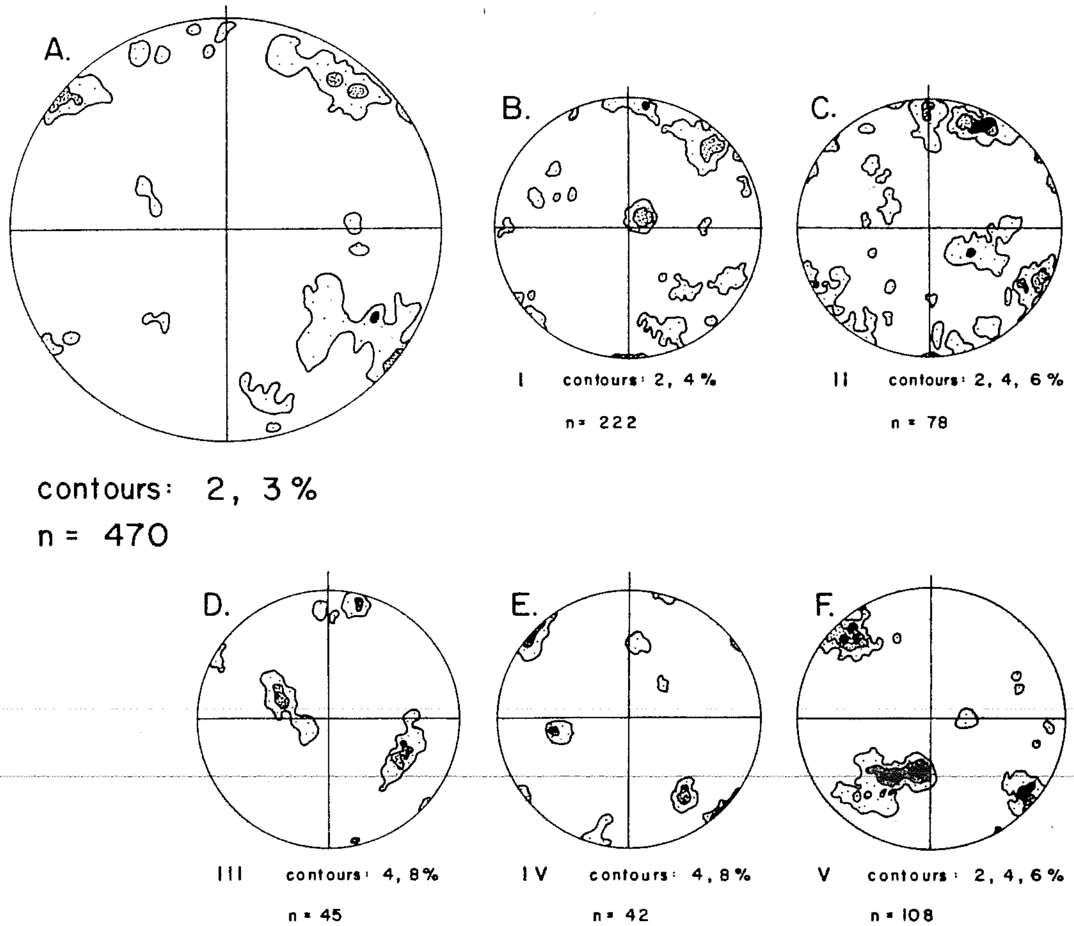


Figure 6. Pole diagrams of common joints in Mesozoic rocks. A. All common joints. B-F. Common joints at sub-areas.

analysis, it was necessary to separate common joints into groups using various criteria such as fracture length, surface features, and sampling locations, and then plotting these groups independently on equal-area nets. Other fracture elements, such as headings and micro-joints, which represent independent classes of brittle features not included in the plots of Figures 5A and 6A, are studied later in the text.

Azimuthal Histograms of Equal-area Net Maxima

Since azimuthal variations of maxima are difficult to perceive on equal-area nets, histograms were prepared. Only those maxima representing poles to planes dipping greater than 65° are included in the histograms. It is reasonable to eliminate those joints which dip at lower angles since, with the exception of sheeting, they are not developed at all in the pre-Mesozoics and constitute a minority in the Mesozoics.

Figure 7B shows such a histogram prepared from a contoured equal-area net plot (Figure 7A). The vertical axis represents the percent of each orientation as it is identified on the contoured equal-area net. The azimuthal range of the planes represented by each maximum on the equal-area net is plotted on the horizontal axis.

In the ensuing discussion, the fracture elements of the pre-Mesozoic rocks will be considered first, followed by a presentation of the fracture system in the Mesozoic rocks.

Jointing in the Pre-Mesozoic Rocks

As defined by Billings (1954, p. 106), joints are "divisional planes or surfaces that divide rocks, and along which there has been

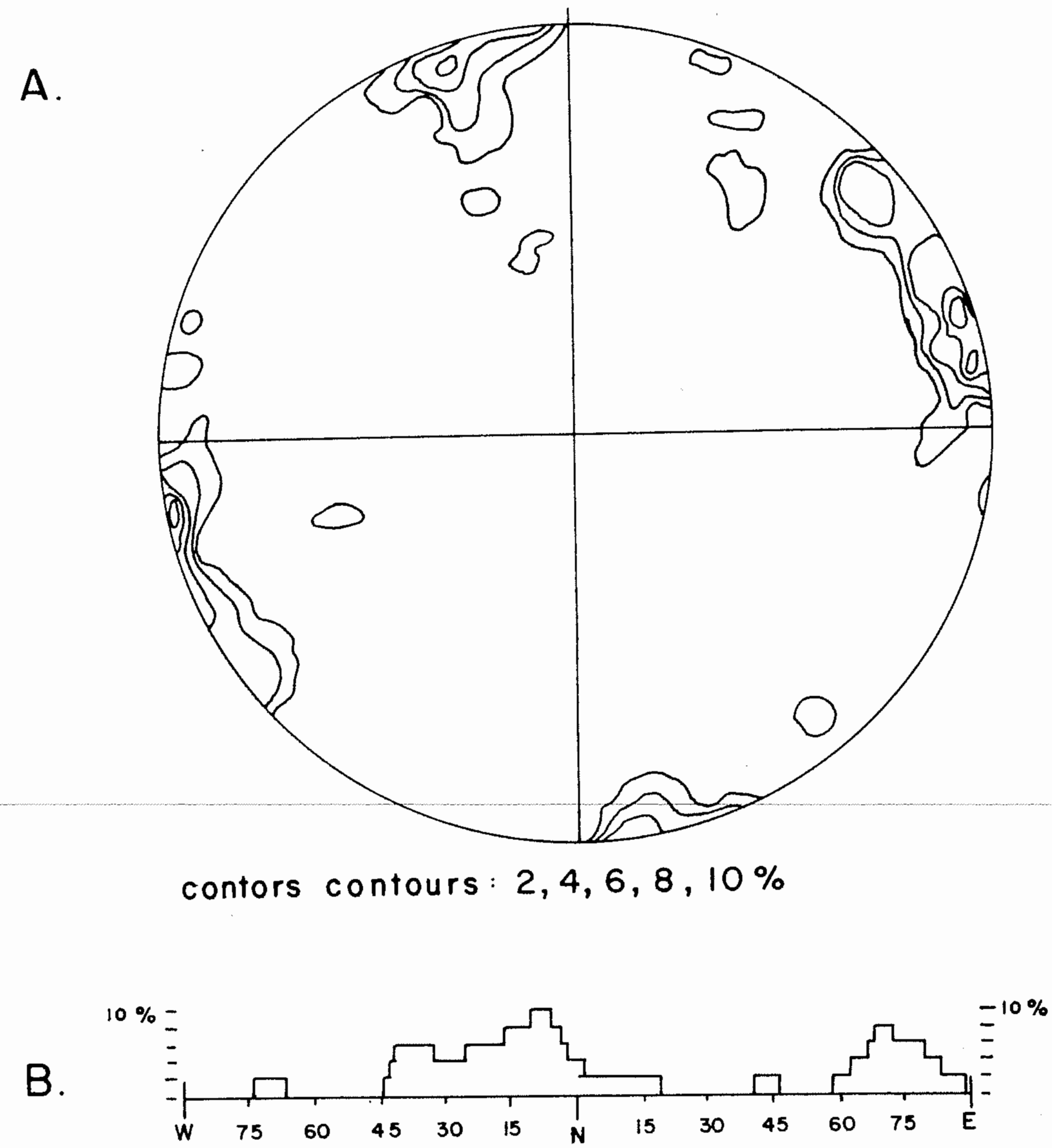


Figure 7. Illustration to show derivation of histograms. A. Poles to planes plotted and contoured on equal-area net. B. Sample azimuthal histogram of equal-area net maxima. Maxima of poles to planes dipping greater than 65° are taken from net in A and plotted in B.

no visible movement parallel to the plane or surface." The first type of joints to be discussed are common joints which are any fractures, of outcrop scale, that are neither headings, microjoints, or faults. Headings are zones of closely spaced, nearly vertical, parallel joints (Dale and Gregory, 1911). Microjoints are four or more small, but not microscopic, closely spaced, sub-parallel fractures that occur within a zone of 3mm. or less in width (Wise, 1964). Faults are fractures that show visible evidence of movement parallel to the fracture plane.

Variation of common joint maxima between sub-areas. The first aspect of the data to be considered will be the variation of all common joints over the pre-Mesozoic study area. Closely clustered fracture stations have been grouped into sub-areas and all common joints recorded within these domains have been represented on both the equal-area plots (Figures 5B-5K) and the histograms (Figure 8).

Although considerable variation exists between each sub-area, a few general observations can be made, suggesting a relation between the fracture patterns. Joints that strike northeast are developed in all sub-areas to some degree. The northeast trends are best developed in sub-areas X, XI, XII, and XIV (Figures 5F, 5G, 5H, 5J). Notably in IX, XI, and XIII (Figures 5E, 5G, 5I) the angle of the dip of northeast striking joints is varied, as indicated by the great circle distribution of their poles.

Northwest striking joints are most well developed in VI, VII, IX, and XIV (Figures 5B, 5C, 5E, 5J). Northerly striking joints are displayed by sub-areas VII, VIII, X, and XIV (Figures 5C, 5D, 5F, 5J).

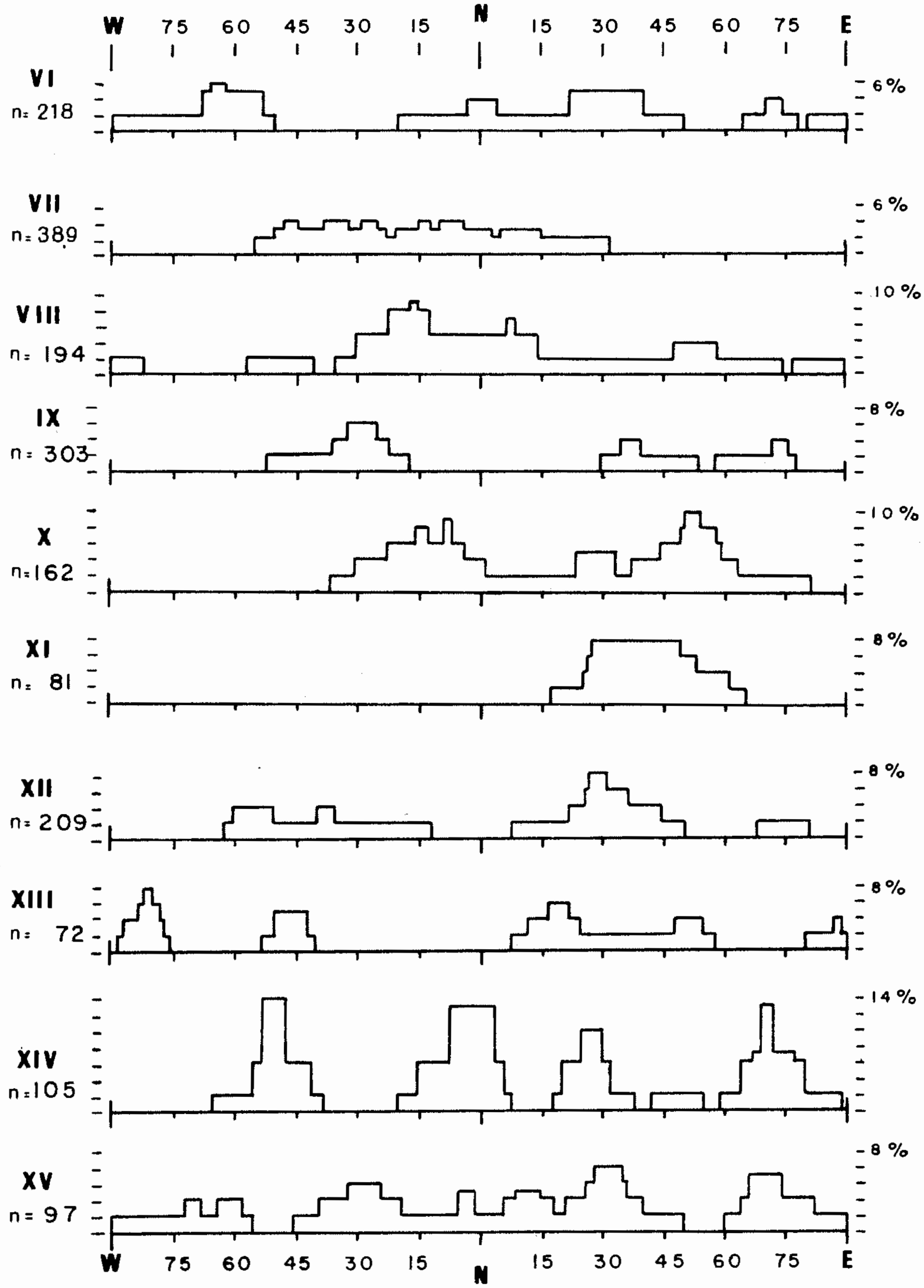


Figure 8. Histograms of common joints at each sub-area in pre-Mesozoic rocks. Roman numerals indicate sub-area locations on map in Figure 4.

Joints striking east-west are poorly developed in all sub-areas except XIII and XV (Figures 5I, 5K).

The majority of well developed sets of common joints in the pre-Mesozoic rocks are steeply dipping. In sub-areas IX, XI, and XIII (Figures 5E, 5G, 5I), however, there is considerable variation of dip of northeast striking joints.

The histograms of Figure 8 display more clearly the azimuthal relation of the joints of each sub-area. No definite correlations can be made that show a systematic fracture pattern throughout the study area.

Separation of size classes of common joints. By using the computer programs in Appendix I, joints were separated into various size groups according to their lengths on the outcrop surface. They are represented by the histograms in Figure 9. This was to determine if prominent fracture sets of any one size class of common joints could be correlated with any of the other brittle features such as micro-joints or headings which are discussed later in the text. A secondary reason for separating all common joints into size classes is to determine if the largest size class of common joints (those joints greater than 3m. long) are more representative of the structural grain of the crystalline rocks than the smaller joints. The histograms representing the various size classes do not reveal any evidence as to the reliability of the larger joints.

Smooth joints. The massive rocks of granite texture commonly contain joints with very smooth, polished surfaces, free from any

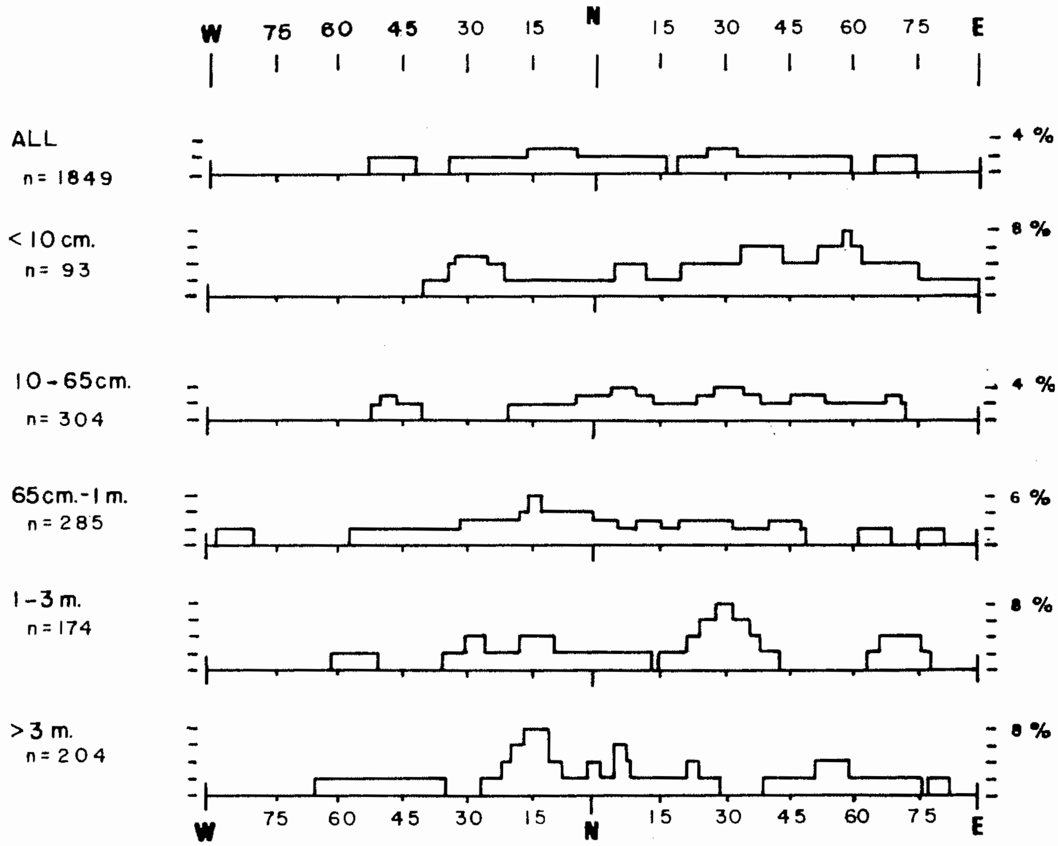


Figure 9. Histograms of common joints in pre-Mesozoic rocks separated into size classes.

irregularities. Smooth joints are a sub-class of common joints and are included in the equal-area net of Figure 5A. A contoured equal-area plot of all smooth joints in the pre-Mesozoic rocks (Figure 10A) shows two well developed maxima representing prominent steeply dipping sets of smooth joints striking N29E and N11W.

To show the variation of smooth joints in the crystalline rocks of the study area, individual equal-area net plots were made of each domain and are illustrated in Figures 10B-10K. Sub-areas IX, XII, XIV, and XV (Figures 10E, 10H, 10J, 10K) show significant clustering of poles to northeast striking joint planes. Northwest striking smooth joints are displayed by VIII, IX, XII, and XIV (Figures 10D, 10E, 10H, 10J). Well clustered sets of northerly striking joints can be seen in VIII, X, and XIV (Figures 10D, 10F, 10J).

The histograms of Figure 11 represent the separate size classes of smooth joints over the whole study area. Two strongly developed maxima oriented N30E and N15W correlate to some extent between the distinct size classes of smooth joints. This suggests that the development of these fractures in the crystalline rocks is independent of their size.

Rough joints. Rough joints are a sub-class of common joints. A common joint is considered to be rough if its surface contains irregularities such as protruding mineral grains. The fracture surface may be nearly planar, however. Rough joints often appear in the same outcrops as smooth joints, implying that the occurrence of these joint types is not dependent upon rock type.

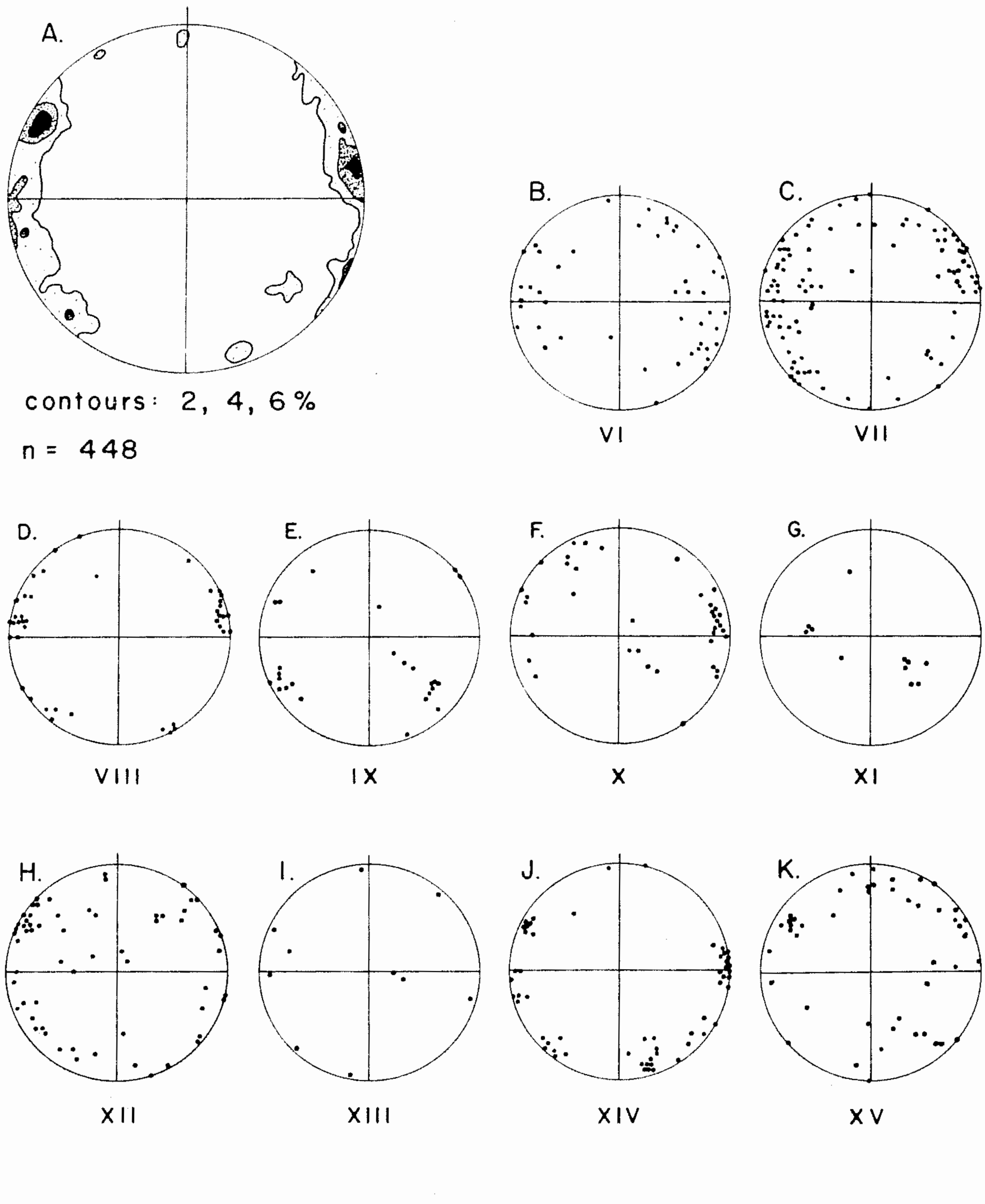


Figure 10. Pole diagrams of smooth joints in pre-Mesozoic rocks. A. All smooth joints. B-K. Smooth joints at sub-areas.

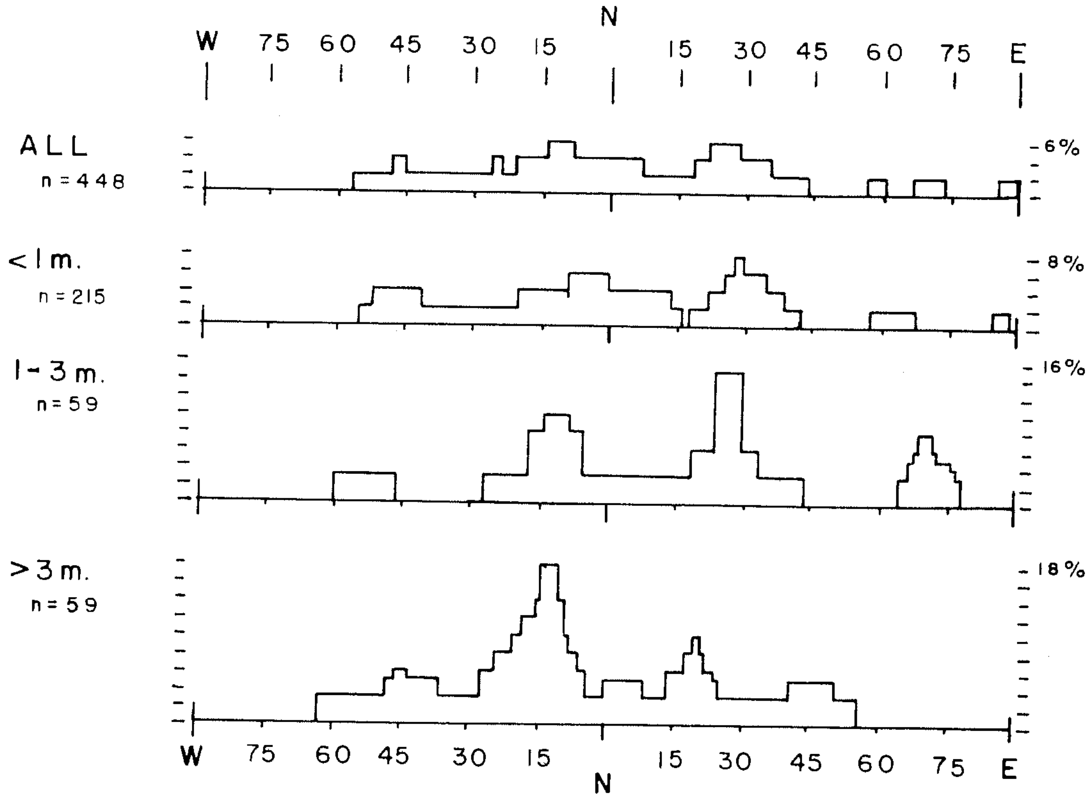


Figure 11. Histograms of size classes of smooth joints in pre-Mesozoic rocks. Note the correlation between each of the three size classes which suggests that the development of smooth joints is independent of their size.

On equal-area nets, the pattern of rough joints (Figure 12) closely resembles that of smooth joints (Figure 10A). The most obvious difference between the two sub-classes is that the smooth joints form sets that are much more well developed than do the rough joints. Note that the number of joints in both sub-classes is approximately the same, which indicates that the smooth joints show preferred orientation to a greater extent.

Microjoints. Microjoints can be seen on the outcrop surface as hairline fractures (Figure 13). This class of tiny fractures is independent of common joints and is a separate element of the fracture system in the crystalline rocks, only occurring in massive rocks of granitic texture.

Microjoints show a much simpler pattern than do any of the other classes of fractures in the crystalline rocks when plotted and contoured on an equal-area net (Figure 14A). A possible orthogonal relation exists between the N15W and N75E sets, although a poorly defined, but well developed trend exists from N5W to N40W.

When discussing fractures in granite, it is necessary to introduce the terms rift, grain, and hardway, which are features in granites that make it suitable for quarrying. Rift is a term used by quarrymen to denote the plane of easiest splitting in granite. Grain is a plane perpendicular to rift which is the second easiest direction in which the granite is split. Hardway is a plane perpendicular to rift and grain and is, of course, that direction in which the rock is least easily split. Dale and Gregory (1911) and Dale (1923) discuss these features,

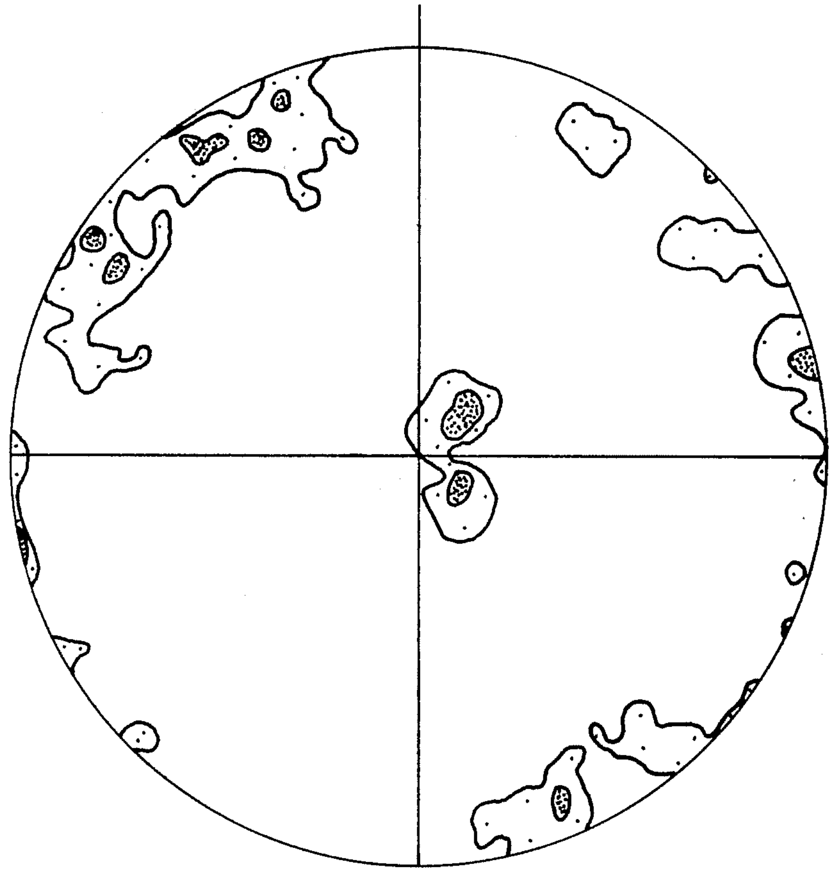


Figure 12. Pole diagram of rough joints in pre-Mesozoic rocks. These joints do not show the well developed N29E and N11W trends, which are shown by smooth joints in Figure 10A.

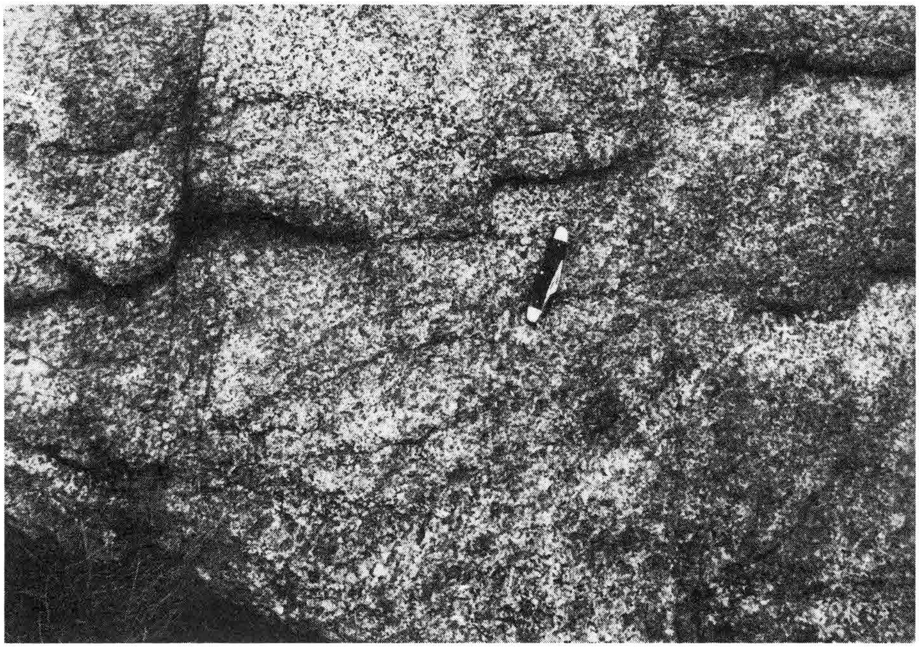


Figure 13. Photograph of microjoints in granitic gneiss. Microjoints are often seen as several sub-parallel hairline fractures in massive granitic rocks.

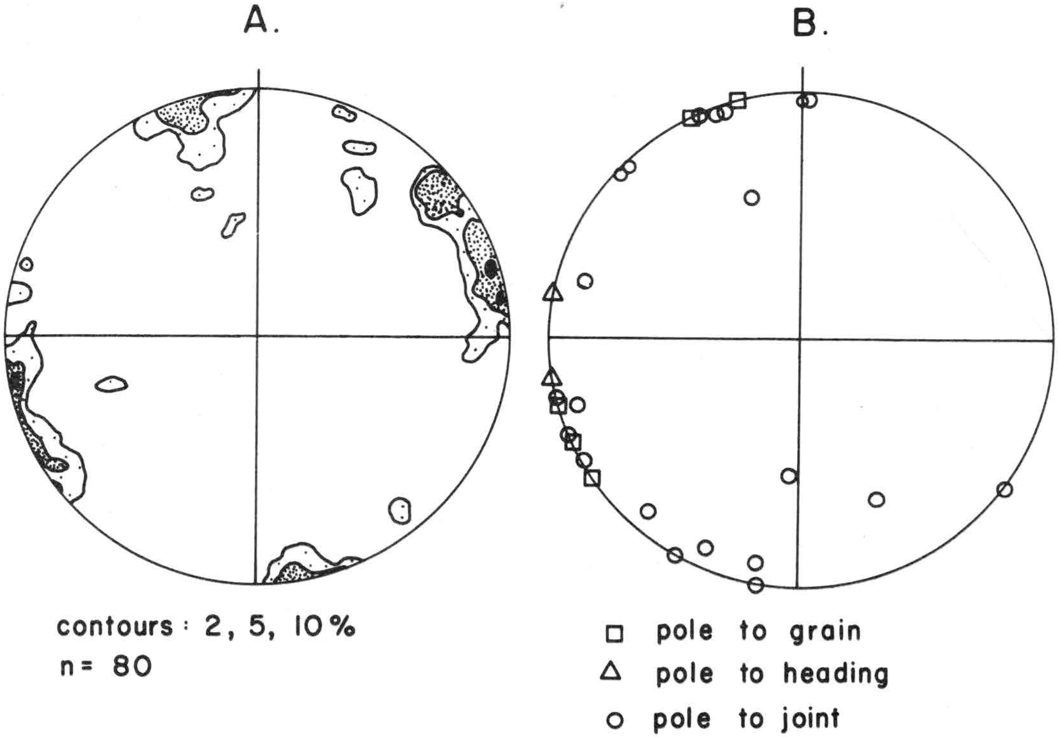
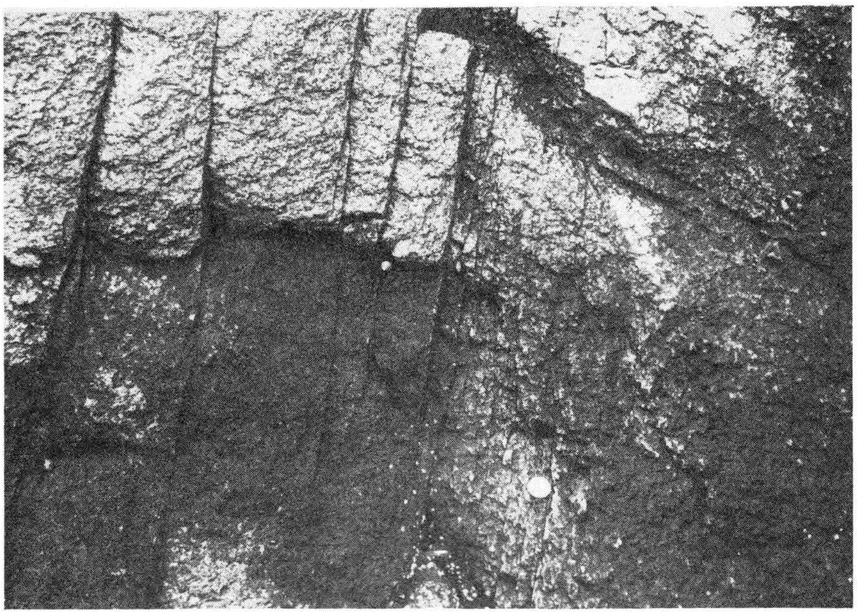


Figure 14. Pole diagrams comparing microjoints to grain in quarries near Branford-Guilford. A. Microjoints in crystalline rocks. B. Grain, headings, and joints observed in quarries in Stony Creek Granite (from Dale and Gregory, 1911).

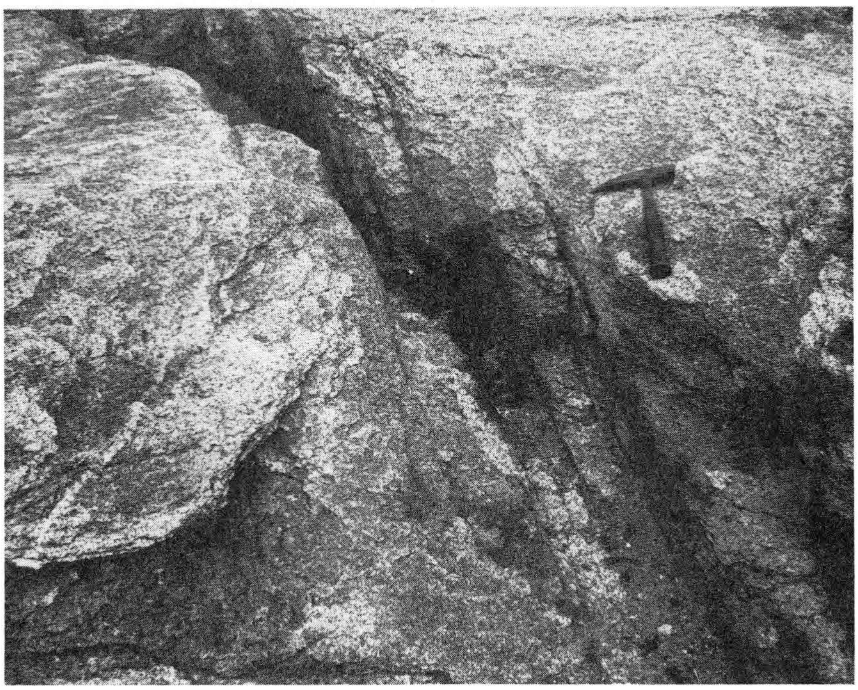
as well as several others common in quarries, in work done on the commercial aspects of the New England granites. Balk (1937) also discusses rift, grain, and hardway.

There appears to be a relation between microjoints recorded in the study area and the development of rift and grain in south-central Connecticut. Dale and Gregory (1911) suggest the correlation of rift and grain with fluid inclusions in the individual mineral grains. Wise (1964) shows that there is a correlation of microjoints with fluid inclusions in the granitic basement rocks of Montana and Wyoming. In the Stony Creek area, Dale and Gregory (1911) have recorded several orientations of grain from the granite quarries near the study area, all with vertical dips (See Figure 14B). These trends are consistent with well developed microjoint maxima. Fluid inclusions, then, may well have controlled the development of microjoints in this study area. However, universal stage microscope work to determine their orientations is not within the scope of this study.

Headings. A heading, common in massive granites, is a vertical zone, usually from 1/2 to 2 meters wide, bounded by two nearly vertical, parallel joints, between which other closely spaced parallel joints are located (Figures 15A, 15B). The joints within the zone are usually spaced from a few centimeters up to 30 centimeters apart. The term "heading" was used in the literature by Dale and Gregory (1911), but originally was used by granite quarrymen. Two such joint zones, spaced a moderate distance apart, defined the bearing or "heading" in which the granite would be worked.



A.



B.

Figure 15. Photographs of headings. A. Heading in Monson Gneiss at station 66. B. En echelon heading at station 66.

The pattern of poles to headings contoured on an equal-area net (Figure 16A) is similar to that of microjoints (Figure 14A), but displays a maximum striking N30E, not detected in the microjoints. The contoured equal-area nets show the simplicity in the patterns of the headings and microjoints, suggesting a relationship between the two classes of fractures. These fracture classes are contrasted on the histograms of Figure 17.

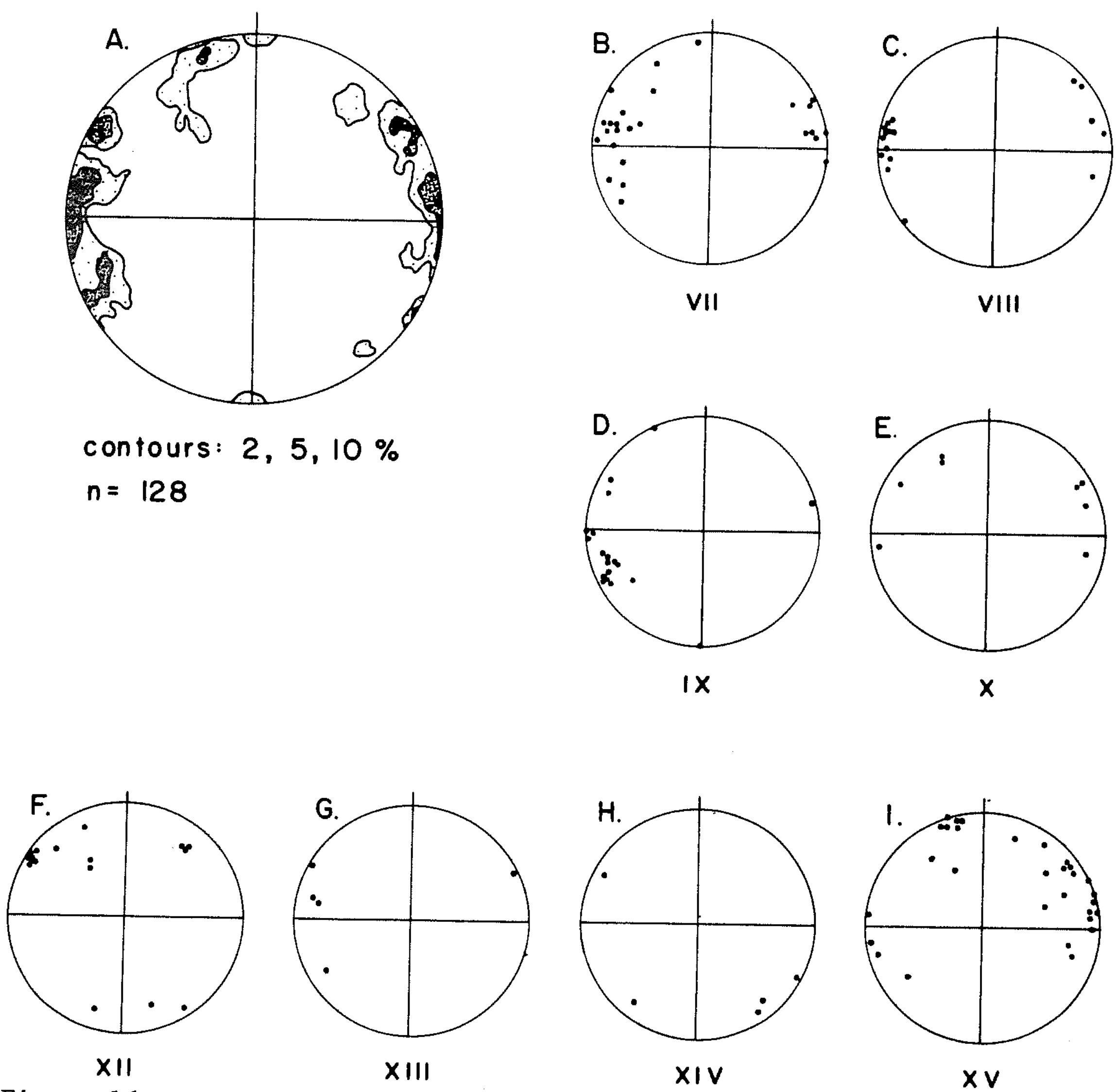


Figure 16. Headings in pre-Mesozoic rocks. A. Poles to all headings plotted and contoured on equal-area net. B-I. Poles to headings in each sub-area.

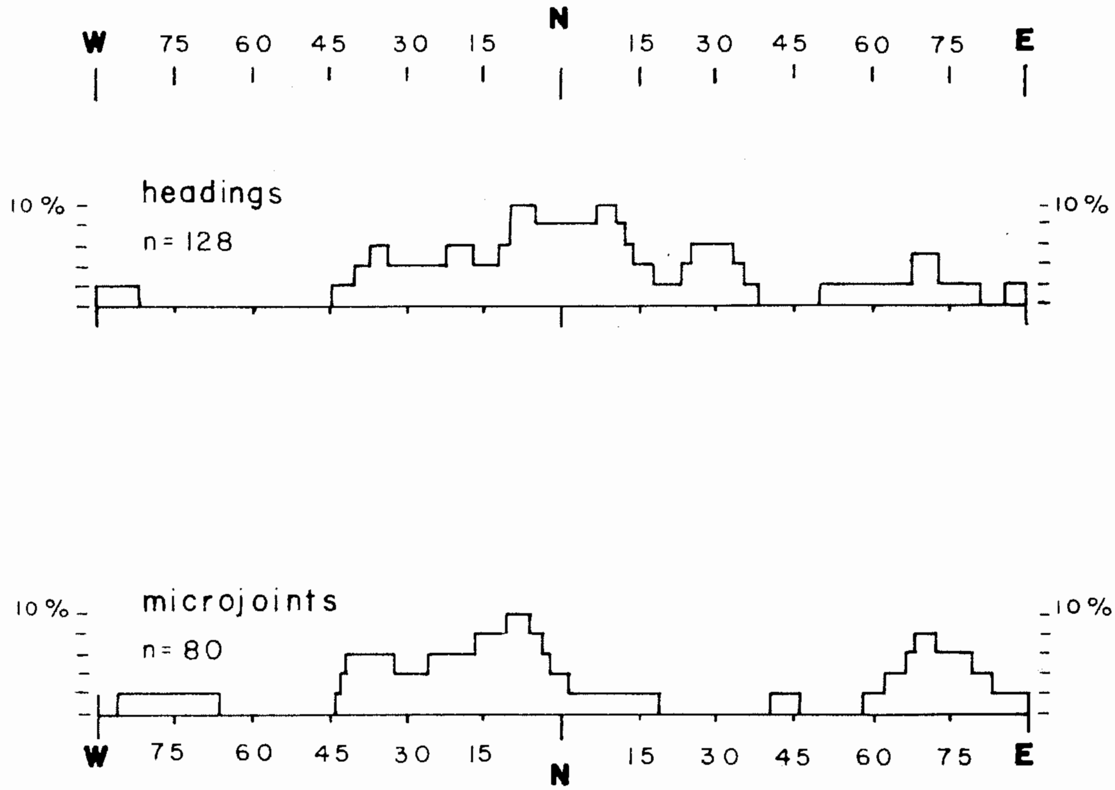


Figure 17. Histograms comparing the orientations of microjoints and headings. Note the similarities between the two types of fractures.

The poles to headings from each sub-area are shown plotted in Figures 16B-16I. A northerly trend persists in sub-areas VII, VIII, and XV (Figures 16B, 16C, 16I). Headings striking northeast occur in all sub-areas except VIII (Figure 16C) and are best developed in XII (Figure 16F) where they strike approximately N30E. Northwesterly striking headings appear in all sub-areas. They are most prominent in sub-areas IX and XV (Figures 16D, 16I). Poles to headings striking east-west appear in all the plots but are not common.

Pegmatite dikes. Pegmatite dikes were observed throughout the crystalline rocks in the study area. These dikes are pre-Triassic and their interlocking granular relations with the country rock suggest they intruded the crystalline rocks during or subsequent to a late stage metamorphic event.

The orientations of 60 pegmatite, aplite, and quartz dikes are represented in Figure 18 in which poles to planes have been plotted and contoured on an equal-area net. Figure 18 shows that some dikes appear to be grouped along planes striking northeast. There also seems to be a clustering of poles to dikes that strike between N15E and N45W.

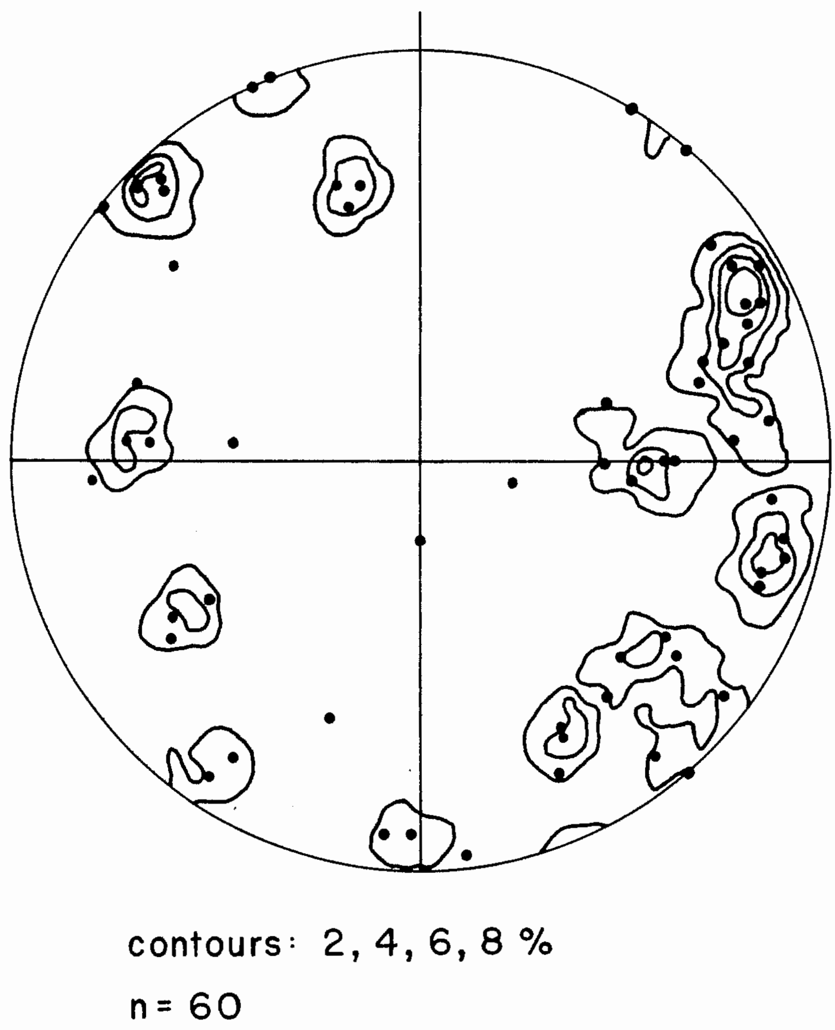


Figure 18. Poles to pegmatite, aplite, and quartz dikes plotted and contoured on equal-area net.

The contoured plot of the pegmatite, aplite, and quartz dikes is not completely unlike plots of smooth joints (Figure 10A), microjoints (Figure 14A), and headings (Figure 16A). All are characterized by a high occurrence of steeply dipping planes that strike between N5W to N40W. The pattern of each of these fracture types also individually exhibits vague similarities with that of the dikes.

Mineralized fractures. Several types of mineralization were observed on the surfaces of joints in the pre-Mesozoic rocks: calcite, epidote, zeolite, chlorite, and quartz. In particular a 1 to 3 centimeter quartz layer, that is cleaved perpendicular to its surface, has been found on fracture planes. Such layers appear to be remnants of quartz dikes and, since these features were not observed in any of the Mesozoic rocks, they may pre-date the deposition of the Mesozoic rocks.

A possible contemporaneous feature has been pointed out by Russell (1922). He discusses the occurrence of a great quartz lode that seals a segment of the Eastern Border Fault immediately north of this study area. Pebbles from the quartz lode are found in the fanglomerates immediately to the west of the fault. Russell (1922) therefore shows that the deposition of the fanglomerate postdated the quartz lode. He also points out that the lowest horizon at which these sediments are found is just below the "lower basalt sheet" (Talcott Basalt ?). Russell (1922) believes that the quartz lode was probably formed during the Appalachian Orogeny by heated magmatic waters.

The poles to all mineralized fractures in the crystallines have been plotted on an equal-area net (Figure 19). Chlorite joints cluster

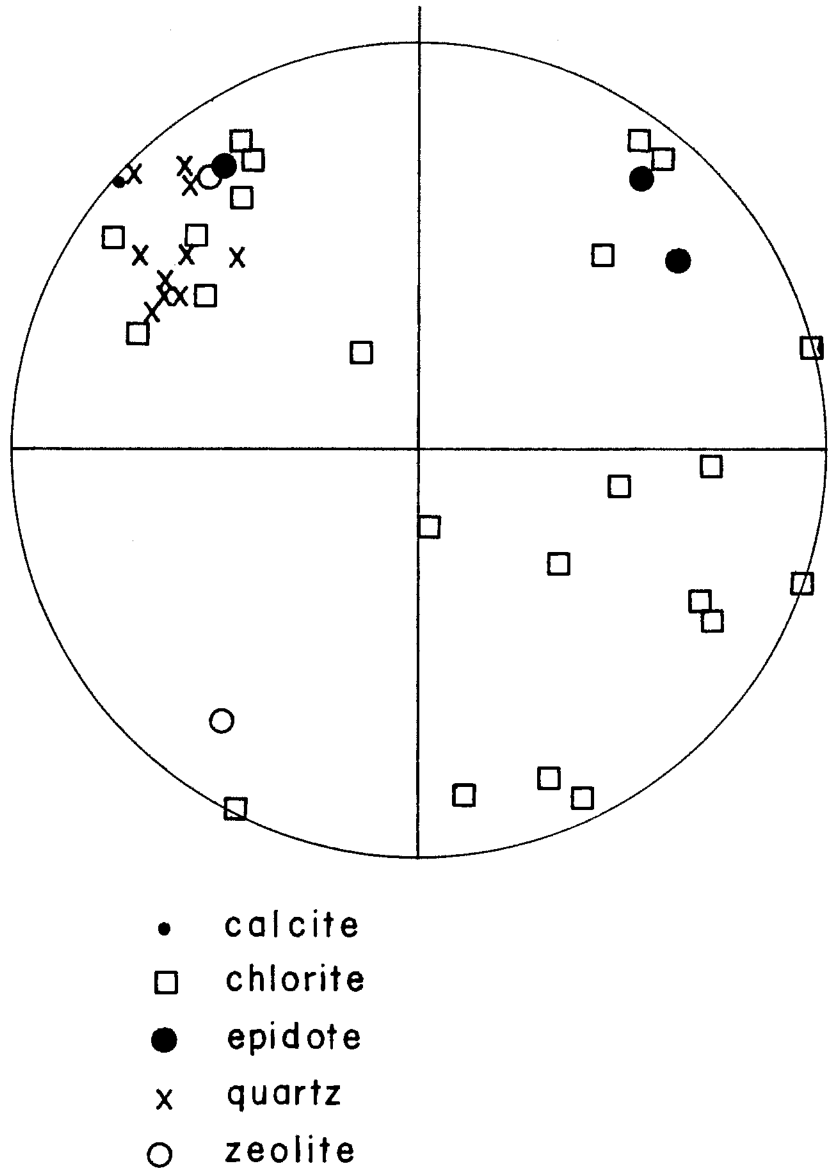


Figure 19. Poles to mineralized joints observed in pre-Mesozoic rocks.

significantly between N20-60E. Weakly defined clusters occur at N50-65W and N65-85E.

More significant are the quartz surfaces which range in strike from N22E to N50E. If the quartz-coated surfaces are Paleozoic features, then an inherent weakness existed along northeast striking planes before the Mesozoic fracturing occurred.

Miscellaneous features. At one locality (Station 39, Figure 4) siliceous dikes, which intruded the Stony Creek Granite, form raised linear features that are due to differential weathering where they intersect the horizontal outcrop surface (Figure 20). Fractures occur along the centers of these dikes, parallel to their edges, and there appears to be a relation in origin between the development of these fractures and the formation of the dikes. The contacts between the dikes and the country rock do not show evidence of shearing. In addition, the interlocking crystals of granite and pegmatite show that the injections of these dikes occurred when the granite was in a somewhat ductile state. It is inconceivable that the granite was in this condition during the Mesozoic and these dikes are therefore considered to be of Paleozoic age. These features have been plotted on an equal-area net in Figure 21 which shows that their strikes range from N18E to N55E.

At station 66 (Figure 4), microjoints and headings (Figure 15B) occur in en echelon form. The en echelon fractures illustrated in Figure 22, all strike between N69E and N75E. Two zones, possibly representing one en echelon system, strike N65W and N70W. A third zone, interpreted to be the conjugate of the latter two zones, strikes N55E.

Figure 20. Fracture along center and parallel to edges of siliceous dike at station 39 in Stony Creek Granite. Due to differential weathering, dikes such as this appear as raised linear features on flat outcrop surfaces.

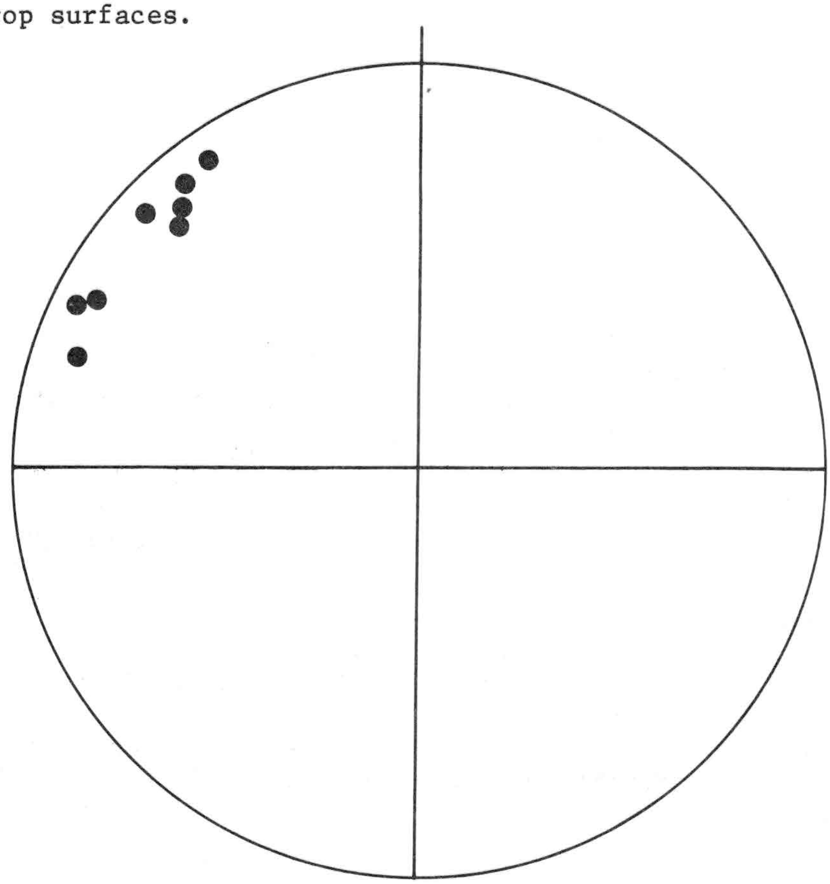


Figure 21. Pole diagram of fractures along centers of siliceous dikes.

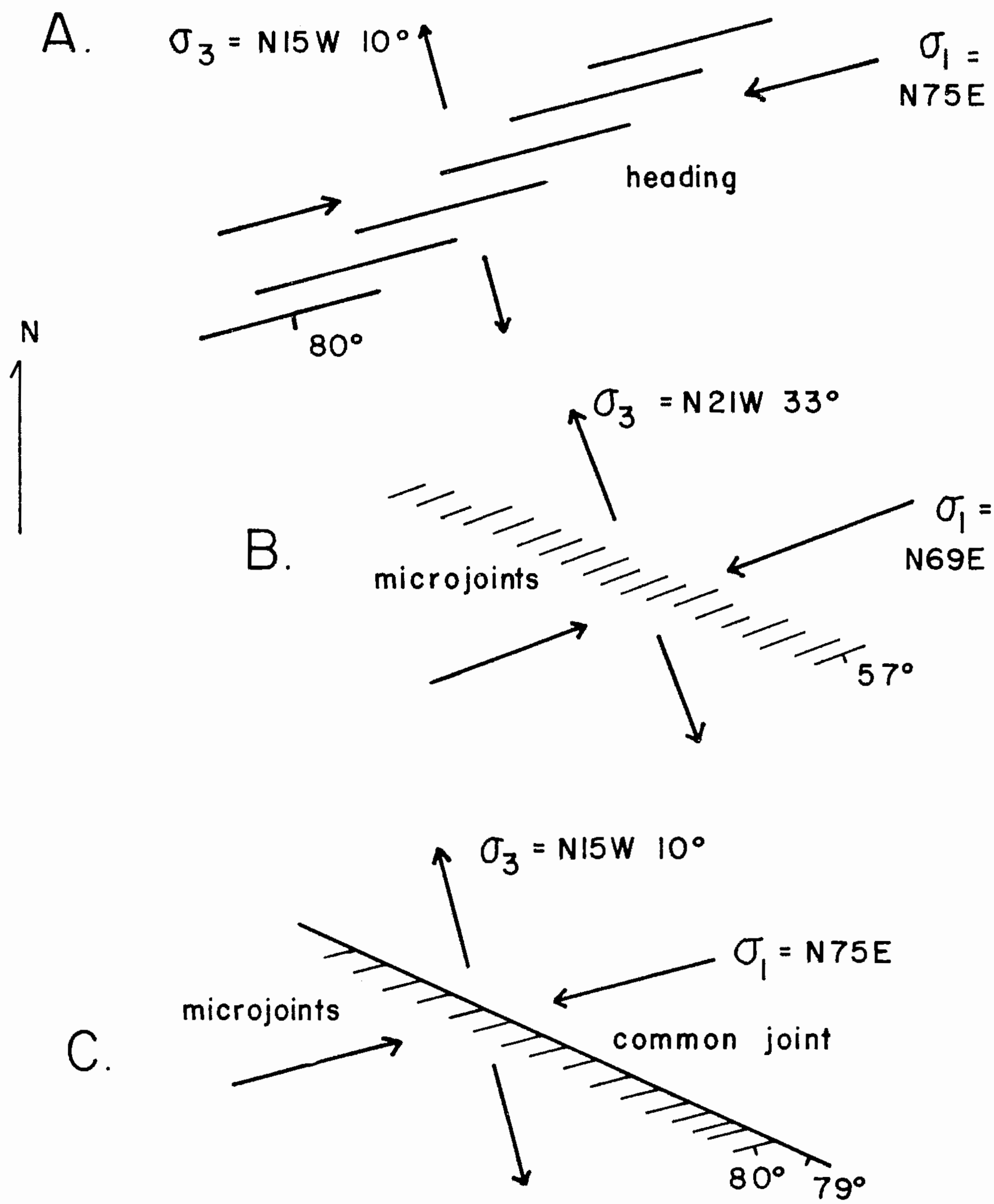


Figure 22. En echelon fractures at station 66. A. En echelon heading. B. En echelon microjoints. C. En echelon microjoints bounded on northeast by common joint. Principal stresses necessary for the observed fracture orientations are given. In all cases, σ_1 assumed to be horizontal.

If this information is representative then a maximum principal stress axis (σ_1) trending approximately N70E is necessary to produce this fracture pattern. The minimum principal stress axis (σ_3) must be oriented about N20W.

It is difficult to ascertain whether the en echelon fractures are the result of a Mesozoic stress system or were produced by an earlier Paleozoic event. The stress system necessary to produce these fractures may be compatible with the concept that the Eastern Border Fault is an extensional feature.

If the Eastern Border Fault formed prior to the development of these fractures, strike-slip motion along the fault may have been induced by a northwest axis of extension operating obliquely to the strike of the fault. The Eastern Border Fault trends nearly east-west in this region. This could account for the orientation of en echelon fractures at Station 66. The en echelon fracture systems, however, may also be due to a Paleozoic stress system, in which case they would be unrelated to Mesozoic fracturing.

Jointing in the Mesozoic Rocks

The pattern of joints in the sedimentary and volcanic sequence (Figure 6A) is much simpler than in the crystalline units (Figure 5A) as shown previously by the comparison of the two composite plots. Two nearly vertical sets of joints strike N40E and N50W (Figure 6A). Two low angle sets strike N50E, one dipping 45°NW and one dipping 30°SE. The latter set corresponds to the attitude of bedding in most of the Mesozoic rocks.

Histograms of sub-areas (Figure 23) display strongly developed northeast striking joints throughout the study area. In particular, N25-45E trending joints recur in all sub-areas west of the Eastern Border Fault. Equal-area plots of joints in each sub-area (Figures 6B-6F) show considerable amount of variation in dips of fractures throughout the Mesozoic rocks. This may be due to tilting of isolated fault blocks.

In Mesozoic rocks there were no distinct classes of fractures except faults, which will be discussed in a later section. Significant classes of fractures, such as headings, microjoints, and smooth joints that are common in the massively developed granitic rocks, were not observed in the more anistropic sedimentary rocks. An attempt was made to investigate the development of common joints of various size classes in the sedimentary and volcanic rocks, but because of the lack of quantitative information concerning fracture lengths, this analysis proved not to be feasible.

Mineralized joints. The majority of mineralized joints in the Mesozoic rocks strike northeast and dip northwest (Figure 24). These joints are coated with calcite, chlorite, and zeolite. Another well developed cluster of poles to mineralized joints in the equal-area net in Figure 24 represents predominantly calcite joints which are nearly vertical and strike between N70E and N90E. Northwesterly striking mineralized joints are not as common as those trending northeast and have chlorite and zeolite.

Mineralized joints recorded in the crystalline rocks (Figure 19) resemble those in the Mesozoic, although there are few data points from

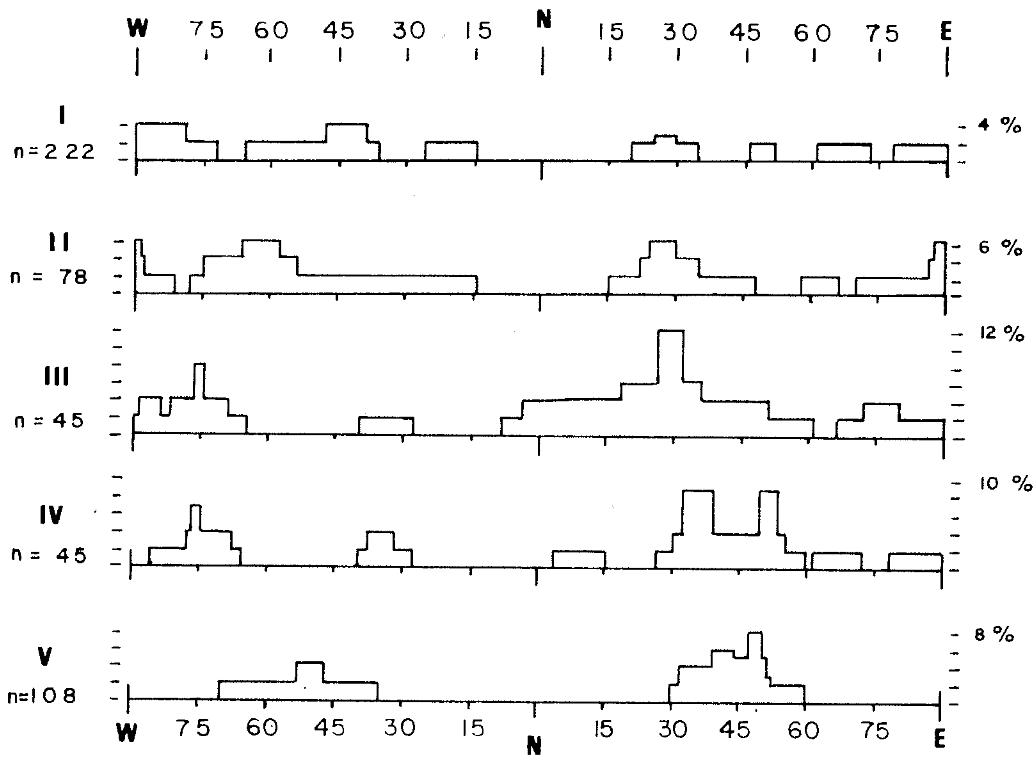


Figure 23. Histograms comparing common joint orientations in Mesozoic sub-areas. See Figure 4 for sub-area locations.

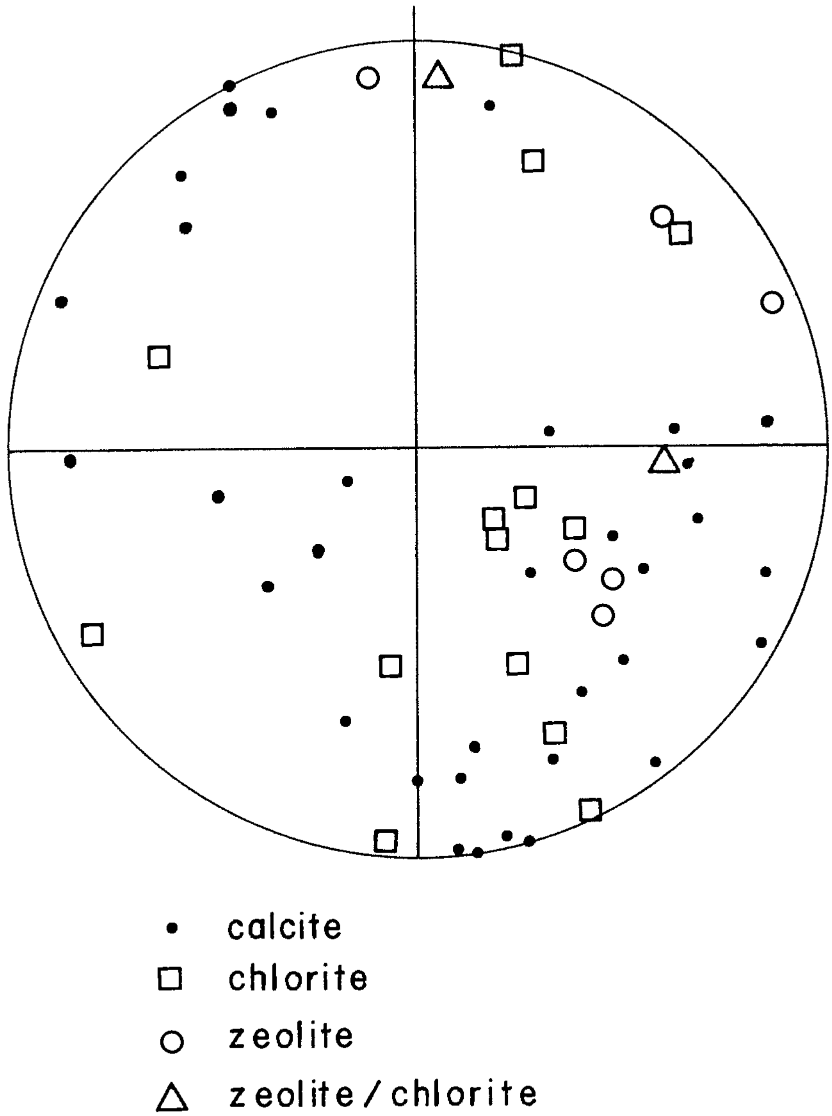


Figure 24. Poles to mineralized joints in Mesozoic rocks plotted on equal-area net.

the crystallines. The chlorite, epidote, zeolite, and calcite mineralized fractures from the pre-Mesozoic rock units are most likely the result of Mesozoic fracturing.

Comparison with Other Fracture Studies

Histogram frequency plots of joint data taken from Loughlin (1912) and Mikami and Digman (1957) are shown in Figures 25A, 25B, and 25C. The quadrangle locations of these studies is shown by the index map (Figure 25D). The data from the earlier studies is insufficient to show any meaningful trend that can be correlated with the results of this study.

Considering the information available, some possible correlations of the fractures represented in Figures 25A and 25C can be made with the following fracture elements of this study:

N70E -- microjoints and headings (Figure 17)

N30E -- all common joints (Figure 9) and headings (Figure 17)

N10E -- headings (Figure 17)

N10W -- microjoints (Figure 17)

N40W -- headings and microjoints (Figure 17)

The number of joint orientations taken in the Mesozoic rocks by Mikami and Digman (Figure 25B) is too few to correlate with data from this study. However, there is a high occurrence of northeast striking joints which is compatible with the results of the present investigation.

Conclusions

1. A complex system of common joints in the pre-Mesozoic rocks shows variation between sub-areas. The majority of common joints in the

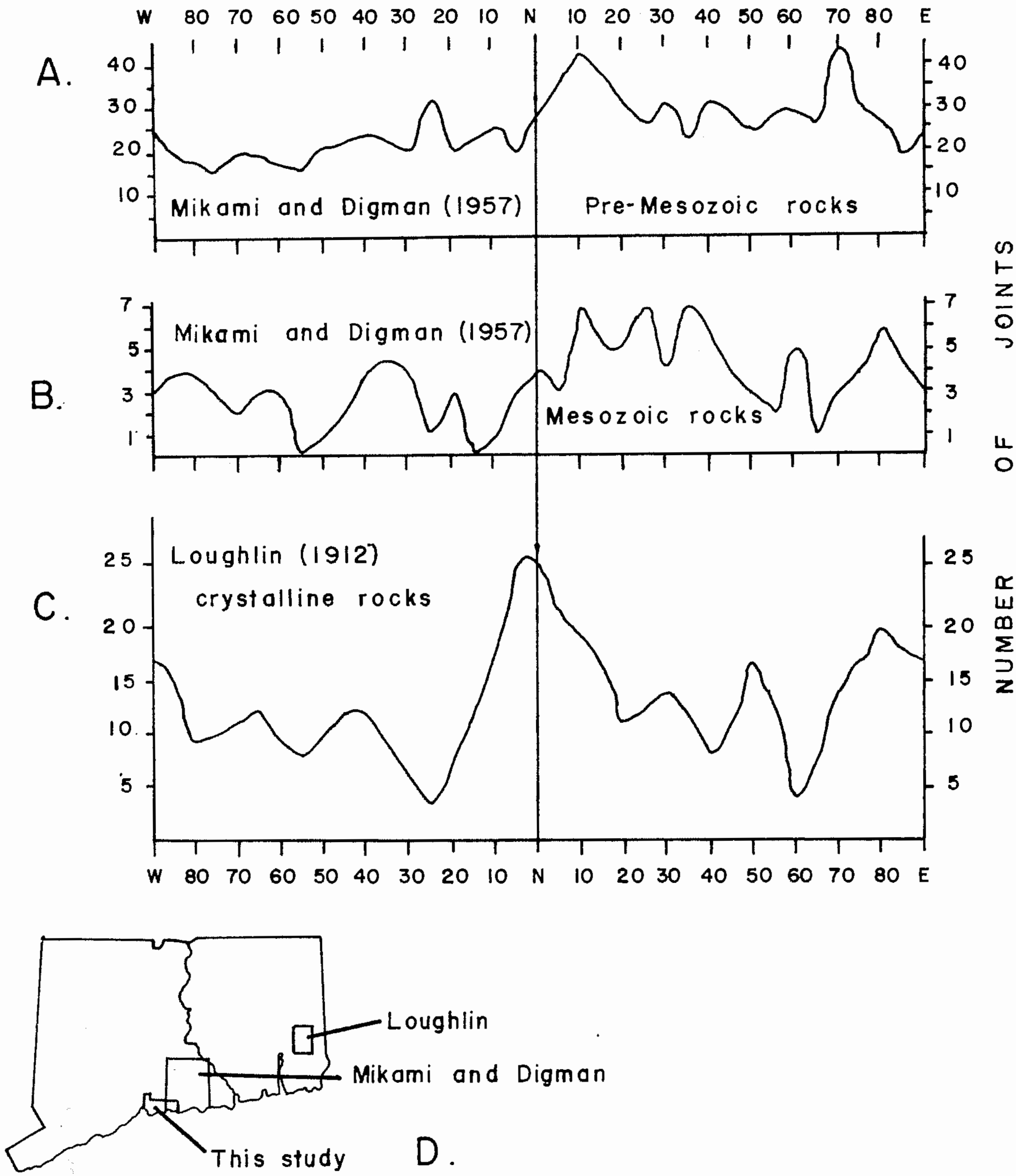


Figure 25. Histograms of frequency versus strike of joints recorded by earlier workers in Connecticut. A. Joints in crystalline rocks in the Guilford 15-minute quadrangle. B. Joints in the Mesozoic rocks in the Guilford 15-minute quadrangle. C. Joints in the vicinity of the Preston Gabbro of eastern Connecticut. D. Index map showing locations of study areas.

crystallines are nearly vertical suggesting that they formed after possible tilting. Fractures striking northeast in many sub-areas vary in dip, possibly indicating they developed prior to tilting.

2. Microjoints form a simpler pattern than do common joints in the crystalline rocks. The two dominant sets of microjoints appear to have an orthogonal relationship. If microjoints can be related to fluid inclusions in the granitic rocks, then they may have existed as inherent planes of weakness or as tiny fractures before the Mesozoic fracturing took place.

3. The headings are geometrically related to microjoints. There may be a genetic relationship between the two, but none was detected in the field.

4. Several types of mineralization on joint surfaces are found in the crystalline rocks. The most consistently oriented are quartz-coated fractures that may be Paleozoic features. If it is true that these are of Paleozoic age, then a pre-Mesozoic weakness in the crystalline rocks existed on northeast striking planes. The most abundant mineralization found in the pre-Mesozoic rocks is chlorite which occurs on joint planes corresponding to the prominent fracture sets in the Mesozoic rocks.

5. Fractures along the centers of siliceous dikes injected into the Stony Creek Granite suggest a Paleozoic weakness along northeast striking planes.

6. Common joints in sub-areas in Mesozoic rocks are most strongly developed along planes trending between N20E to N40E. These are

similar in orientation to a set of common joints in the pre-Mesozoic sub-areas.

7. Information obtained from earlier fracture studies is not sufficient to indicate an extensive regional fracture system. To determine how the fractures of this study correlate with fractures in other parts of Connecticut, intensive investigations are necessary in these areas.

MINOR FAULTS

Since a fault is defined as a fracture along which movement has occurred, evidence for this motion was necessary in identifying the surface as a fault. The presence of slickensides, displacement of marker horizons, drag along the fracture plane, and the occurrence of fault gouge are the criteria used in identifying faults. If a fracture did not have any of these features, it was considered to be a joint.

Two linear features associated with fault planes were recorded: 1) the trend and plunge of the slickensides and 2) the orientation of imaginary lineations lying in the plane of a fault at right angles to the slickensides called rotation axes. If the sense of displacement along the fault plane can be determined it is recorded in terms of a rotation sense looking down the plunge of this imaginary axis. The rotation axes on conjugate fault planes are parallel to the intermediate principal stress axis (σ_2).

Over 300 minor faults have been recorded in the pre-Mesozoic and Mesozoic rocks of this study area. Faults observed on each side of the Eastern Border Fault have been plotted and contoured on the equal-area nets in Figures 26A and 27A. Several sets of faults exist with a variety of motion patterns, suggesting a complicated stress history in this region. It is now necessary to investigate the nature of the motion along each individual set of faults.

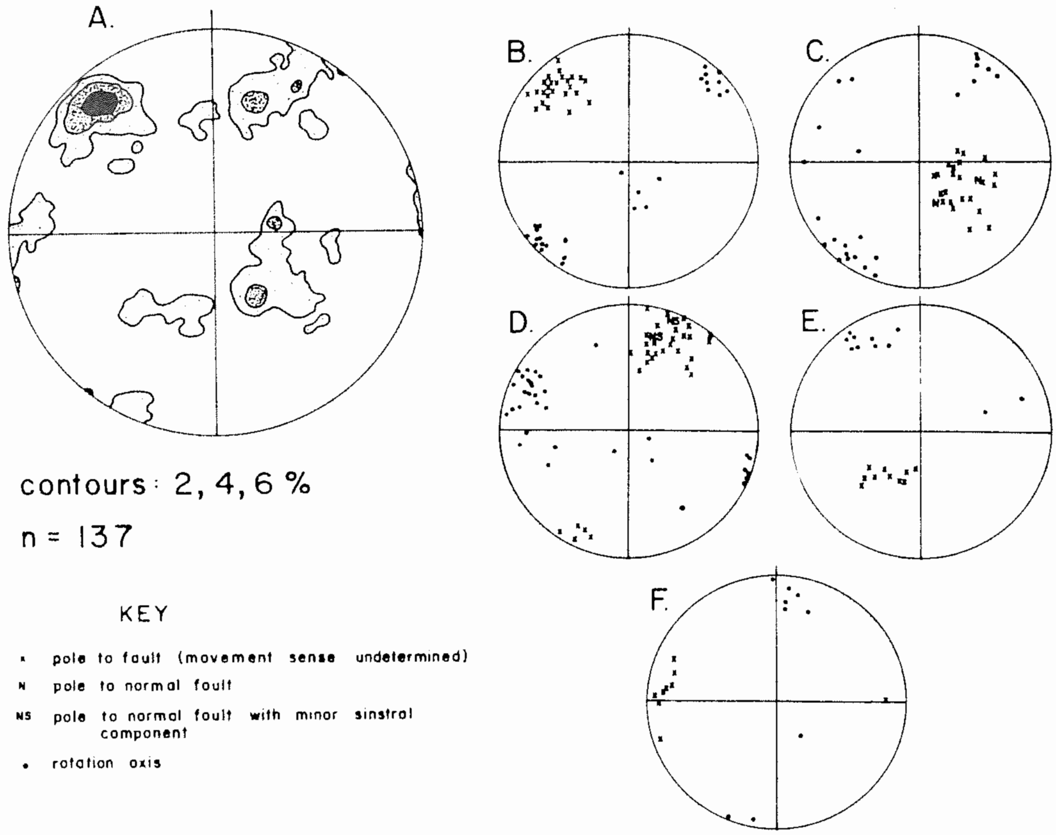


Figure 26. Diagrams of poles to faults with rotation axes in pre-Mesozoic rocks. A. Contoured plot of all minor faults in pre-Mesozoic rocks. B-F. Poles associated with each maximum in A plotted with their respective rotation axes.

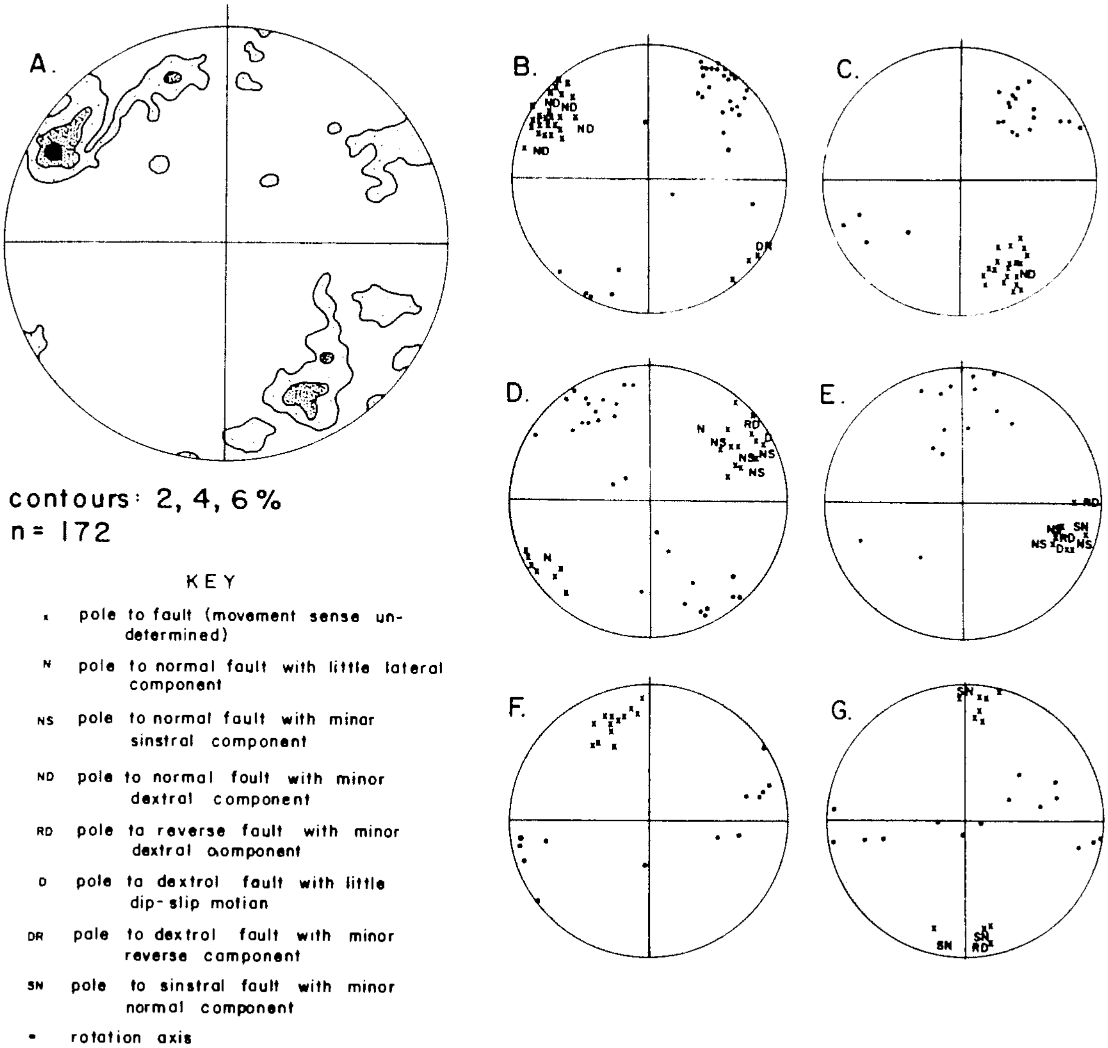


Figure 27. Diagrams of poles to faults with rotation axes in Mesozoic rocks. A. Minor faults plotted and contoured. B–G. Poles associated with each maximum in A plotted with their respective rotation axes.

Faults in Pre-Mesozoic Rocks

Figure 26A shows five distinct sets of faults in the terrain east of the Eastern Border Fault. In analyzing the motion vectors on these fault planes, each independent set has been isolated and the poles to these surfaces have been plotted with their respective rotation axes on an equal-area net (Figures 26B-26F).

Figures 26B and 26C represent the two northeast sets of faults with their rotation axes. The cluster of poles to each set of faults indicates both strike N45E, one dipping approximately 80SE and the other dipping about 40NW. Note that with a few exceptions, the rotation axes of each fault set form a cluster which trends between N25E to N45E, indicating almost all of these faults are dip-slip. The angle between the planes, determined by the approximate pole of each fault set, is about 78° (See Figure 28).

The angular relation of the fault planes of each set and the coincidence of their rotation axes suggest a conjugate relation between the northwest and southeast dipping faults. However, conflicting age relations between these sets have not been found to prove they are contemporaneous. It should also be pointed out that movement senses were not determined on many of these fault planes. Of the northwest dipping faults, two are normal which is compatible with a conjugate pair interpretation.

The planes, poles to planes, and rotation axes of each fault set are represented in Figure 28. Assuming a conjugate relation between the two sets of faults, the σ_1-σ_3 plane is nearly vertical, dipping about 80NE and striking N50W. The minimum principal stress, σ_3, plunges

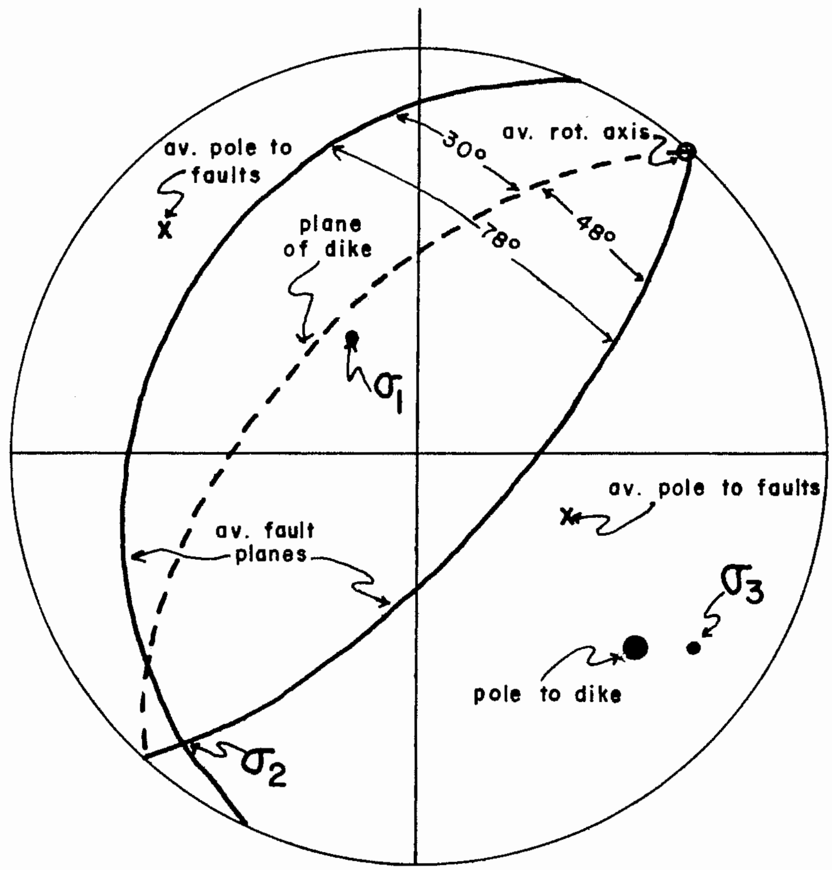


Figure 28. Stress system determined from the orientations of the northwest and southeast dipping faults in pre-Mesozoic rocks (Figures 26B and 26C) which are considered to be conjugate and normal. Relation between major diabase dike and faults is shown.

approximately 30SE. The intermediate principal stress axis is nearly horizontal, striking N40E and nearly corresponds with the approximate mean of the rotation axes.

An interesting relation exists between the two northeast striking fault sets and a major diabase dike in the crystalline rocks, adjacent to the Eastern Border Fault, that strikes N40E parallel to the fault (Figure 2). Mikami and Digman (1957) suggest the dike dips 60NW as determined by the attitude of columnar jointing. The diabase dike and pole to the dike have also been plotted on the equal-area net in Figure 28. Although the dike does not accurately bisect the acute angle formed between the two fault planes, the orientations of σ_3 of the fault system and the pole to the dike are nearly parallel. This analysis suggests the possibility that the northeast sets of minor faults and the diabase dike, which parallels the Eastern Border Fault, developed under the same stress orientations.

Other sets of faults in the crystalline rocks are also dip-slip with little lateral movement. Faults belonging to a N65W set have rotation axes that also indicate dip-slip motions with little lateral movement (Figure 26D). However, several fault planes, along which considerable strike-slip motion occurred, are indicated by the steeply plunging rotation axes. Note that there are two normal faults with minor left-lateral displacements in this set.

The approximate mean of a fourth set of low angle faults is oriented N65W 30NE. Figure 26E shows that the majority of their rotation axes trend in the vicinity of N30W, plunging 30° indicating dip-slip faulting with a slight strike-slip component. The direction of displacement was not determined on any of these faults.

A set of faults (Figure 26F) in the pre-Mesozoic rocks, striking N10E and dipping about 85SE, shows dip-slip motion. One steeply plunging rotation axis indicates a fault plane with considerable lateral motion.

In crystalline rocks, indicators on fault planes consistently show dip-slip motion with little lateral component. The direction of dip-slip motion has only been determined on two fault planes which strike N70W and dip southwest and one fault which strikes northeast and dips northwest. These faults are normal. No reverse faults were detected in the pre-Mesozoic rocks. The two northeast sets of faults are interpreted to be normal and to have a conjugate relation. The evidence indicating this is: 1) the acute angle between the two mean planes is 78°; 2) almost all of the rotation axes on these fault planes are nearly horizontal and form a well defined cluster, the center of which has approximately the same orientation as the intersection of the two mean planes; and 3) one fault belonging to the northwest dipping set is normal.

From this composite analysis of minor faults in the crystalline rocks, only the sets of faults striking northeast appear to have a conjugate relation. At some individual stations, however, northwest striking faults are interpreted to be conjugate as well as northeast sets and will be discussed later in the text.

Faults in Mesozoic Rocks

Six clusters of poles to faults (Figures 27B-27G) in the Mesozoic units have been isolated. Although many of these faults show dominant dip-slip movements, they have more strike-slip component than the faults in the crystalline rocks.

Two northeast striking sets of faults are interpreted to be conjugate: N32E 80SE and N50E 70NW. In Figures 27B and 27C, the rotation axes of these faults form a significant cluster trending about N38E. Those axes related to the southeast dipping faults plunge more gently than those associated with the northwest dipping set of faults. Normal faults do occur in each of these two sets. If these faults are considered to be conjugate normal sets, a northwest axis of extension, with σ_1 nearly vertical, is necessary to produce these fault patterns (Figure 29).

Dip-slip faults strike N25W and dip 75SW (Figure 27D). Of this set, several normal faults with left-lateral components have been determined. However, this set also includes some faults showing minor and major right-lateral components. The majority of these faults are dip-slip.

A N25E set (Figure 27E) includes normal, left-lateral faults, reverse right-lateral faults, and dominant strike-slip faults with both left-lateral and right-lateral displacements. Rotation axes on these planes are quite dispersed about an approximate mean trending N0E and plunging 40°.

Predominantly dip-slip faults occur on N65E oriented planes (Figure 27F) which dip about 65SE. A few of these faults are strike-slip. No displacement senses have been determined.

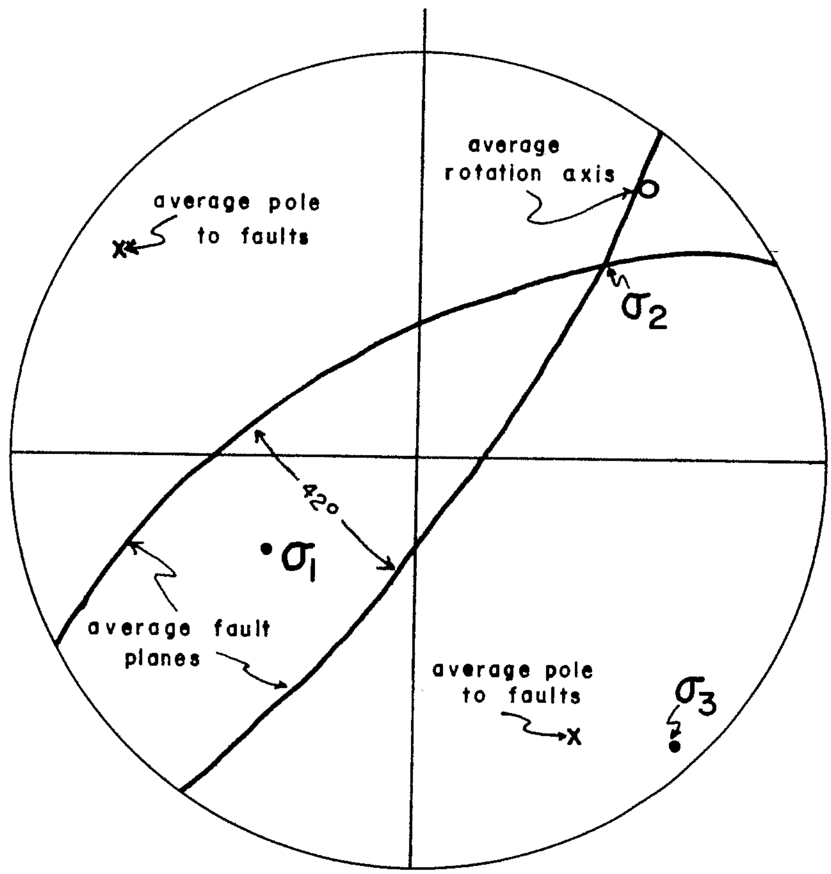


Figure 29. Stress system determined from the orientations of northwest and southeast dipping faults in the Mesozoic rocks (Figures 27B and 27C).

East-west faults in Figure 27G show predominantly strike-slip motions along four planes. These faults were recorded at station 60 (Figure 4) located on a basalt ridge, south of the ridge offset at the southern end of Lake Saltonstall. On a geologic map (Figure 3), several major strike-slip faults with left-lateral displacement have been inferred (Sanders, 1970). Also within this cluster of poles to faults, there is a reverse fault with minor right-lateral component and several dip-slip faults with more or less strike-slip component.

Faults in the Mesozoic rocks show more variability in their motion patterns than do faults in the crystalline rocks. The orientations of rotation axes on these faults show more strike-slip component than rotation axes on faults in the crystallines. Two sets of northeast striking faults are interpreted to be conjugate. Indications of movement sense show many of these faults to be normal, thereby implying horizontal extension (and vertical compression). Other sets contain faults predominantly of normal motion, possibly indicating horizontal extension.

Faults at Sub-areas

The minor faults in the preceding section show senses of displacement that are predominantly normal. Other faults with no indicators of movement sense are considered to be normal because 1) their orientations are sub-parallel to known normal faults, 2) their rotation axes are similarly oriented, and 3) their angular relation is about 60°, with the acute bisectrix being nearly vertical.

Assuming normal motion along dip-slip faults, horizontal extension is interpreted to be responsible for the majority of faults observed in the crystalline and Mesozoic rocks of this study area. Two sets of northeast striking faults, dipping northwest and southeast, indicate northeast-southwest extension.

Faults observed in each sub-area were analyzed as groups if the amount of data was sufficient. The stress systems necessary for the fault patterns at each sub-area are plotted in Figure 30. Two distinct orientations for the minimum principal stress axis can be seen. A northwest-southeast trend of σ_3 indicates extension along that axis and is likely to be responsible for northeast trending normal faults. Sets of northwest striking normal faults indicate a northeast-southwest extension and trend for σ_3.

Throughout the study area, σ_1 appears to be consistently oriented in a nearly vertical position. At some sub-areas, where two stress systems are required to explain the fault patterns, σ_2 and σ_3 appear to swap orientations. Reverses of σ_2 and σ_3 indicate stress redistribution.

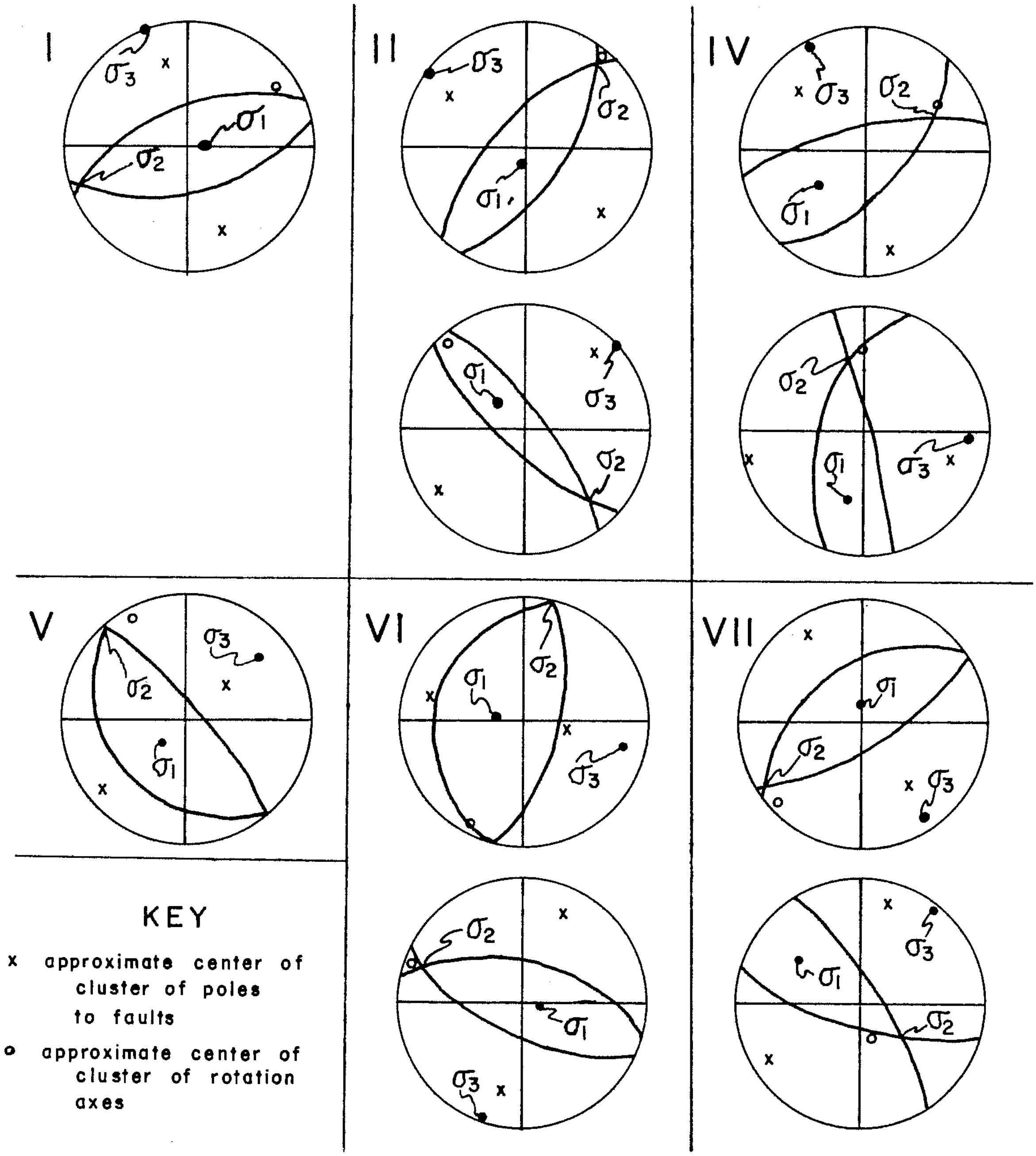


Figure 30. Principal stress orientations that explain the observed patterns of faults at each sub-area.

DIABASE DIKES

Three diabase dikes dipping at intermediate angles were observed in the study area. Two dikes intruding pre-Mesozoic rocks (Stations 42 and 45, Figure 4) dip to the east and one dike intruding the New Haven Arkose (Station 40, Figure 4) dips to the west. All are represented in Figure 31 on an equal-area net. Not one cross-cutting relation was found between a minor fault and any of the dikes. Although joints were observed in the diabase dikes, none extended into the country rocks.

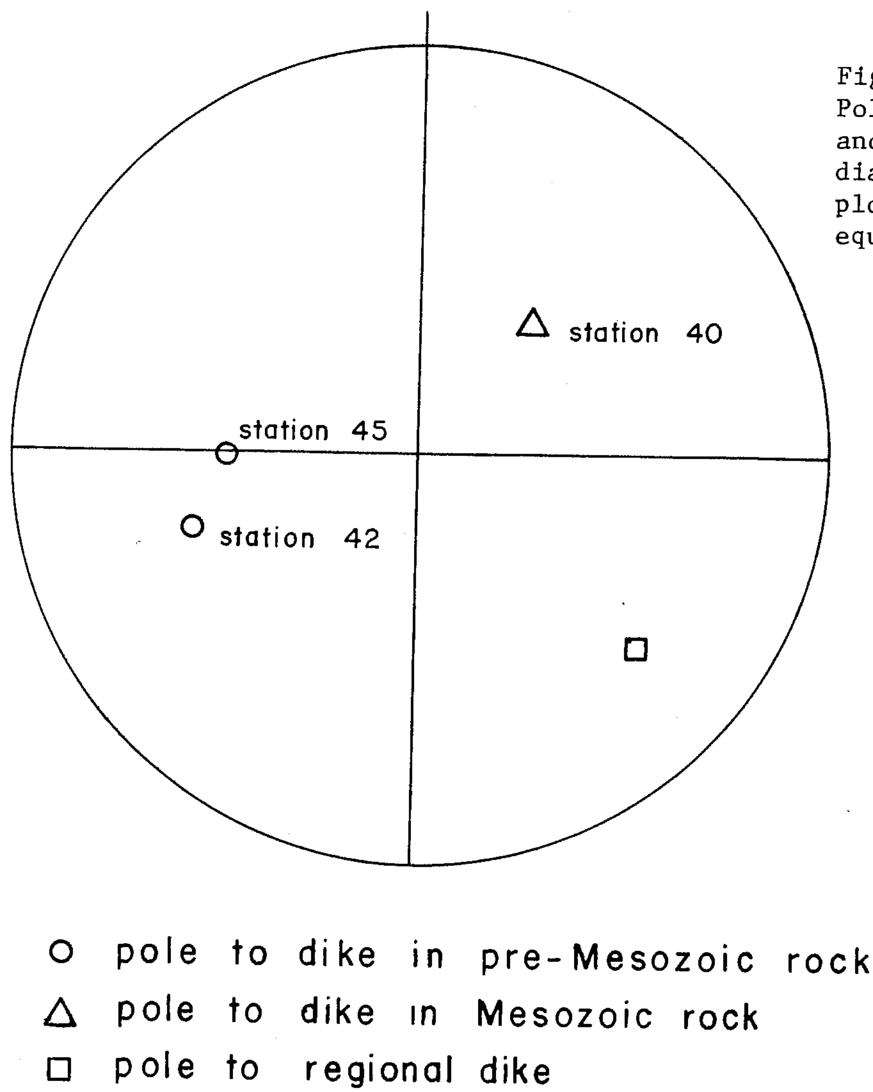


Figure 31. Poles to minor and regional diabase dikes plotted on equal-area net.

DISCUSSION

Faults in Mesozoic and Pre-Mesozoic Rocks

The system of minor faults in the Mesozoic rocks bears a resemblance to that of the minor faults in the pre-Mesozoic rocks, even though there is considerable azimuthal variation between each well developed maximum. The resemblance in the pattern of faults in Mesozoic and pre-Mesozoic rocks suggests that similar stress systems are responsible for brittle deformation. The difference in fault patterns, however, can be explained by the following considerations:

1. The Mesozoic rocks behave in a more anisotropic manner than the massive crystalline rocks.

2. The stress sytem acted on the deeper basement rocks and could be re-oriented as it was transmitted into the overlying sediments.

3. Tilting of fault blocks very likely occurred in the Mesozoic basin and the fault pattern does not indicate the true stress system imposed on the region.

Relation Between Faults and Joints

Many fracture studies have shown that in a particular area faulting is somehow related to the system of joints that has developed. Faults are known to develop along pre-existing fracture planes. Donath (1962) shows that an earlier system of strike-slip faults provided planes of weakness along which dip-slip movement later occurred. McGill and Stromquist (1974) demonstrate how an orthogonal system of joints plays a role in graben development in Canyonlands, Utah.

Jointing and faulting may also be related to the same stress system. Extension joints are known to develop perpendicular to σ_3.

Price (1966) has illustrated the formation of vertical orthogonal joints after the development of normal faults. The joint system may, however, only have developed recently, caused by topographic expansion due to erosion of material. Chapman (1958) and Chapman and Rioux (1958) have shown that jointing can occur after rock material has been removed by glacial activity.

It is now necessary to discuss the fault patterns in relation to the systems of other fracture elements.

Pre-Mesozoic rocks. The most notable similarity between the various fracture elements is shown in the sets of vertical faults (Figure 26A), smooth joints (Figure 10A), microjoints (Figure 14A), and headings (Figure 16A) which strike N15W. There also may be some significance to the coincidence of weakly developed maxima seen in the plots of all common joints (Figure 5A) and all rough joints (Figure 12). Aside from the northerly striking fractures, the systems of smooth joints, microjoints, and headings are entirely different from the fault patterns.

It is therefore postulated that smooth joints, microjoints, and headings occurred prior to faulting which developed during the Mesozoic. It is also suggested that the northerly striking faults developed along pre-existing fracture planes. Weakly developed joint sets, such as exhibited by rough joints (Figure 12) which coincide with fault maxima, may have provided favorably oriented planes of weakness along which faults developed later, but evidence for this is lacking.

Mesozoic rocks. Two seemingly orthogonal joint sets (Figure 6A) may be related to the northeast set of faults (Figure 27A) in the

Mesozoic rocks. The joints may very well be extension joints similar to those described by Price (1966). From the existing evidence such an interpretation would not be justified.

Regional Considerations

Recently, similar studies have been carried out in other parts of the Mesozoic Basin in the Connecticut Valley. Fracture investigations in Meriden, Connecticut (Wise et al., 1975) show a predominance of northeast strike-slip faults. In the Mount Holyoke area, Massachusetts both dip-slip and strike-slip faults have been observed largely on northeast striking planes (Naso, 1975). Goldstein (1975) reports a complex system of strike-slip and dip-slip faults in the Turners Falls area, Massachusetts. Northeast striking faults show left- and right-lateral displacements. Both normal and reverse dip-slip faults have also been observed on northeast striking planes. Northwest striking faults show right-lateral displacement.

A discrepancy obviously exists in fault motion patterns between the New Haven area and the rest of the Connecticut Basin to the north. To explain this, Wise et al. (1975) have advanced the idea that the trend of the Eastern Border Fault plays an important role in the development of minor fault patterns.

In the New Haven area, the Eastern Border Fault strikes between N40E and N75E. A northwest axis of extension acted perpendicular to the Eastern Border Fault, creating normal faults with very little lateral component.

In areas north of this study area, where the Eastern Border Fault attains a more northerly strike, a northwest axis of extension acted obliquely to the Eastern Border Fault. This would induce a strike-slip component on the fault. Stresses would become re-oriented in the Connecticut Basin such that σ_1 is compressive in a north-south direction, σ_2 vertical, and σ_3 nearly horizontal and striking east-west.

Evidence indicating the directions of principal stress axes in the crystalline rocks of northern Connecticut and Massachusetts is lacking. No intensive fracture studies have been made in the pre-Triassic rocks. However, the northeasterly strikes of major diabase dikes suggest that the minimum principal stress axis is oriented northwest. These dikes are considered to be contemporaneous with the deposition of sediments and faulting during the Jura-Triassic.

CONCLUSIONS

1. The use of a computer-based information system greatly facilitated the analysis of fracture data and made it possible to study this information in greater depth.
2. Some fracture elements show more consistency in orientation than other elements. They are: smooth or polished joints, micro-joints, and headings. All have distinguishing characteristics and are systematically oriented at the outcrop level. In future field investigations, more emphasis should be placed on recording these elements in preference to nondescript common joints.
3. The analysis of jointing shows that there is a structural grain in the crystalline rocks that may have existed prior to the Mesozoic and may be related to the deformational history of the Paleozoic.
4. A northeast structural weakness, possibly Paleozoic in origin, exists and may have controlled the present pattern of faults which formed during the Mesozoic period of fault activity.
5. Movements along the northeast striking minor faults in the crystallines show a consistency in dip-slip motion with little lateral component. Many of these faults have indicators of being normal and others are probably normal. This further strengthens the concept that the Eastern Border Fault is an extensional feature. Northwest sets of minor faults, which are also dip-slip and probably normal, imply extension along a northeast trending axis and indicate stress redistribution. Minor faults in the

Mesozoic rocks also show northwest as well as northeast extension, but there is more inconsistency in their strikes and more variability in the orientations of their rotation axes. This is probably due to a redistribution of stresses and tilting on individual fault blocks.

6. The minor faults in southern Connecticut are distinctly different from those observed in the rest of the Connecticut Valley. In the northern part of the Valley, there is considerable strike-slip faulting, whereas in this study area, fault motions are almost entirely dip-slip. This difference is attributed to the northeasterly trend of the Eastern Border Fault near New Haven, which attains a northerly strike in the central and northern sections of the Connecticut Valley.

APPENDIX I: DESCRIPTION OF COMPUTER DATA-BASE SYSTEM

The data-base system used for analysis of information during this research project consists of three parts:

1. Data collection -- recording the information in the field using a format compatible with the computer.
2. Data storage and retrieval -- storing the field data in the computer system and searching through the raw data to extract the desired information.
3. Data display -- representing the data in a form that can be easily assimilated by the geologist.

All programs are written in FORTRAN and were used on a CDC Cyber 74 computer at the University of Massachusetts, Amherst.

Data Collection

Field information was recorded as codes on forms that were transcribed to computer cards by keypunching. The data forms used in this study are modeled after Pferd (1975) who has developed a system for use in collecting and analyzing detailed structural data in metamorphic terrains. The data forms were revised to accommodate the necessary information recorded in this study.

Each form contains 73 boxes or spaces in which to place coded information. One alphabetic or numeric character may be placed in each box. The boxes correspond with the columns on a computer card.

Three separate forms (Figures 32-34) were used to collect fracture information in this study: 1) the general data form; 2) the planar data form; 3) the linear data form. Each is printed on a different color paper for easy recognition. An integer code in box 1 of each form distinguishes the data type after the information has been keypunched

CODES

Size
1 <1m.
2 1–5m.
3 5–10m.
4 10–20m.
5 20–50m.
6 >50m.

Type of outcrop
1 natural – seacoast
2 natural – inland
3 roadcut
4 quarry – abandoned
5 quarry – operating

Auxiliary information
1 sketch
2 photograph
3 sample
4 separate sheet

Comments
G general
F folds
L lineations
P planar elements
Followed by box number where additional comment is to be made.
Eg.

G	2	5
C	O	M
M	E	N
T		

Joint development
1 very massive
2 slighted jointed
3 moderately jointed
4 well jointed
5 very well jointed

Notes:
Notes, sketches, or important information that does not fit into the form or comments section. Use reverse side of general sheet if more space is required.

GENERAL DATA [1] 1

Station Number [ ][ ][ ][ ] 5

Joint development [ ] 6 Date [ ][ ] [ ][ ] [ ][ ] 12

Outcrop Size [ ] 13 Type [ ] 14

Auxiliary information [ ] 15

Comments :

__ __ __ __ __ __ __ __ __ 24
__ __ __ __ __ __ __ __ __ 33
__ __ __ __ __ __ __ __ __ 42
__ __ __ __ __ __ __ __ __ 51
__ __ __ __ __ __ __ __ __ 60
__ __ __ __ __ __ __ __ __ 69
__ __ 71

Notes:

page number [ ][ ] 73

Figure 32. General data form.

onto cards. These codes are: 1 for general data, 3 for planar data, and 4 for linear data. These particular codes were chosen in order to be consistent with Pferd's coding of data forms (1975).

Since all geologic data is associated with a location, boxes 2-5 have been designated for recording a four digit station number. The last two boxes (72-73) are reserved for a two digit page number. Page numbers are useful in keeping the data forms in sequential order. In addition, the page numbers are extremely useful when the computer cards become disarranged. The order can be restored by using a card sorting machine.

General data form. The general data form (Figure 32) accommodates descriptive information recorded at each locality. It serves three functions:

1. To record general information describing the outcrop. This information is preserved as codes and is stored in the computer system.

2. To record written comments without the restriction of codes. This information can be stored in the computer system. This section served the additional purpose of recording information that could not be entered on the planar and linear data sheets.

3. To record drawings and sketches. This information cannot be stored in the computer.

Planar data form. Features described as surfaces are recorded on the planar data form (Figure 33). Note that for each feature seven groups of boxes are used.

The A code denotes the type of feature and is recorded in the A column. A list of planar features and corresponding codes found in this study area is located on the left-hand side of the page under A=SURFACE FEATURE. The list is self-explanatory.

PLANAR DATA CODES

A=SURFACE FEATURE

- Ø bedding/foliation
- 1 common joint
- 2 fault
- 3 heading
- 4 columnar joint
- 5 tabular inclusion
- 6 dike/vein
- 7 axial plane
- 8 slip cleavage
- 9 topographic plane
- A quarry feature
- B microjoint

CARACTER CODES

- Ø calcite
- 1 chlorite
- 2 epidote
- 3 Fe-stain
- 4 pyrite
- 5 quartz
- 6 zeolite
- 7 quartz/chlorite
- 8 zeolite/chlorite
- 9 other
- A smooth
- B rough
- C plumose
- D brecciated
- E featureless
- F calcite/chlorite
- G weathered
- H altered

B=ROCK TYPE
use rock type codes

C=DESCRIPTORS

when A=Ø: B=1 massive
2 faintly bedded/foliated
3 moderately bedded/foliated
4 well bedded/foliated
5 extremely well bedded/foliated

A=1-4, B use character codes

A=5-6 use rock type codes

A=7-8 B=blank

A=9 B= 1 slope of topography 2 cliff face 3 quarry wall 4 road cut

A=A B= 1 rift 2 grain 3 hardway

QUANTITATIVE CODES

- Ø Ø
- 1 1cm.
- 2 2cm.
- 3 3cm.
- 4 4cm.
- 5 5cm.
- 6 6cm.
- 7 7cm.
- 8 8cm.
- 9 9cm.
- A 10cm.
- B 15cm.
- C 20cm.
- D 30cm.
- E 40cm.
- F 50cm.
- G 65cm.
- H 80cm.
- I 1m.
- J 2m.
- K 4m.
- L 6m.
- M 8m.
- N 10m.
- O 15m.
- P 20m.
- Q 30m.
- R 40m.
- S 50m.
- T 1mm.
- U 2mm.
- V 5mm.
- W 7.5mm.
- X gr. 50m.
- Y small undetermined
- Z large undetermined

Q1=TYPE OF MEASUREMENT FOR Q2

1 length of surface in outcrop
2 thickness/dilation distance
3 distance to next coplanar surface
4 distance to next cocharacter surface
5 distance to next coscalar surface
6 vertical displacement on fault
7 spacing within joint zone

Q2= MEASUREMENT VALUE
use quantitative codes

STRIKE 360° azimuth taken with dip to right

DIP angle of inclination

ROCK TYPE CODES

- A granite
- B gneiss
- C amphibolite
- D schist
- E quartzite
- F sandstone
- G shale
- H conglomerate
- I basalt
- J pink pegmatite
- K white pegmatite
- L pink aplite
- M white aplite
- N pegmatite (undifferentiated)
- O aplite (undifferentiated)
- P quartz pod
- Q quartz dike/vein
- R gneiss inclusion
- S amphibolite inclusion
- T schist inclusion
- U quartzite inclusion
- V sandstone inclusion
- W shale inclusion
- X conglomerate inclusion
- Y diabase dike
- Z tuff breccia

TAG letters from A-Z; number from 0-9; asterisk (*) for data continued on next line.
1. footnote for comment on GENERAL data sheet.
2. give lineations same TAG as associated plane.
3. for up to 2 more lines of C codes and up to 6 more lines of Q1 and Q2 codes, place asterisk (*) in TAG column preceeding each line of additional data.
   a) no * in last line of data. A TAG letter or number may be entered here.

PLANAR DATA [3] 1

Station number [| | |] 5

A	B	C	Q1	Q2	STRIKE	DIP	TAG	
								16
								27
								38
								49
								60
								71

page number [|] 73

Figure 33. Planar data form.

The type of rock in which the fracture occurs is recorded in the B column. A list of possible rock types with respective codes is provided under ROCK TYPE CODES.

The information recorded in the C column is given under C= DESCRIPTORS. The surface feature is dependent upon the type of planar element being recorded. As can be noted on the data form, the C code may have a different meaning with each planar type. If bedding in a well-bedded sandstone is recorded, then A is Ø, B is F, and C is 4. However, a chlorite coated joint observed in granite is recorded: A is 1, B is A, C is 1. The C code, in this case, is found under the list of CHARACTER CODES.

Quantitative information is accommodated in the Q1 and Q2 columns. The code recorded under Q1 indicates the type of measurement. Under the heading Q1=TYPE OF MEASUREMENT FOR Q2 a list of seven measurement types is provided. The measurement value is recorded under the Q2 column as a code that is found in the list with the heading of QUANTITATIVE CODES.

The STRIKE is recorded as an azimuth from 0-360°. When the orientation of a planar element was measured in the field, an azimuthal compass was used. The azimuth of the strike was measured with the dip of the plane to the right as a convention. In this way the strike and dip can be measured and recorded unambiguously, using only five digits.

The TAG column serves three purposes:

1. It can be used to footnote a particular field measurement by using a number from 0-9 or a letter from A-Z. The field measurement can then be described in the notes section on the general data form by referring to this label.

2. The TAG is also used to relate a linear feature with its related planar feature. It was frequently used to keep track of slickensides with the fault planes on which they were observed.

3. An asterisk (*) in the TAG column is used to indicate that additional C and/or Q1 and Q2 codes are recorded on the following line. Up to three different C codes and up to seven types of quantitative measurements may be recorded for each data point.

Linear data form. The linear data form (Figure 34) accommodates elongated features. This form is structured in the same way as the planar data form. A list of linear features observed in this study with corresponding codes is provided under A=LINEAR FEATURE. The code for the linear feature is placed under the A column. The codes placed in the B, C, Q1, and Q2 columns take on different meanings when a different A code is used. The various codes and their meanings are self-explanatory on the data sheet.

The TREND of a linear element is measured as an azimuth in the down-plunge direction. The PLUNGE, of course, is the angle of inclination of the linear element with a horizontal plane.

The TAG is used in the exact manner on the linear data form as it was used on the planar data form. It is used to footnote, to label related measurements, and to denote a line of continuation.

Versatility of the data forms. The codes on each data form may be changed to accommodate information from other types of geological studies. To ensure compatibility with the data-base system, several restrictions must be observed when modifying these data forms:

1. The same general format must be used.

2. The data type codes must remain the same. 1 for general data, 3 for planar data, and 4 for linear data.

LINEAR DATA CODES

A=LINEAR FEATURE
- 1 fold axis
- 2 rotation axis
- 3 slickenside
- 4 plumose structure

B=DESCRIPTORS

when A=1 B=fold type:
- 1 drag on fault
- 2 chevron/kink
- 3 isoclinal
- 4 concentric
- 5 broad warp

A=2 B=certainty code for rotation sense:
- 1 excellent
- 2 good
- 3 poor

A=3 B=fault movement direction:
- 1 strike-slip
- 2 oblique-slip
- 3 dip-slip

A=4 B=blank

QUANTITATIVE CODES

Ø Ø	D 30cm.	Q 30m.
1 1cm.	E 40cm.	R 40m.
2 2cm.	F 50cm.	S 50m.
3 3cm.	G 65cm.	T 1mm.
4 4cm.	H 80cm.	U 2mm.
5 5cm.	I 1m.	V 5mm.
6 6cm.	J 2m.	W 7.5mm.
7 7cm.	K 4m.	X gr. 50m.
8 8cm.	L 6m.	Y small undetermined
9 9cm.	M 8m.	
A 10cm.	N 10m.	Z large undetermined
B 15cm.	O 15m.	
C 20cm.	P 20m.	

C=MOVEMENT SENSE/PROPAGATION DIRECTION

when A=1-2 C=rotation sense:
- 1 clockwise
- 2 counterclockwise

A=3 C=fault motion sense: (for combinations see TAG)
- 1 normal
- 2 reverse
- 3 right-lateral
- 4 left-lateral
- 5 up on N
- 6 up on E
- 7 up on S
- 8 up on W

A=4 C=propagation direction of plumose structure:
- U stem up plunge
- D stem down plunge

Q1=MEASUREMENT TYPE CODE FOR Q2 (see TAG)
- 1 wavelength of fold
- 2 amplitude of fold
- 3 net displacement on fault

Q2=MEASUREMENT VALUE
use quantitative codes

TREND azimuth of lineation pointing down plunge

PLUNGE angle of inclination

TAG letters from A-Z; numbers from Ø-9; asterisk (*) for data continued on next line.

Uses:
1. footnote for comment on GENERAL data sheet.
2. give lineations same TAG as associated plane
3. for up to two more lines of C, Q1, and Q2 codes, place asterisk (*) in TAG column preceeding each line of additional data.
   (a) no * in last line of data. A TAG number or letter may be entered here.

LINEAR DATA [4] 1

Station number [ ][ ][ ][ ] 5

A	B	C	Q1	Q2	TREND	PLUNGE	TAG	
								16
								27
								38
								49
								60
								71

page number [ ][ ] 73

Figure 34. Linear data form.

3. Only measurement type codes are permitted in the Q1 column.

4. Only an integer between 1 and 7 or a blank may be recorded under the Q1 column.

5. Only integer values may be recorded under STRIKE and DIP.

Data Storage and Retrieval

After the data has been keypunched, the cards can be copied onto a storage device within a computer system where they reside as a data file. The data file can then be referred to as many times as desired by using a computer program.

Data files. There are three types of data files used in this data-base system. The first type is a primary data file and corresponds to the raw data on the field forms (Figure 35). Program SORT searches the primary or raw data file and extracts the desired information which is copied to the storage device, thus creating a secondary file in the computer system.

A listing of a secondary data file is shown in Figure 36. The first line of information indicates the number of sets of data in the file. Each set is preceded by a header containing information about the data set. The following information is contained within each header: the number of data points in the set, the data type (planar or linear), an instruction to plot or contour the data (if it is to be represented on equal-area nets), and the title of the set. The header information is vital in that it affords uninterrupted output from the computer when executing data display programs.

Finally there may be files containing station numbers (Figure 37). These files indicate how sampling localities are to be grouped and

```
3    112H 1J18777 121   18977 122   29277 12K1I 18476 12H   28271 12H 1K28074   1
3    112H   33535 22    28265A12H 1J29174 12H   01757 82H 1J19372 12H    17070  2
3    122 1D33847B                 22 1D24775C             22H 1J2238 4D         3
3    122G1I 18765E                22 1A35278F             22G1F3248 5G          4
3    122H 1D19777H                22H 1B30426I            22H 152108 0J         5
3    122G 1E31773K                22E1524044L             22E1G00871M           6
3    122E1I 23268N                22H 143152208 2H 1J20058 22I    31339P        7
3    122I   009620                22H 1J02277R            22C1K 198 58 S        8
3    122H 1I 03265T               22E1D02260U             22 1E35060V           9
3    122E1D01660W22H 1L20060X                             22 1I 35068Y          10
3    122H 1J35035Z                22H 1A349 600           2241Z18090*   H       111
3    132G1L20059*    22           22G1J356322122 1L20653 2211L 19266312 21K20951 12
3    122H 1N180704                22 1I 174675            22E1I 335706          13
3    212B1220569 120   20231 12B1H08585 12E   19454 1211I04333 12B3C20563   1
3    212H 1F03845 12H 1320670 12E1F14569*    3A       12E1I21069  12E1I20264* 2
3    2    3I         12L1E10287 12L1J22960 12E1E25581 12R1J19657A12R1K19260B 3
3    212S1I20166C12L    35420 12T1L20271 12H1E01584 12L1G19955 12T1K20570* 4
3    2    3C         12S1L20372D12E1K20557 12E1H25283 1211J20283*    E      5
3    212H1F00715 12E1L20257 12U1502020*    1          12U1K09281*     1     6
3    212E1E15347 1211I 8638 12E1F11278 22E1F18072E12J1020562 12H 1I22448    7
3    222E1E16570F22L    18983G22C1I 18345H                                  8
3    212T1B27388 22T    19488I22 1F00378J22H 1F18276K12E   08162 12E1D16976 9
3    222T   20069L22H 1F18584M22 1I 19178N22    198 5803 2H 1F19272        10
3    222E   21969P                                                         11
3    222T   24274022    18885R12H 1E17484 12H    19480 12H1421570          12
3    322E1J33860A12 1J30403 12 1J29909 12G1K21372 1271K25085 122    18393   1
3    312B1J33285 12F1J19545 12B1J19585 12C1I30265 12B1I32586 22B1N21473B   2
3    32241020678C12 1A19311 12 1J05008 12G1D23070 1271J2 [illegible]  12C1I27416   3
3    312B1A26939 1201F31266 1201K22773 1201A35063 1241Z2248 4D22     03987E 4
3    322E1E19460F22 1K19668G                                               5
3    402      1707 02      4210 62 3J34576 16 1N17076 16 1C19190 1221F  6830  1
3    422 1J01173A1601E11532 32 1L22585 22 1K21783B22 1K05079C12E1I01585   2
3    422E  20075D22E  04070E22 1F  1272F1221I06887 12E1I 19286             3
3    412E3100570 1BE2B01675 22 1B15775G22 1J00977H1221J08381 22  1P19481I  4
3    422G  22051J22T1I 17977K32    03090 22M   00276L                      5
3    412    20080 12 1J00280 22 1M00570M22    34878N22B1L155750            6
3    422M   18855P12B   18582 22N   210650                                 7
3    516H1421242 2651D01227A2651D10418B26 1L21835C1601I20679  16  1K18187  1
3    516B1I15088 1611I17065 1601I13085 26    08176D1601J07089 1611J20588   2
3    526 162588 4E26     23345F              161   24681 26 1J35377G       3
3    526 1017085H26     01430I                                             4
3    6062  01010 26 1N20244 1601A20275 1671J17878 16 1J19580 1671K34588    1
3    61671K22236 1671K  1277 1671K  3279 26 1L00061A1601J23068 16B1I21075  2
3    626B1A 3859B26 1L23280C26      2086D                                  3
3    62671J21781E16 1J12688 16B1G19383*    2U        0       5210 2    22582F 4
3    72241Z22782A            22H 1J05889B            22B1I 04284C12     22680 1
3    712B  21382 12B   21377 22H1Z04385D12B   24487 12B   22752 12B1M12377 2
3    712 1J21381 12B1K04487 22H1Z21381E22B1L23187F1211I17259*    B         3
3    712H   26552 12B1M06984 12B    17318 12B1J12180 22B1G12582G12B1I22780 4
3    71211J19338 12B1J11590 22B1N23582*   9          2241Z2127 1H22B1Z23287I 5
3    712B1Z19884 22B1L22584J12  1Z22488 12B1N22486 22B   03188K22     04289L 6
3    722B1Z03389M12B   04186 12B1D04480 12B1R04189 22B1L03988N12B   05065  7
3    722    0379 0022H   0359 0P2241Z22089622 1L03186R2      24589 S      8
3    722    01683T                                                        9
3    8023   35606 12H1H  4285 12H1G23285 22F1C10786A12H1F21985 22F1C15565B 1
3    81251H21679 22B1C20982C22 1J34213D12B1I 32180                        2
3    812H1K12678 12B1J00588 12B1G22588 12H1J19459 12H1K12979 12H1I22385   3
3    81271I  9089 2231C 8286E12H1L22989 12H1B28441 2271K  5090F2271K14568G 4
3    81271I  4289 22 1L24676H12B1K22560 22 1J06876I 12B1L23280 22 1K23476J 5
3    8              22B1M23461K12E1H33947 22      2428 SL          22    20985M 6
3    822C16218 37P22C1C20943N82H 1L2427601241C354580         8  4    23978O 7
3    8              12C1A  1928 12E1H10384 22 1L23188R22 1J19468S12B1H19447T 8
```

Figure 35. Listing of sample raw data file

```
2
   24        3   PLOT      GUARTZ JOINTS
  21F5               2396 8
  21FA5              2686 5
  21F5   Z           2466Ø
  21F5   Z           26Ø73
  21F5               27542
 121DA5              26267
 161H5   Z        C  3Ø345
 221Z5               2Ø38Ø
 221ZB5              18255
 221Z5B              25Ø65
 221Z5B              1757Ø
 221Z5A              19Ø6Ø
 221Z5               12Ø66
 221Z5               18188
 231F5               17982
 291Z5               3Ø562
 291D5            U  32847
 291D5            U  31938
 291D5            U  31744
 291D5               33552
 291D53 Z    G       31Ø69
 381I5               1656Ø
 381I5               19562
 381I5            C  26Ø72
   7        3   PLOT       OTHER (MISC.) JOINTS
 171FZ       2       19867
 171FZ               19678
 171FZ               18758
 171FZ               2Ø572
 171FZ               2Ø47Ø
 171FZ                4386
 171FZ               1955Ø
```

Figure 36. Listing of a secondary data file.

```
3
  12      9   NA        SUB AREA 1
 1
 2
 3
 4
 5
 6
 7
 8
 9
 1Ø
 11
 12
  8       9   NA        SUB AREA 2
 13
 14
 15
 16
 17
 18
 19
 2Ø
  3       9   NA        SUB AREA 4
 21
 22
 23
```

Figure 37. Listing of a station number file.

correspond with sub-areas or domains which are decided by the geologist. Station number files are read by SORT when the user wishes the location parameter to be automatically defined during program execution.

In this data-base system, file names may be no longer than six characters. The names must begin with a letter. The other characters may be letters or numbers. The following names are legal: JOINTS, F360, STA1. The following names are not permitted: MINJNTS, 4FAULT.

Program SORT. SORT searches through the primary or raw data file and extracts the data points that the user wishes to analyze. Before SORT reads the primary data file it is necessary to indicate what data are to be extracted. This is done by specifying the following parameters through interaction at the computer terminal: location (station numbers), TAG, A, B, C, Q1, and Q2 codes (Figure 38). Any of these parameters may be bypassed by typing $$ when the input is requested. These parameters define a filter template which tests each data point. If a match occurs between the codes of the filter template and the codes identifying each data point, the data point is written into a secondary file.

Samples of interaction between the user and the teletype are provided in Figures 38-41. Note that the user may choose the location parameters during program execution at the terminal (Figure 38) or automatically select the station numbers if they reside in a file. The option to read an existing station number file, from which the localities are automatically specified, is illustrated in the sample program run in Figure 39.

Figure 38. Sample of interaction during execution of SORT when station numbers are defined at the terminal.

```
RNH

NAME OF RAW DATA FILE
? PLDATA
NAME OF FILE TO BE CREATED
? JOINT1
READ STA NOS FROM FILE OR TERMINAL
TYPE F/T      TYPE "$$" TO BYPASS SORT BY STA NO
? T
INPUT STA NOS;  TO BYPASS SORT BY TAG TYPE "$$"
    TO END TYPE "0" ZERO
STA NO
? 1
TAG
? $$
STA NO
? 0
INPUT FILTER TEMPLATE TO BYPASS CODE TYPE "$$"
A CODE
? 1
B CODE
? $$
C CODE
? $$
MEASUREMENT TYPE CODE   TO BYPASS TYPE "0"
? 0
ANOTHER TEMPLATE FOR THIS SET?
? N
NO. MEAS. =     88
PLOT OR CONTOUR DATA    PLOT/CONT
? CONT
TYPE TITLE OF DATA SET---20 CHAR
? JOINTS AT STA 1
ANOTHER SET OF DATA?  Y/N
? Y
```

(continued on next page)

Figure 38 (continued from previous page).

```
SAME RAW DATA FILE?  Y/N
? Y
SAME FILTER TEMPLATE?  Y/N
? N
BYPASS STA NO SORT?  Y/N
? N
SAME STA NOS.  Y/N
? N
INPUT STA NOS;   TO BYPASS SORT BY TAG TYPE "$$"
    TO END TYPE "0" ZERO
STA NO
? 2
TAG
? $$
STA NO
? 3
TAG
? $$
STA NO
? 0
INPUT FILTER TEMPLATE TO BYPASS CODE TYPE "$$"
A CODE
? 1
B CODE
? $$
C CODE
? $$
MEASUREMENT TYPE CODE   TO BYPASS TYPE "0"
? 1
LOWER LIMIT
? K
UPPER LIMIT
? Z
ANOTHER TEMPLATE FOR THIS SET?
? N
NO. MEAS. =      16
PLOT OR CONTOUR DATA     PLOT/CONT
? PLOT
TYPE TITLE OF DATA SET---20 CHAR
? JOINTS > 4 METERS
ANOTHER SET OF DATA?  Y/N
? N


DATA FILE====JOINT1     NO SETS OF DATA= 2

NO MEAS    TYPE     P OR C   TITLE OF SET

    88       3        CONT     JOINTS AT STA 1
    16       3        PLOT     JOINTS > 4 METERS
 END.


CP        1.546 SECS.

RUN COMPLETE.
```

```
RNH

NAME OF RAW DATA FILE
? PLDATA
NAME OF FILE TO BE CREATED
? SUBJT
READ STA NOS FROM FILE OR TERMINAL
TYPE F/T      TYPE "$$" TO BYPASS SORT BY STA NO
? F
NAME FILE CONTAINING STA NOS.
? SUBS


STA NO SET=====SUBI
INPUT FILTER TEMPLATE TO BYPASS CODE TYPE "$$"
A CODE
? 1
B CODE
? $$
C CODE
? $$
MEASUREMENT TYPE CODE   TO BYPASS TYPE "0"
? 0
ANOTHER TEMPLATE FOR THIS SET?
? N
NO. MEAS. =    825
PLOT OR CONTOUR DATA     PLOT/CONT
? CONT
TYPE TITLE OF DATA SET---20 CHAR
? JOINTS AT SUBI
SAME SET OF STA NOS.  Y/N
? N


STA NO SET=====SUBII
SAME FILTER TEMPLATE  Y/N
? Y
NO. MEAS. =    569
PLOT OR CONTOUR DATA     PLOT/CONT
? CONT
TYPE TITLE OF DATA SET---20 CHAR
? JOINTS AT SUB II
SAME SET OF STA NOS.  Y/N
? N


STA NO SET=====SUBIII
SAME FILTER TEMPLATE  Y/N
? Y
NO. MEAS. =    727
PLOT OR CONTOUR DATA     PLOT/CONT
? CONT
TYPE TITLE OF DATA SET---20 CHAR
? JOINTS AT SUB III
SAME SET OF STA NOS.  Y/N
? N
```

Figure 39. Partial sample of interaction during execution of SORT when a station number file is read to define the location parameters.

It is not necessary that SORT read only a file specifying the sub-areas to define the localities at which data is to be analyzed. SORT may also read a secondary file consisting of a data list formed during a previous execution. The following example will help in illustrating the advantages of such a feature:

> The user desires to determine the motion patterns of a particular set of faults, the poles to which are well clustered on an equal-area net. By using a program called FILTER, the faults may be isolated and written into a secondary data file (plotted in Figure 42A). The user now wishes to plot on an equal-area net all the rotation axes associated with these fault planes. The file containing the isolated set of faults is read as a station number file. In this way, the station number and TAG of each fault is specified. When SORT reads through the raw data file, the rotation axes with the same station number and TAG as the fault planes will be extracted. They are then written into a secondary data file. The rotation axes can now be plotted on an equal-area net to show the patterns of motion on these faults (Figure 42B).

The codes that define the filter template are nothing more than the codes that identify each data point on the data sheets. To bypass sorting by a particular code $$ is typed when the code is requested by the computer. It is possible to use several filter templates when extracting data. This feature is convenient when it is desired to display several types of data together. In other words, faults and dikes may be included in the same data set. A more frequent example is to extract all mineralized joints together in order to be plotted on the same equal-area net. The sample interaction (Figure 41) illustrates how two filter templates may be used to extract two types of mineralized joints and to write them into the same file. Note that the option may be chosen by typing Y to the question, ANOTHER FILTER TEMPLATE FOR THIS SET?.

```
RNH

NAME OF RAW DATA FILE
? LIDATA
NAME OF FILE TO BE CREATED
? ROTAX
READ STA NOS FROM FILE OR TERMINAL
TYPE F/T      TYPE "$$" TO BYPASS SORT BY STA NO
? F
NAME FILE CONTAINING STA NOS.
? CLUSTR


STA NO SET=====FAULTS 125 20 20
INPUT FILTER TEMPLATE   TO BYPASS CODE TYPE "$$"
A CODE
? 2
B CODE
? $$
C CODE
? $$
MEASUREMENT TYPE CODE   TO BYPASS TYPE "0"
? 0
ANOTHER TEMPLATE FOR THIS SET? Y/N
? N
NO. MEAS. =     39
PLOT OR CONTOUR DATA     PLOT/CONT
? PLOT
TYPE TITLE OF DATA SET---20 CHAR
? FILTERED ROT AXES
SAME SET OF STA NOS.  Y/N
? N


DATA FILE====ROTAX       NO SETS OF DATA= 1

NO MEAS    TYPE     P OR C   TITLE OF SET

    39       4       PLOT     FILTERED ROT AXES
 END.


CP        1.315 SECS.

RUN COMPLETE.
```

Figure 40. Sample interaction during execution of SORT when a secondary data file containing the cluster of poles to fault planes (plotted in Figure 42A) is read as a station number file. The interaction illustrates how the rotation axes (plotted in Figure 42B) associated with these fault planes are extracted.

```
RNH

NAME OF RAW DATA FILE
? PLDATA
NAME OF FILE TO BE CREATED
? MINJNT
READ STA NOS FROM FILE OR TERMINAL
TYPE F/T      TYPE "$$" TO BYPASS SORT BY STA NO
? %-$$
INPUT FILTER TEMPLATE TO BYPASS CODE TYPE "$$"
A CODE
? 1
B CODE
? $$
C CODE
? 5
MEASUREMENT TYPE CODE   TO BYPASS TYPE "0"
? 0
ANOTHER TEMPLATE FOR THIS SET?
? Y
A CODE
? 1
B CODE
? $$
C CODE
? 6
MEASUREMENT TYPE CODE   TO BYPASS TYPE "0"
? 0
ANOTHER TEMPLATE FOR THIS SET?
? N
NO. MEAS. =     27
PLOT OR CONTOUR DATA     PLOT/CONT
? PLOT
TYPE TITLE OF DATA SET---20 CHAR
? QUARTZ ZEOLITE JNTS
ANOTHER SET OF DATA?  Y/N
? N


DATA FILE====MINJNT    NO SETS OF DATA= 1

NO MEAS    TYPE    P OR C  TITLE OF SET

    27       3       PLOT    QUARTZ ZEOLITE JNTS
 END.


CP        5.768 SECS.

RUN COMPLETE.
```

Figure 41. Sample interaction during execution of SORT showing how two filter templates are used to extract quartz joints and zeolite joints into one data set.

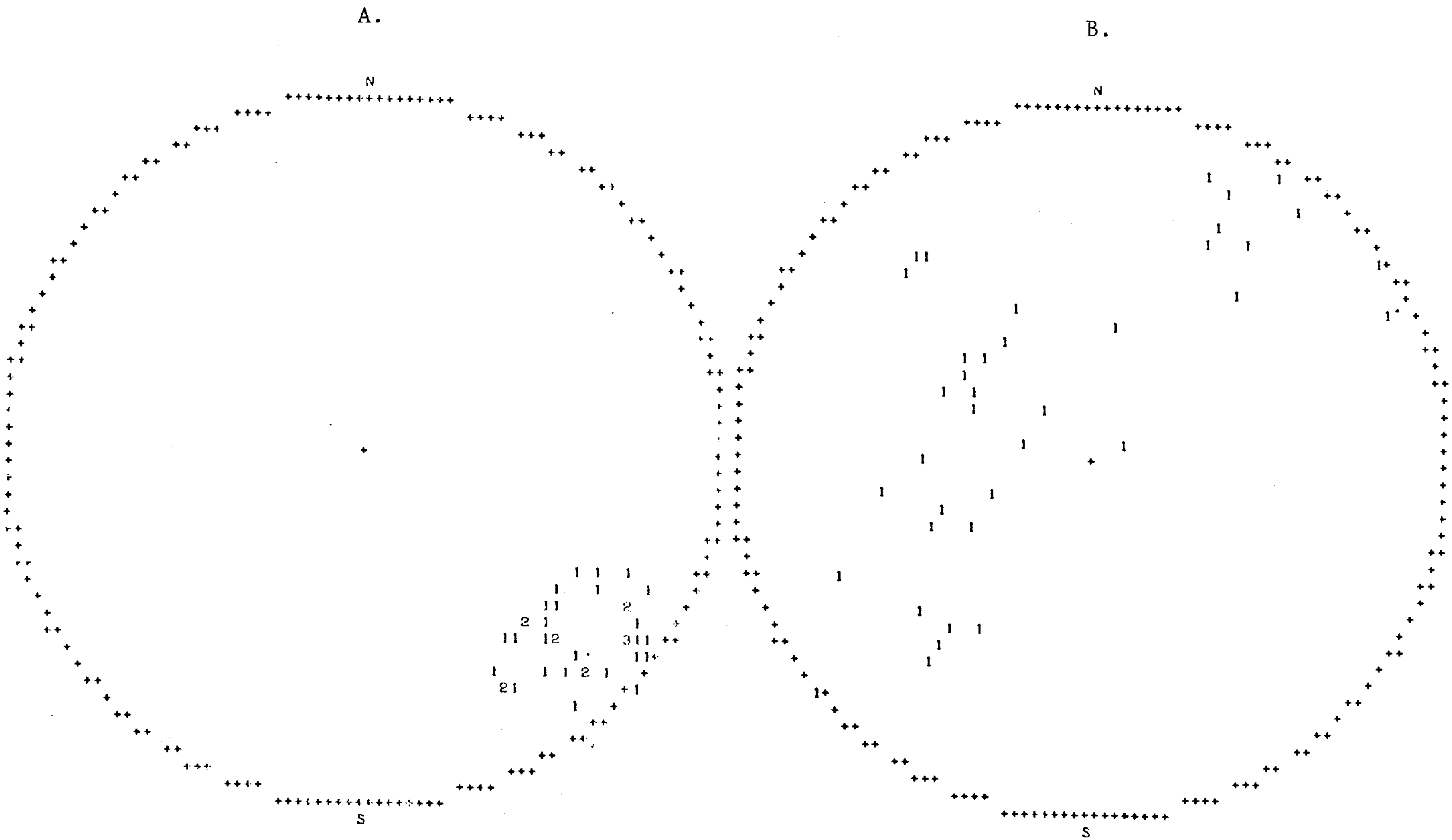


Figure 42. Computer-drawn equal-area plots of poles to faults and rotation axes. A. Cluster of poles to faults extracted from the total fault population. Data represented on this diagram were used to define the station numbers and TAG codes of the rotation axes in B.

It is possible to create a file containing up to 20 sets of data points. When the user responds Y to the question, ANOTHER SET OF DATA? Y/N, the program again searches through the raw data file. The user also has the option to select another raw data file residing in computer storage. It may not always be necessary to redefine the filter template during each recycle. There are options to indicate that the same filter template is to be used again. There are similar options concerning the station number parameters (Figures 38, 39).

Near the completion of program execution, information pertaining to each data set within the file is summarized in a table (Figures 38, 40, 41). The table consists of the number of data points in each set, the type of data (planar or linear), whether the data is to be plotted or contoured, and the title of the data set. This table may be useful when the user wishes to keep a record of each data file that is stored in the computer system.

Program STASET. This program establishes a file containing station numbers. Up to 20 sets of station numbers are allowed in one file and a limit of 100 station numbers are permitted in each set. Each set of station numbers may be considered as a sub-area or domain of a study area.

A station number file is advantageous when the user wishes to extract data from sub-areas (as in Figure 39). This eliminates the need to redefine the station number parameters during the execution of SORT.

At the beginning of execution of STASET, the user is required to input the name of the file to be formed. Station numbers are then requested which the user types individually on one line following the question mark (?) generated by the computer system. The user then presses the carriage return key and the computer system responds with another ? . If it is desired to input another station number in this set the user types it. To terminate that set of station numbers, a zero (Ø) is typed.

To identify each station number set, the user is requested to input a title. The title of each set may consist of 20 of any of the characters displayed on the keys of the teletype. The title may be shorter or longer than 20 characters. However, if over 20 characters have been typed only the first 20 will be stored in memory and no error message will occur.

Following the creation of each station number set with its title, the user then has the option of creating another set. The question, ANOTHER SET OF STA NOS? Y/N, provides this option and the user simply types Y or N (yes or no).

A sample of program interaction is provided in Figure 43. At the end of program execution, a list is printed at the teletype. The list is for the user's information, indicating which station numbers are in each set. The bottom of Figure 43 shows the list printed before the termination of STASET.

Program FILTER. This program reads a secondary data file and filters data by orientation. For each set of data, a filter vector is defined by an azimuth and plunge. The radius of the filter area is specified in degrees. FILTER determines if the vector defined by the azimuth and plunge of each data point (if planar data, the azimuth and

```
INPUT NAME OF FILE TO BE FORMED
? DOMAIN
INPUT STA NOS. AFTER LAST TYPE "0"
? 12
? 10
? 2
? 5
? 4
? 11
? 9
? 1
? 3
? 6
? 7
? 8
? 0
INPUT TITLE OF THIS SET
? SUB AREA 1
ANOTHER SET OF STA NOS.?  Y/N
? Y
? 13
? 15
? 14
? 16
? 17
? 18
? 19
? 20
? 0
INPUT TITLE OF THIS SET
? SUB AREA 2
ANOTHER SET OF STA NOS.?  Y/N
? Y
? 21
? 23
? 22
? 0
INPUT TITLE OF THIS SET
? SUB AREA 4
ANOTHER SET OF STA NOS.?  Y/N
? N


          ***DATA FILE=== DOMAIN    NSETS= 3

                 NO STA =   12       TITLE== SUB AREA 1

       1         2         3         4         5         6         7
       8         9         10        11        12

                 NO STA =   8        TITLE== SUB AREA 2

       13        14        15        16        17        18        19
       20

                 NO STA =   3        TITLE== SUB AREA 4

       21        22        23
 END.

CP        0.266 SECS.

RUN COMPLETE.
```

Figure 43. Sample interaction during the execution of STASET.

plunge of the pole to each plane) lies within the limits of the filter. Another option may be chosen if the user wishes to extract those data points which lie outside the limits of the filter. Those data points which have been extracted are written into a secondary data file.

FILTER handles up to 20 sets of data. In each set 1000 data points are permitted. The same data set may be filtered more than once. Figure 44 is a sample of interaction during the execution of FILTER, showing the options available.

The interactive questions printed at the terminal during the execution of FILTER are straightforward (Figure 44). The names of the file to be filtered and the file to be formed are requested. Following this, the header of the first data set in the input file is printed at the terminal. Then the user is requested to specify whether the data points to be extracted are to lie inside or outside the limits of the filter area by typing EX or IN.

The user inputs the azimuth and plunge of the filter vector and the radius, in degrees, of the filter area. If linear data are filtered, the azimuth and plunge of each data point are tested against the filter vector. When planar data are being filtered, the pole to each plane is tested. The sample run in Figure 44 shows the filter vector specified in isolating the poles to faults plotted in Figure 42A.

The computer prints the number of data points that have been isolated. The user must then specify if the data is to be plotted or contoured (the user types PLOT or CONT) when represented on equal-area nets. Next the user must type the title of the data set which has just been isolated.

Finally, the user has the option of filtering the same data set by using a different vector or filtering the next set of data. The above interaction is repeated for either choice.

FILTER is extremely useful when used in conjunction with SORT as illustrated in the example on page 82. First, all faults are extracted from the study area. The fault clusters of interest are isolated as shown by the sample run of FILTER in Figure 44. This execution of FILTER produces a file called CLUSTR. SORT reads CLUSTR as a station number file to define the station numbers and TAG codes of the rotation axes on each of the isolated fault planes (Figure 40). These can then be plotted as in Figure 42B to show fault movement patterns.

Data Display

After the desired elements have been extracted from the raw data file, they are ready to be displayed in a form recognizable by the geologist. Orientation data is commonly represented on equal-area nets. Several programs used for analysis of orientation data are available in the Geology Department library within the University of Massachusetts computer system.

NETTS plots and contours data on equal-area nets and is executed at a timesharing terminal. A similar program (NETBAT) operates in BATCH and is extremely useful when a great deal of printed output is expected. Other programs include BETA for finding the intersections of planes and VECOMP (modified from Schuenemeyer et al., 1972) which performs cluster statistics. All programs are written in FORTRAN.

```
RNH

WHAT FILE DO YOU WISH TO PROCESS
? FLTS
PURGE SOURCE FILE?  YES/NO
? YES
INPUT NAME OF FILE YOU WISH TO FORM
? CLUSTR

N =     313        TYPE - 3        CONT        DATA SET == ALL FAULTS

INCLUDE OR EXCLUDE DATA W/IN FILTER LIMITS  EX/IN
? IN
INPUT FILTER VECTOR-- AZ AND PLUNGE - ALSO RAD OF AREA
? 125,20,20
NO OF DATA PTS FOUND=      38
PLOT OR CONTOUR DATA?
? PLOT
TITLE OF FILTERED DATA?
? FAULTS 125 20 20


FILTER SAME DATA SET ?  Y/N
? N


DATA FILE==  CLUSTR        NO DATA SETS=  1

NO MEAS   TYPE    P OR C  TITLE OF SET              EX OR IN   VECTOR  RAD

   38       3       PLOT    FAULTS 125 20 20          IN        125 20  20
   STOP

CP        0.668 SECS.

RUN COMPLETE.
```

Figure 44. Sample interaction during the execution of FILTER.

Summary

By recording field information on the data forms described above, geologic information can easily be transferred to a computer system. The system of programs discussed provides rapid access to the field data. Features of interest are easily retrieved and presented graphically in a form easily absorbed by the geologist. Figure 47 provides a summary of the data-base system, showing how the computer programs are related.

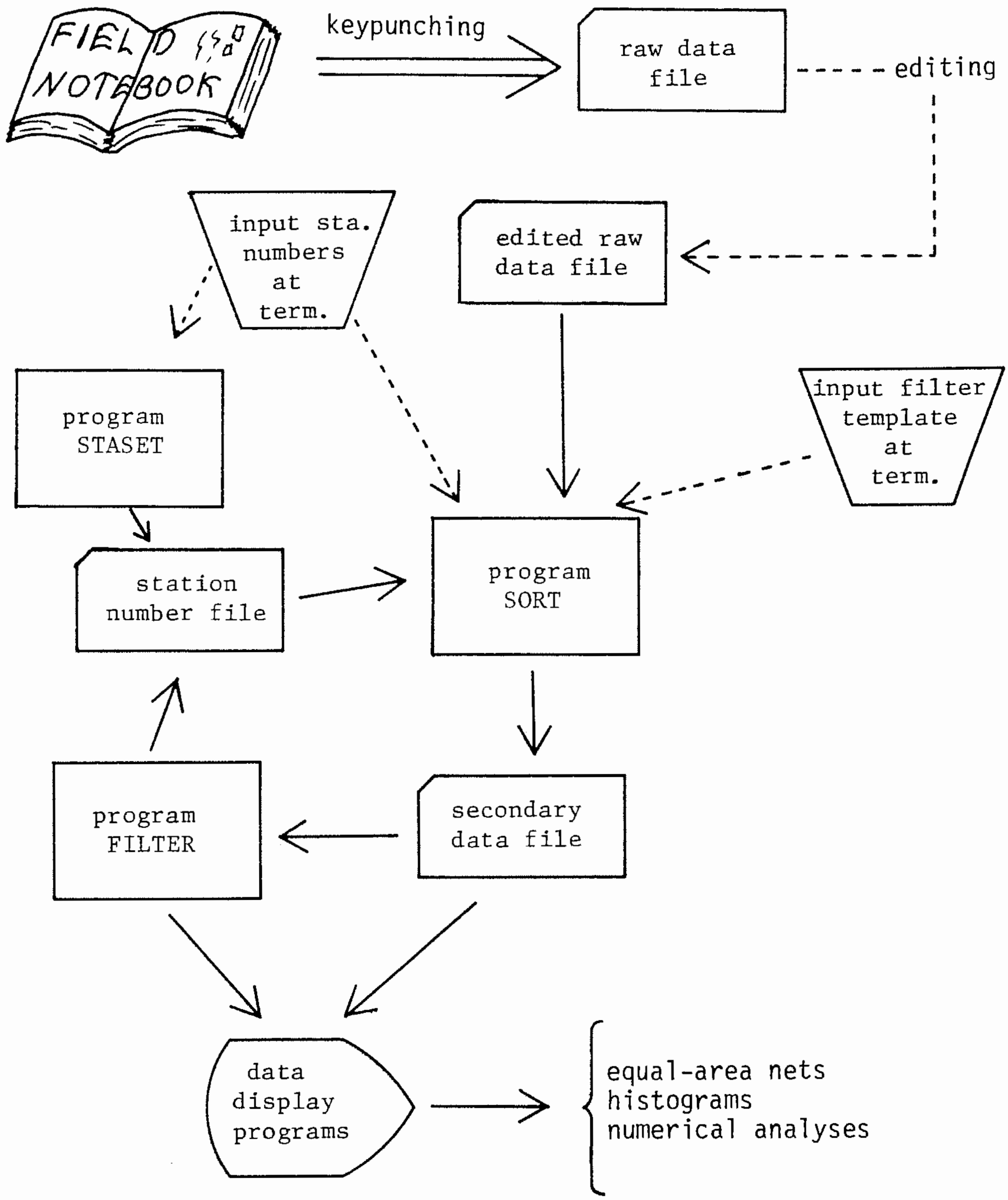


Figure 45. Flow diagram illustrating the interrelation of programs and approach used in data analysis.

APPENDIX II: PROGRAM LISTING OF SORT

```
      PROGRAM SORT(INPUT,OUTPUT,TAPE1,TAPE2,TAPE8,TAPE9)
*
*  PROGRAM READS CODED GEOLOGIC DATA -- EXTRACTS DESIRED ELEMENTS
*       BY INPUTING CODES IN A FILTER TEMPLATE
*
*     BY R. PIEPUL -- U MASS. GEOLOGY DEPT 1975
*
      DIMENSION ICODE(18),JCODE(5)
      COMMON KOUNT,ICOUN,NSETS,IHEADR(20,5),NUMB(1000),
+     T(1000),COMON(1100)
      NSETS=0
      PRINT 282
  282 FORMAT(*NAME OF RAW DATA FILE*)
      READ 290 ,NDFILE
  290 FORMAT(A6)
      CALL GET(5HTAPE1,NDFILE,0,0)
      PRINT 300
  300 FORMAT(*NAME OF FILE TO BE CREATED*)
      READ 290,NAME
*
*   STATION NOS ARE INPUT FROM FILE OR TERMINAL
*    BY USING SUBROUTINES FILRD  AND  TERMRD
*
      PRINT 420
  420 FORMAT(*READ STA NOS FROM FILE OR TERMINAL*/
+     *TYPE F/T     TYPE *$$* TO BYPASS SORT BY STA NO*)
      READ 425,IFTF
  425 FORMAT(A2)
      IF(IFTF.NE.1HF)GO TO 430
      CALL FILRD
      GO TO 440
  430 CALL TERMRD(IFTF)
*
*   DUMP DATA FROM TAPE 8 TO TAPE 1
*    WRITE HEADINGS
*
  440 CALL RETURN(5HTAPE1)
      REWIND 2
      REWIND 8
      WRITE(2,445) NSETS
  445 FORMAT(I2)
      DO 480 I=1,NSETS
      WRITE (2,450)(IHEADR(I,J),J=1,5)
  450 FORMAT(1X,I5,5X,I1,2X,A4,5X,2A10)
      KEND=IHEADR(I,1)
      DO 470 K=1,KEND
      READ(8,460)NS,(ICODE(J),J=1,13),OR,(JCODE(L),L=1,5)
  460 FORMAT(I4,13A1,1X,I5,5A1)
      WRITE(2,460)NS,(ICODE(J),J=1,13),OR,(JCODE(L),L=1,5)
  470 CONTINUE
  480 CONTINUE
      REWIND 2
      CALL SAVE(5HTAPE2,NAME,0,0,0)
*
*   PRINT HEADING INFORMATION
*
      PRINT 500,NAME,NSETS
  500 FORMAT(///*DATA FILE====*,A6,4X,*NO SETS OF DATA=*,I2/)
      PRINT 505
  505 FORMAT(*NO MEAS*,3X,*TYPE*,4X,*P OR C*,2X,*TITLE OF SET*/)
      DO 600 I=1,NSETS
      PRINT 602,(IHEADR(I,J),J=1,5)
  600 CONTINUE
  602 FORMAT(1X,I5,6X,I1,6X,A4,4X,2A10)
```

(cont.)

APPENDIX II: PROGRAM LISTING OF SORT (cont.)

```
*      CALL RETURN(5HTAPE2)  $ CALL RETURN(5HTAPE8)
       CALL RETURN (5HTAPE9)
       END
*
*
*
**********    SUBROUTINE TO READ STA. NOS. FROM TERMINAL***********
*
       SUBROUTINE TERMRD(IFTF)
       COMMON KOUNT,ICOUN,NSETS,IHEADR(20,5),NUMB(1000),T(1000)
       JRUN=0
     2 REWIND 1
*
*      YES OR NO VARIABLES:  IANS     IAN2     IAN3     IAN4
*
       IAN4=1HN
       IAN2=1HN
       IF(JRUN.EQ.0)GO TO 30
*
       PRINT 3
     3 FORMAT(//*SAME RAW DATA FILE\  Y/N*)
       READ 4,IANS
     4 FORMAT(A1)
       PRINT 6
     6 FORMAT(*SAME FILTER TEMPLATE\  Y/N*)
       READ 4,IAN2
       PRINT 7
     7 FORMAT(*BYPASS STA NO SORT\  Y/N*)
       READ 4,IAN3
       IF(IAN3.EQ.1HY)GO TO 9
       PRINT 8
     8 FORMAT(*SAME STA NOS.  Y/N*)
       READ 4,IAN4
     9 IF(IAN3.EQ.1HY)IFTF=2H$$
       IF(IANS.EQ.1HY)GO TO 30
     5 PRINT 10
    10 FORMAT(*NAME OF NEW RAW DATA FILE*)
       READ 20,NDFILE
    20 FORMAT(A6)
       CALL GET(5HTAPE1,NDFILE,0,0)
    30 ICOUN=0
*
*          INPUT STATION NUMBERS AND TAGS
*
       IF(IAN4.EQ.1HY)GO TO 202
       IF(IFTF.NE.2H$$)GO TO 70
       NUMB(1)=2H$$
       T(1)=2H$$
       KOUNT=1
       GO TO 202
*
    70 PRINT 80
    80 FORMAT(*INPUT STA NOS:  TO BYPASS SORT BY TAG TYPE #$$#  *
+      /*     TO END TYPE #0# ZERO*)
       KOUNT=0
    90 PRINT 100
   100 FORMAT(*STA NO*)
       KOUNT=KOUNT+1
       READ,NUMB(KOUNT)
       IF(NUMB(KOUNT).EQ.0)GO TO 200
       PRINT 110
   110 FORMAT(*TAG*)
       READ 115,T(KOUNT)
   115 FORMAT(A2)
```

(cont.)

APPENDIX II: PROGRAM LISTING OF SORT (cont.)

```
      GO TO 90
 200  KOUNT=KOUNT-1
 202  READ(1,205)IT
       REWIND 1
 205  FORMAT(I1)
      IF(IT.NE.3.AND.IT.NE.4)GO TO 215
      CALL SEARCH(IAN2)
      GO TO 220
 215  STOP
*
 220  PRINT 225,ICOUN
 225  FORMAT(*NO. MEAS. = *,I5)
      IF(ICOUN.LE.0)GO TO 240
      NSETS=NSETS+1
      CALL HEAD(IT)
      IF(NSETS.EQ.20)GO TO 250
 240  PRINT 230
 230  FORMAT(*ANOTHER SET OF DATA\  Y/N*)
      READ 4,JANS
      JRUN=1
      IF(JANS.EQ.1HY)GO TO 2
 250  RETURN
      END
*
*
*
********     SUBROUTINE TO READ STA. NOS. FROM FILE    *************
*
      SUBROUTINE FILRD
      COMMON KOUNT,ICOUN,NSETS,IHEADR(20,5),NUMB(1000),T(1000)
      DIMENSION JHEADR(2)
      IAN2=1HN
      JRUN=0
      PRINT 10
  10  FORMAT(*NAME FILE CONTAINING STA NOS.*)
      READ 20,NASN
  20  FORMAT(A6)
      CALL GET(5HTAPE9,NASN,0,0)
      READ(9,30)LSETS
  30  FORMAT(I2)
      IF(LSETS.GT.20)GO TO 401
*
*      THIS LOOP DECIDES FORMAT OF STA NO FILE.   THEN CALLS
*      THE APPROPRIATE    SUBROUTINE TO READ FILE
*
      DO 400 I=1,LSETS
      READ(9,35) NO,ITY,IPL,(JHEADR(K),K=1,2)
  35  FORMAT(1X,I5,5X,I1,2X,A4,5X,2A10)
  40  FORMAT(//*STA NO SET=====*,2A10)
      PRINT 40,(JHEADR(K),K=1,2)
      IF(NO.LE.0)GO TO 400
      IF(ITY.NE.9)GO TO 50
      CALL RWOTAG9(NO)
      GO TO 70
  50  IF(ITY.NE.3.AND.ITY.NE.4)GO TO 60
      CALL RWTAGS(NO)
      GO TO 70
  60  IF(ITY.NE.1)GO TO 400
      CALL RWOTAG(NO)
  70  ICOUN=0
  71  REWIND 1
      READ(1,72)IT
       REWIND 1
  72  FORMAT(I1)
```

(cont.)

```
      IF(JRUN.EQ.0)GO TO 73
      PRINT 75
   75 FORMAT(*SAME FILTER TEMPLATE  Y/N*)
      READ 76,IAN2
   76 FORMAT(A1)
   73 JRUN=1
      IF(IT.NE.3.AND.IT.NE.4)GO TO 401
      CALL SEARCH(IAN2)
  300 PRINT 90,ICOUN
   90 FORMAT(*NO. MEAS. = *,I5)
      IF(ICOUN.LE.0)GO TO 350
      NSETS=NSETS+1
      CALL HEAD(IT)
      IF(NSETS.EQ.20)GO TO 400
  350 PRINT 390
  390 FORMAT(*SAME SET OF STA NOS.  Y/N*)
      READ 460,IAN4
      IF(IAN4.EQ.1HY)GO TO 70
  400 CONTINUE
      GO TO 450
  401 PRINT 402
  402 FORMAT(*RAW DATA FILE INCOMPATIBLE*)
  410 STOP
  450 RETURN
  460 FORMAT(A1)
      END
*
*
*
********    SUBROUTINE TO DEFINE HEADERS FOR DATA SETS***********
*
      SUBROUTINE HEAD(IT)
      COMMON KOUNT,ICOUN,NSETS,IHEADR(20,5),NUMB(1000),T(1000)
      PRINT 20
   20 FORMAT(*PLOT OR CONTOUR DATA    PLOT/CONT*)
      READ 30,IHEADR(NSETS,3)
   30 FORMAT(A4)
      IHEADR(NSETS,1)=ICOUN
      IHEADR(NSETS,2)=IT
      PRINT 40
   40 FORMAT(*TYPE TITLE OF DATA SET---20 CHAR*)
      READ 50,(IHEADR(NSETS.K),K=4,5)
   50 FORMAT(2A10)
      RETURN
      END
*
*
*
********    SUBROUTINE TO SEARCH THRU RAW DATA FILE           *****
*    AND EXTRACT DATA.    USES FILTER WHICH IS ESTABLISHED
*    INTERACTIVELY BY INPUTTING CODES
*
      SUBROUTINE SEARCH(IFTF)
      COMMON KOUNT,ICOUN,NSETS,IHEADR(20,5),NUMB(1000),T(1000),
+     A(15),B(15),C(15),D(15),E
+(15),F(15),AC(6),BC(6),CC(6),Q1(6), Q2(6),OR(6),TA(6),NSTA(100),
+     ACODE(100),BCODE(100),CCODE(100),ORIENT(100),TAG(100)
      DIMENSION QUINF(100,7),ICK(100),ADDC(100,3)
      TYPE INTEGER A,B,C,D,E,F,T,AC,BC,CC,Q1,Q2.OR,TA,NSTA,ACODE,
+     BCODE,CCODE,ORIENT,TAG,QUINF,ADDC
      JNFI=1
       IF(IFTF.EQ.1HY)GO TO 1420
      LCOU=1
*
```

(cont.)

APPENDIX II: PROGRAM LISTING OF SORT (cont.)

```
*  ESTABLISH FILTER TEMPLATE
*
        PRINT 1320
   1320 FORMAT(*INPUT FILTER TEMPLATE TO BYPASS CODE TYPE #$$#*)
   1331 PRINT 2021
        READ 2026, A(LCOU)
        PRINT 2022
        READ 2026, B(LCOU)
        PRINT 2023
        READ 2026,C(LCOU)
        PRINT 2031
        READ,D(LCOU)
        IF(D(LCOU).NE.0)GO TO 1380
        D(LCOU)=2H$$
        E(LCOU)=F(LCOU)=2H$$
        GO TO 1392
   1380 PRINT 2028
        READ2026,E(LCOU)
        PRINT 2029
        READ2026,F(LCOU)
   1392 PRINT 2025
        READ,MANS
        IF(MANS.EQ.1HN)GO TO 1420
        LCOU=LCOU+1
        GO TO 1331
*
*  INITIALIZE VARIABLES
   1420 KA=1
        DO 1430 LM=1,100
        DO 1427 MM=1,3
   1427 ADDC(LM,MM)=1H
        DO 1430 MM=1,7
        QUINF(LM,MM)=1H
   1430 CONTINUE
*
*       IF  *  OCCURS IN TAG COLUMN OF LAST SIX,
*     THEN ANOTHER LINE MUST BE READ
*     BETWEEN 30 AND 100 DATA LINES ARE READ,IN THIS LOOP, DEPENDING
*      ON THE  *.
*
        DO 1434 I=1,100
        ICK(I)=1
   1434 CONTINUE
   1440 READ(1,2020)NS,(AC(J),BC(J),CC(J),Q1(J),Q2(J),OR(J),TA(J)
+       ,J=1,6),IPG
        IF(EOF,1)2010,1550
   1511 FORMAT(A2)
   1550 DO 1740 I=1,6
        IQAT=Q1(I)
        IF(KA.EQ.1)GO TO 1630
        KAT=KA-1
        IF(TAG(KA-1).NE.1H*)GO TO 1630
        IF(Q1(I).EQ.0)GO TO 1585
        QUINF(KAT,IQAT)=Q2(I)
   1585 IF(CC(I).EQ.1H ) GO TO 1620
        ICK(KA-1)=ICK(KA-1)+1
        ICAT=ICK(KA-1)
        ADDC(KAT,ICAT)=CC(I)
   1620 TAG(KA-1)=TA(I)
        GO TO 1740
   1630 IF(AC(I).EQ.1H )GO TO 1740
        NSTA(KA)=NS
        IF(Q1(I).EQ.0)GO TO 1680
        QUINF(KA,IQAT)=Q2(I)
```

(cont.)

APPENDIX II: PROGRAM LISTING OF SORT (cont.)

```
1680 ORIENT(KA)=OR(I)
     ACODE(KA)=AC(I)
     BCODE(KA)=BC(I)
     ADDC(KA,1)=CC(I)
     TAG(KA)=TA(I)
     KA=KA+1
1740 CONTINUE
     IF(TAG(KA-1).EQ.1H*)GO TO 1440
     IF(JNFI.EQ.0)GO TO 1780
1760 IF(KA.LT.30)GO TO 1440
*
*       NOW SORT DATA
*
1780 KAT=KA-1
     IF(KAT.EQ.0)GO TO 2040
     DO 2005 I=1,KAT
*
*   SORT BY STATION       $$  MEANS BYPASS SORT BY STA NO
*
     IF(NUMB(1).EQ.2H$$)GO TO 1850
     IF(NUMB(KOUNT).LT.NSTA(I))GO TO 2040
     DO 1830 J=1,KOUNT
     IF(NUMB(J).NE.NSTA(I))GO TO 1830
     IF(T(J).EQ.TAG(I).OR.T(J).EQ.2H$$)GO TO 1850
1830 CONTINUE
     GO TO 2003
*
*       SORT BY CODES USING FILTER TEMPLATE  --  $$ MEANS BYPASS
*
1850 DO 2000 J=1,LCOU
     IF(A(J).NE.ACODE(I).AND.A(J).NE.2H$$)GO TO 2000
     IF(B(J).NE.BCODE(I).AND.B(J).NE.2H$$)GO TO 2000
     IF(C(J).EQ.2H$$)GO TO 1900
     ICAT=ICK(I)
     DO 1885 LI=1,ICAT
     IF(C(J).EQ.ADDC(I,LI))GO TO 1900
1885 CONTINUE
     GO TO 2000
*
*  SORT BY QUANTITATIVE MEAS. CODE USING UPPER AND LOWER LIMITS
*
1900 IF(D(J).EQ.2H$$)GO TO 1970
     IF(E(J).EQ.2H$$.OR.F(J).EQ.2H$$)GO TO 1970
     IDAT=D(J)
     IF(QUINF(I,IDAT).EQ.1H )GO TO 2000
     IQF=QUINF(I,IDAT)
     INQ=LETER(IQF)
     IEJ=E(J) $ IFJ=F(J)
     LOW=LETER(IEJ)
     LUP=LETER(IFJ)
     IF(INQ.LT.LOW .OR. INQ .GT. LUP)GO TO 2000
*
1970 WRITE(8,2030)NSTA(I),ACODE(I),BCODE(I),
+    (ADDC(I,IZ),IZ=1,3),(QUINF(I,IV),IV=1,7),TAG(I),ORIENT(I)
     ICOUN=ICOUN+1
     GO TO 2003
2000 CONTINUE
2003 CONTINUE
2005 CONTINUE
     IF(JNFI.EQ.0)GO TO 2040
     GO TO 1420
2010 JNFI=0
     GO TO 1780
*
```

(cont).

APPENDIX II: PROGRAM LISTING OF SORT (cont.)

```
 2020 FORMAT(1X,I4,6(3A1,I1,A1,I5,A1),A1)
 2021 FORMAT(*A CODE*)
 2022 FORMAT(*B CODE*)
 2023 FORMAT(*C CODE*)
 2025 FORMAT(*ANOTHER TEMPLATE FOR THIS SET\*)
 2026 FORMAT(A2)
 2027 FORMAT(I1,1X,A2,1X,A2)
 2028 FORMAT(*LOWER LIMIT*)
 2029 FORMAT(*UPPER LIMIT*)
 2030 FORMAT(I4,13A1,1X,I5,5X)
 2031 FORMAT(*MEASUREMENT TYPE CODE   TO BYPASS TYPE #0#*)
 2035 FORMAT(7(A2,1X))
 2040 RETURN
      END
*
*
*
********    FUNCTION SUBPROGRAM TO CONVERT QUANTITATIVE   **********
*   DATA TO INTEGER BASED ON HIERARCHY OF CODE
*
      FUNCTION LETER(LR)
      DIMENSION KODE(36)
      DATA(KODE(J),J=1,36)/1HC,1HY,1HT,1HU,1HV,1HW,1H1,1H2,1H3,
+     1H4,1H5,1H6,1H7,
+     1H8,1H9,1HA,1HB,1HC,1HD,1HE,1HF,1HG,1HH,1HI,1HJ,1HK,1HL,1HM,
+     1HN,1HO,1HP,1HQ,1HR,1HS,1HX,1HZ/
      DO 3160 I=1,36
      IF(KODE(I).NE.LR)GO TO 3160
      LETER=I
      GO TO 3170
 3160 CONTINUE
 3170 RETURN
      END
*
*
*
*  ****** SUBROUT TO READ STA NOS WITHOUT TAGS WHEN TAGS    *******
*                    ARE PRESENT
*
      SUBROUTINE RWOTAG(N)
      COMMON KOUNT,ICOUN,NSETS,IHEADR(20,5),NUMB(1000),T(1000)
      KOUNT=0
      DO 10 I=1,N
*
      READ(9,50)NUMB(I)
    5 KOUNT=KOUNT+1
      T(I)=2H$$
   10 CONTINUE
   20 RETJRN
   50 FORMAT(I4,24X)
      END
*
*
*
********  SUBROUTINE TO READ STA NOS WITHOUT TAGS    ***********
*   WHEN TAGS ARE NOT PRESENT
*
      SUBROUTINE RWOTAG9(N)
      COMMON KOUNT,ICOUN,NSETS,IHEADR(20,5),NUMB(1000),T(1000)
      KOUNT=0
      DO 10 I=1,N
      READ(9,50)NUMB(I)
    5 KOUNT=KOUNT+1
      T(I)=2H$$
```

(cont.)

APPENDIX II: PROGRAM LISTING OF SORT (cont.)

```
   10 CONTINUE
   20 RETURN
   50 FORMAT(I4)
      END
*
*
*
*********    SUBROUTINE TO READ STA NOS WITH TAGS    ***************
*
      SUBROUTINE RWTAGS(N)
      COMMON KOUNT,ICOUN,NSETS,IHEADR(20,5),NUMB(1000),T(1000)
      KOUNT=0
      DO 10 I=1,N
      READ(9,50)NUMB(I),T(I)
    5 KOUNT=KOUNT+1
   10 CONTINUE
   20 RETURN
   50 FORMAT(I4,12X,A1,11X)
      END
```

APPENDIX III: PROGRAM LISTING OF FILTER

```
      PROGRAM FILTER(INPUT,OUTPUT,TAPE1,TAPE7)
      DIMENSION IDAT(1000,3),IHEADR(20,9),JHEADR(2)
      COMMON IHEADR,IDAT
      MAX=1000
      LSET=0
      REWIND 1  $  REWIND 7
       IAN=1HN
      PRINT 80
   80 FORMAT(*WHAT FILE DO YOU WISH TO PROCESSA*)
      READ 1050,INFIL
      PRINT 100
  100 FORMAT(*PURGE SOURCE FILE\  YES/NO*)
      READ 1080, IFPU
      CAL_ GET(5HTAPE1,INFIL,0,0)
      READ(1,140)NSET
  140 FORMAT(I2)
      PRINT 220
  220 FORMAT(*INPUT NAME OF FILE YOU WISH TO FORM*)
      READ 1050,NOUT
      DO 1020 KDO=1,NSET
      READ(1,256)IDO,IP,IPLT,(JHEADR(K),K=1,2)
  256 FORMAT(1X,I5,5X,I1,2X,A4,5X,2A10)
      PRINT 258,IDO,IP,IPLT,(JHEADR(K),K=1,2)
 258 FORMAT(/*N = *,I5,6X,*TYPE - *,I1,6X,A4,6X,*DATA SET == *,2A10
        /)
  280 PRINT 300
  300 FORMAT(*INCLUDE OR EXCLUDE DATA W/IN FILTER LIMITS  EX/IN*)
      READ 1080,IFEX
      IF(IFEX.NE.2HEX.AND.IFEX.NE.2HIN)GO TO 280
      PRINT 380
 380 FORMAT(*INPUT FILTER VECTOR-- AZ AND PLUNGE - ALSO RAD OF AREA
        *)
      READ,KAZ,KDP,KDIA
  460 RCIP=RAD(KDIA)/2.
      R=2.*SIN(RCIR)
        R=ABS(R)
      CALL DIRCOS(KAZ,KDP,X,Y,Z)
      NOM=0
*
*    BEGIN READING DATA
*
      KOUNT=0
      IF(IAN.EQ.1HY)GO TO 650
       DO 600 I=1,IDO
      READ (1,1040)(IDAT(I,K),K=1,3)
  600 CONTINUE
  650  DO 940 K=1,IDO
      ISTK=IDAT(K,3)/100
      IDIP=IDAT(K,3)-ISTK*100
      IF(IP.EQ.4)GO TO 720
      CALL POLE(ISTK,IDIP,ISTK,IDIP)
  720 CALL DIRCOS(ISTK,IDIP,XD,YD,ZD)
     TEST=0.
       IF(IFEX.EQ.2HIN)TEST=2.
  740 DIST2=(XD-X)**2+(YD-Y)**2+(ZD-Z)**2
      D=SQRT(DIST2)
      IF(IFEX.EQ.2HEX)GO TO 840
      IF(D.LE.R)GO TO 860
      GO TO 930
  840 IF(D.LE.R)GO TO 930
  860 KOUNT=KOUNT+1
      WRITE(7,1040)(IDAT(K,MM),MM=1,3)
      GO TO 940
  930 IF(TEST.LT.1.)GO TO 940
```

(cont.)

APPENDIX III: PROGRAM LISTING OF FILTER (cont.)

```
      TEST=0.
      XD=-XD
      YD=-YD
      ZD=-ZD
      GO TO 740
 940  CONTINUE
      PRINT 945,KOUNT
 945  FORMAT(*NO OF DATA PTS FOUND= *,I5)
      IF(KOUNT.LE.MAX)GO TO 1000
      PRINT 950
 950  FORMAT(*NO DATA PTS TGREATER THAN 1000 - FILTERING NOT*
+     * POSSIBLE*)
      GO TO 1090
1000  IF(KOUNT.LE.0)GO TO 1003
      LSET=LSET+1
      CALL HEAD(LSET,KOUNT,IP,IFEX,KAZ,KDP,KDIA)
      IF(LSET.EQ.20)GO TO 1022
1003  PRINT 1006
1006  FORMAT(///*FILTER SAME DATA SET \   Y/N*)
      READ 1010,IAN
1010  FORMAT(A1)
      IF(IAN.EQ.1HY)GO TO 280
1020  CONTINUE
1022  CALL DUMP(LSET,NOUT)
      IF(IFPU.NE.2HYE)GO TO 1025
      CALL PURGE(INFIL,0,0)
1025  CONTINUE
1040  FORMAT(I4,12X,A1,1X,I5,5X)
1050  FORMAT(A6)
1070  FORMAT(2A10)
1080  FORMAT(A2)
1090  STOP
      END
*
*
      SUBROUTINE POLE(IS,ID,L,M)
      L=IS+270
      M=90-ID
      RETURN
      END
*
*
      SUBROUTINE DIRCOS(IS,ID,X,Y,Z)
      T=RAD(IS)
      P=RAD(ID)
      X=COS(P)*COS(T)
      Y=COS(P)*SIN(T)
      Z=SIN(P)
      RETURN
      END
*
*
      FUNCTION RAD(K)
      PI=355./115.
      RAD=FLOAT(K)*PI/180.
      RETURN
      END
*
*
      SUBROUTINE HEAD(N,K,IP,IF,KZ,KP,KD)
      COMMON IHEADR(20,9)
      IHEADR(N,1)=K
      IHEADR(N,2)=IP
      IHEADR(N,6)=IF  $ IHEADR(N,7)=KZ
```

(cont.)

APPENDIX III: PROGRAM LISTING OF FILTER (cont.)

```
      IHEADR(N,8)=KP   $ IHEADR(N,9)=KD
      PRINT 100
  100 FORMAT(*PLOT OR CONTOUR DATA\*)
      READ 110,IFPL
  110 FORMAT(A4)
      IHEADR(N,3)=IFPL
      PRINT 120
  120 FORMAT(*TITLE OF FILTERED DATA\*)
      READ 130,(IHEADR(N,J),J=4,5)
  130 FORMAT(2A10)
      RETURN
      END


      SUBROUTINE DUMP(N,NAME)
      COMMON IHEADR(20,9),IDAT(1000,3)
      PRINT 40,NAME,N
   40 FORMAT(///*DATA FILE== *,1X,A6,6X,*NO DATA SETS= *,I2)
      PRINT 50
   50 FORMAT(//*NO MEAS*,3X,*TYPE*,4X,*P OR C*,2X,*TITLE OF SET*
     ,11X,*EX OR IN*,3X,*VECTOR*,2X,*RAD*/)
  100 FORMAT(I2)
      REWIND 1
      REWIND 7
      WRITE(1,100)N
      DO 500 I=1,N
      WRITE(1,150)(IHEADR(I,L),L=1,5)
      M=IHEADR(I,1)
  150 FORMAT(1X,I5,5X,I1,2X,A4,5X,2A10)
       DO 200 J=1,M
  200 READ(7,400)(IDAT(J,MM),MM=1,3)
       DO 300 J=1,M
  300 WRITE(1,400)(IDAT(J,MM),MM=1,3)
  400 FORMAT(I4,12X,A1,1X,I5,5X)
  450 FORMAT(1X,I5,6X,I1,6X,A4,4X,2A10,
     5X,A2,8X,I3,1X,I2,2X,I2)
  500 PRINT 450,(IHEADR(I,L),L=1,9)
      REWIND 1
      CALL SAVE(5HTAPE1,NAME,0,0,0)
      RETURN
      END
```

APPENDIX IV: PROGRAM LISTING OF STASET

```
      PROGRAM STASET(INPUT,OUTPUT,TAPE1)
      DIMENSION NSTA(20,100),IHEADR(20,5)
*
*     ESTABLISHES A FILE CONTAINING UP TO 20 SETS OF
*                STATION NUMBERS
*
      COMMON NSTA
         REWIND 1
      PRINT 40
   40 FORMAT(*INPUT NAME OF FILE TO BE FORMED*)
      READ 50,NAME
   50 FORMAT(A6)
*
*       BEGIN EACH SET
*
      PRINT 60
   60 FORMAT(*INPUT STA NOS. AFTER LAST TYPE #0#*)
      NSET=0
   70 NSET=NSET+1
      N=0
*
*        INPUT STATION NUMBERS
*
   80 READ,NUM
      IF(NUM.EQ.0)GO TO 100
      N=N+1
      NSTA(NSET,N)=NUM
      IF(N.EQ.100)GO TO 100
      GO TO 80
*
*        DEFINE HEADERS
*
  100 IHEADR(NSET,1)=N
      IHEADR(NSET,2)=9
      IHEADR(NSET,3)=2HNA
      PRINT 110
  110 FORMAT(*INPUT TITLE OF THIS SET*)
      READ 120,(IHEADR(NSET,K),K=4,5)
*
*         SORT STATION NUMBERS IN INCREASING ORDER
*
      CALL SORTR(N,NSET)
  120 FORMAT(2A10)
      IF(NSET.EQ.20)GO TO 145
      PRINT 130
  130 FORMAT(*ANOTHER SET OF STA NOS.\  Y/N*)
      READ 140,IAN
  140 FORMAT(A1)
*
*         WRITE AND PRINT STA NOS.
*
      IF(IAN.EQ.1HY)GO TO 70
  145 WRITE(1,150)NSET
  150 FORMAT(I2)
      PRINT 154,NAME,NSET
   154 FORMAT(///11X,15H***DATA FILE===,1X,A6,4X,6HNSETS=,I2)
      DO 200 I=1,NSET
      WRITE(1,160)(IHEADR(I,K),K=1,5)
  160 FORMAT(1X,I5,5X,I1,2X,A4,5X,2A10)
      N=IHEADR(I,1)
      PRINT 162,N,(IHEADR(I,K),K=4,5)
  162 FORMAT(//18X,*NO STA = *,I3,8X,*TITLE== *,2A10
+/)
PRINT 175,(NSTA(I,J),J=1,N)
```

(cont.)

APPENDIX IV: PROGRAM LISTING OF STASET (cont.)

```
      DO 190 J=1,N
      WRITE(1,170)NSTA(I,J)
175   FORMAT(7I10)
170   FORMAT(I4)
190   CONTINUE
200   CONTINUE
         REWIND 1
         CALL SAVE(5HTAPE1,NAME,0,0,0)
      END
*
*
******* SUBROUTINE TO SORT NOS IN INCREASING ORDER**************
*
      SUBROUTINE SORTR(K,N)
       COMMON NSTA(20,100)
       TYPE INTEGER S
      IF(K.EQ.1)GO TO 140
      DO 130 I=2,K
      IF(NSTA(N,I-1).LE.NSTA(N,I))GO TO 130
      S=NSTA(N,I)
      NSTA(N,I)=NSTA(N,I-1)
      J=I-2
 60   IF(J.LT.1)GO TO 80
      IF(S.LT.NSTA(N,J))GO TO 100
 80   NSTA(N,J+1)=S
      GO TO 130
100   NSTA(N,J+1)=NSTA(N,J)
      J=J-1
      GO TO 60
130   CONTINUE
140   RETURN
      END
```

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