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The geology of the Saddleback Mountain Area, Northwood quadrangle, southeastern New Hampshire

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THE GEOLOGY OF THE SADDLEBACK MOUNTAIN AREA, NORTHWOOD QUADRANGLE, SOUTHEASTERN NEW HAMPSHIRE

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Introduction

Saddleback Mountain is a four-peaked saddle-shaped mountain located 39 km west of Portsmouth, NH (Figure 1). The mountain lies along the boundary between the New England Uplands and the Seaboard Lowlands Sections of the New England Physiographic Province of Fenneman (1938). It also lies adjacent to the western boundary of the Massabesic Gneiss Complex as designated by Anderson (1978). Figure 2 of this text is a generalized Geologic Map of Southeastern New Hampshire compiled from Billings (1956) and later workers cited in the references from Figure 1. Portions of Figure 2 show that the Saddleback Mountain area is on strike with two convergent fault zones which are postulated to be of regional tectonic significance: the Nurambego of southern Maine (Hussey and Pankiwskyj, 1976; Hussey and Newberg, 1978), and the Pinnacle-Campbell-Hill-Hall Mountain Faults mapped by Carnein (1976). (See Lyons et.al., 1982). This area may be an example of one of the critical areas referred to by Hamilton and Meyers (1967).

Freedman (1950) mapped the Saddleback Mountain area as an isolated, faulted metamorphic roof pendant of supposedly Littleton Formation (Mid-to Late Devonian, ?) within granitic units of the Fitchburg Pluton of the New Hampshire Magmatic Series, as designated on the 1956 Geologic Map of New Hampshire (Billings, compiler). Recent isotopic studies of previously presumed Devonian granitic units have yielded Precambrain ages (Besancon et.al., 1977, Kelly, 1980): these units lie south and westwards of the Saddleback Mountain area, but belong to the units of the "Fitchburg Pluton", which has been redesignated the Massabesic Anticlinorium by Lyons et.al., (1982). Alienikoff, et. al., (1979) reported Precambrian age dates for units even farther south and west. Still, the structural complexities of the Massabesic Anticlinorium have yet to be deciphered.

The Saddleback Mountain area is an advantageous one to study for these reasons:

1. There are over 600 feet of vertical relief (250m) between the topographic base of the mountain and its top.

2. In comparison to many areas of southeastern New England, there is relatively good exposure.

3. The metamorphic units on Saddleback Mountain are isolated from other metamorphic units along strike, thus allowing treatment of the problem structurally, in a non-stratigraphic context without regional prejudice.

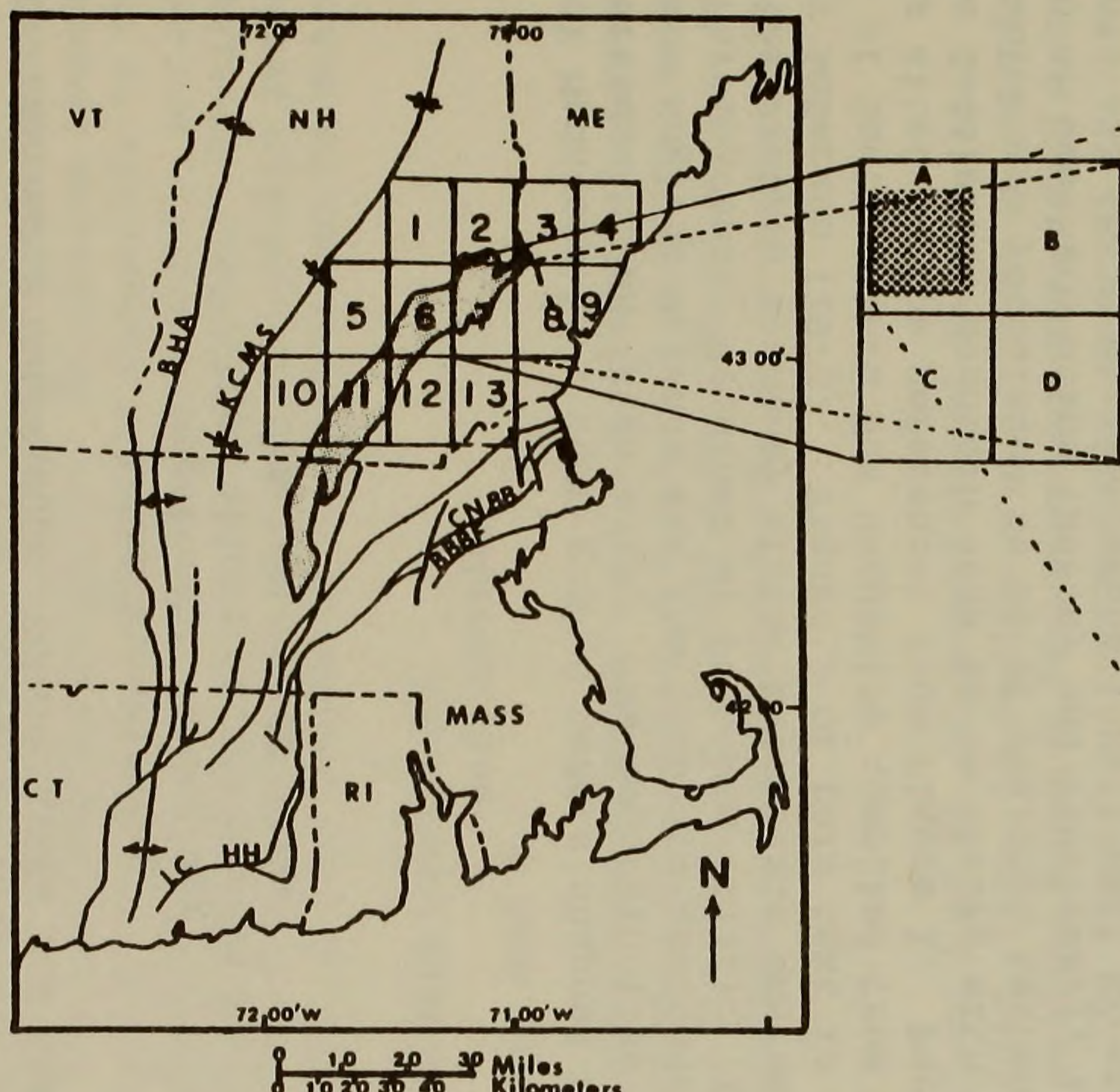


FIGURE I LOCATION MAP WITH REGIONAL STRUCTURAL FEATURES AND QUADRANGLE INDEX

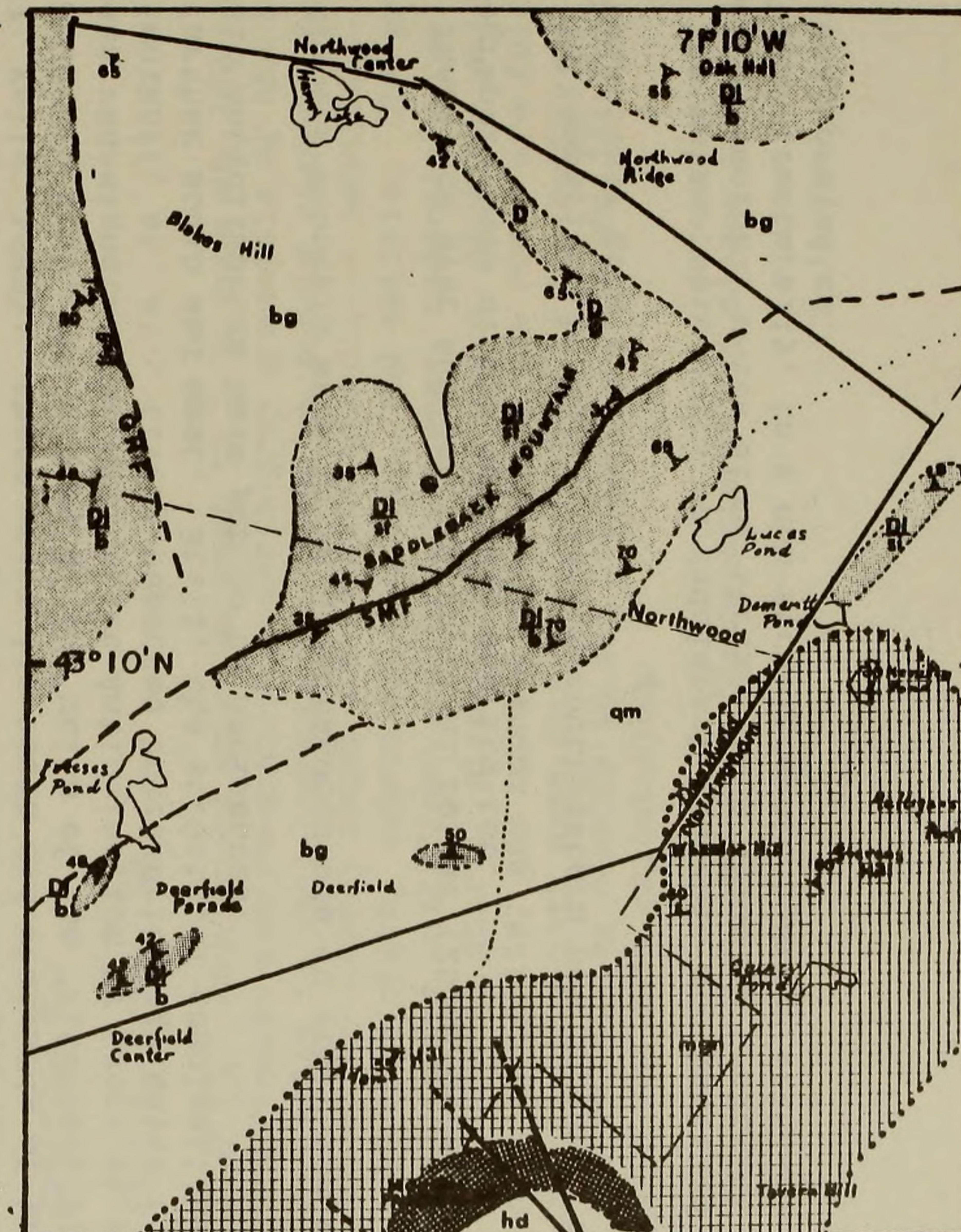


FIGURE IA LOCATION MAP

GUIDE TO FIGURE I

STUDY AREA

MASSABESIC ANTICLINORIUM (FITCHBURG PLUTON)

15 MINUTE QUADRANGLE INDEX

1. GILMANTON [HEALD, 1955]
2. ALTON [STEWART, 1961]
3. BERWICK [HUSSEY, 1962; HUSSEY & PANKIWSKYJ, 1976]
4. KENNEBUNK as above
5. CONCORD [VERNON, 1971]
6. SUNCOOK [CARNEIN, 1976]
7. MT. PAWTUCKAWAY [FREEDMAN, 1950]
   - A. NORTHWOOD 7 1/2
   - B. BARRINGTON 7 1/2
   - C. MT. PAWTUCKAWAY 7 1/2
   - D. EPPING 7 1/2
8. DOVER [NOVOTNY, 1963, 1969]
9. YORK: as 3 above
10. PETERBOROUGH [GREENE, 1970]
11. MILFORD [ALIENIKOFF, 1978]
12. MANCHESTER [SRIRAMIDAS, 1966]
13. HAVERHILL [SUNDEEN, 1971]
14. EXETER [NOVOTNY 1963, 1969]

ABBREVIATIONS

BBBF - BOSTON BASIN BOUNDARY FAULT
BHA - BRONSON HILL ANTICLINORIUM
CNBB - CLINTON-NEWBURY BLOODY-BLUFF FAULT ZONE

KCMS - KEARSARGE CENTRAL MAINE SYNCLINORIUM
LCHH - LAKE CHAR HONEY HILL FAULT ZONE

GUIDE TO FIGURE IA

GEOLOGIC CONTACT (INFERRED) BETWEEN 'LITTLETON' FORMATION AND IGNEOUS UNITS

GEOLOGIC CONTACT (INFERRED) BETWEEN (bg) BINARY GRANITE and 'qm) QUARTZ MONZONITE

GEOLOGIC CONTACT BETWEEN 'MASSABESIC GNEISS' AND QUARTZ MONZONITE according to ANDERSON (1978)

FAULT

FAULT INFERRED

HM–CHF = HALL MOUNTAIN–CAMPBELL HILL FAULT (as projected by ANDERSON, 1978 from CARNEIN, 1976)

GHF = GULF HILL FAULT

SMF = SADDLEBACK MOUNTAIN FAULT

ATTITUDE OF 'BEDDING' AND FOLIATION as mapped by FREEDMAN, 1950

ATTITUDE OF FOLIATION

LITTLETON FORMATION

$\frac{Dl}{b}$ = BIOTITE GRADE

$\frac{Dl}{st}$ = STAUROLITE GRADE

$\frac{Dl}{si}$ = SILLIMANITE GRADE

mgn = MASSABESIC GNEISS

MOUNT PAWTUCKAWAY SUITE

COARSE GRAINED MONZONITE

HORNBLENDE DIORITE

BOUNDARY OF STUDY AREA

FIGURE 2: GEOLOGIC SKETCH MAP, S.E. NEW HAMPSHIRE

MODIFIED FROM BILLINGS (1956) AND LATER QUADRANGLE MAPS.

GUIDE TO MAP SYMBOLS

1–14 15' Quadrangles as Indexed in Figure 1

15 ISLES OF SHOALS (Fowler-Billings, 1977; Bloomshield, 1975)

Coastline

ME/NH Stateline or territorial boundary

Formation boundary after Billings (195)

Formation boundary sketched following quadrangle maps

Physiographic section boundary

Silicified zone or fault

Town or city

State capital

Anticlinal Axis

Synclinal Axis

Axis of Major structure

METAMORPHIC ISOGRADS

—si— Sillimanite

—st— Staurolite

—g— Garnet

—b— Biotite

—c— Chlorite

SCALE

0 5 10 15 mi

0 8 16 24 km

GEOLOGIC FORMATIONS OR LITHOLOGIES

a. Igneous

mgn Massabesic Gneiss

g/big Granite/Two Mica Granite

kqm Kinsman Quartz Monzonite

nqd Newburyport Quartz Diorite

agd Ayer Granodiorite

qd Quartz Diorite

LITHOLOGIES (continued)

b. Metamorphic

Dg,t,r Shapleigh Group } SW Maine

Dl... Littleton Formation } SE, Central NH

Sb Berwick Fm } Merrimack Group

Se Eliot Fm } Merrimack Group

Sk Kittery Fm } Merrimack Group

Or Rye Formation

ABBREVIATIONS

EA Exeter Anticline

ELS Eliot Syncline

MT Merrimack Trough

RA Rye Anticline

BBF Beaver Brook Fault

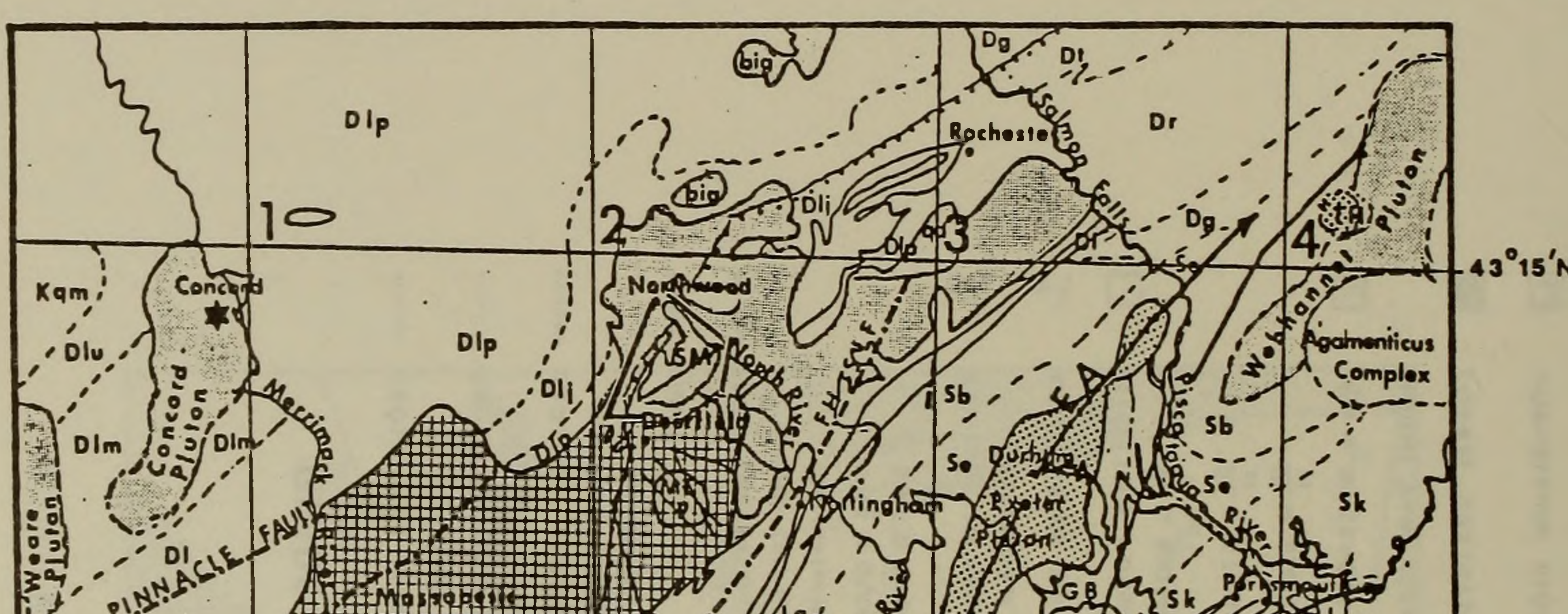
FH-SLF Flint Hill - Silver Lake Fault

HM-CHF Hall Mountain-Campbell Hill Fault

MT P Mount Pawtuckaway

SM Saddleback Mountain

TH Tatnic Hills



4. The area serves as a test area for the possibility of through-going faults connecting with others mapped previously: i.e., Hussey and Pankewskyj, 1976; Hussey and Newberg, 1978; Carnein, 1976.

A study of Freedman's (1950) Geologic Map of the Mount Pawtuckaway Quadrangle indicated that alternative hypotheses to his interpretation of the structure of the area might be viable. The following hypotheses were maintained throughout the field mapping process:

1. The model provided by Freedman (1950) of a metamorphic roof pendant to the Devonian intrusives lying along a drag fold on a structural terrace on the eastern limb of the Merrimack Synclinorium.

2. In light of the isotopic studies to the south, the metasedimentary mass might rest nonconformably on older crystalline basement rocks, with the map pattern produced as a function of topographical surface in relation to the dip of the units.

3. The metasedimentary lithology might be a screen in a large granite-migmatite complex.

4. The metamorphic outcrop pattern is a reflection of a horst or graben structure.

5. The metamorphic mass might represent a klippe, or erosional remnant of a larger decollement surface, or nappe structure.

6. The pattern might represent a basin and dome interference pattern between major folds.

These hypotheses were carried through, or modified throughout the mapping process.

The geographic area of concentration for detailed mapping was the immediate vicinity of Saddleback Mountain which lies diagonally across the coordinate grid in a N55 to 60 degrees E trend, encompassing an area of approximately 37 km^2. The reconnaissance mapping in the rest of the Northwood Quadrangle, the Mt. Pawtuckaway, and Suncook Quadrangles to the south and west encompassed approximately 102 km^2.

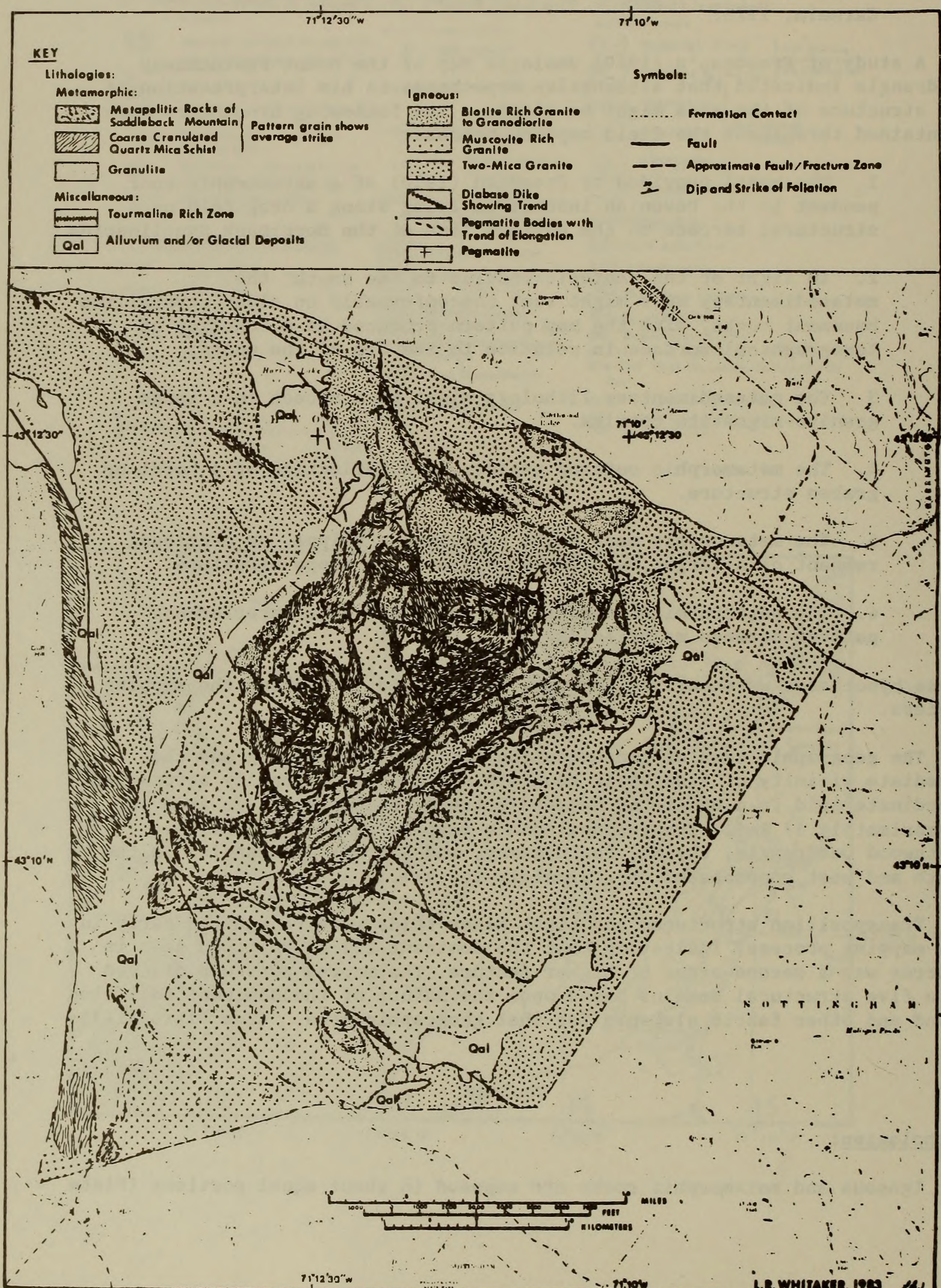
Transposition structures and tight minor folds were recognized early in the mapping process, indicating that the dominant foliation trend seen in outcrop was a second-order or higher feature. The mapped area was divided into five structural domains based upon the nature of the dominant foliation trend and other fabric elements for that geographic area. (See Plates 1-3).

Geology

Lithologies:

Igneous and metamorphic rocks are exposed in about equal portions (Plate

PLATE 1: GEOLOGIC MAP OF SADDLEBACK MOUNTAIN, NORTHWOOD QUADRANGLE, N.H.



1, Geologic Map). Igneous units tend to be more poorly exposed, and to create a more rounded topography than areas underlain by metasedimentary rocks. In exception to this, pegmatite bodies commonly crop out as knobs above the surrounding topography.

The igneous lithologies are subdivided into a felsic to intermediate category which is in turn, subdivided and, a mafic one which is represented by basalt dikes.

The metasedimentary lithologies are divided into two broad categories: granulites and metapelites. The granulitic units are interlayered with more schistose units, and sequences in which the granulitic layers predominate over metapelitic ones will be termed granulites. In this report the term granulite is used in its textural context and not as an indicator of metamorphic facies.

The granulitic metasedimentary rocks crop out on the east and south sides of the mountain along a northeast-southwest trending band which narrows in the central zone, then fans southwards. Exposure width of the band inceases also northwards with decreasing elevation. Drill chips from a well on the northeast flank of the mountain confirm the presence of granuliltes at depth in an area where they are not well exposed at the surface. The elevation of the exposures of granulites on the east side of the mountain ranges between 470 ft. (145m) to 700 ft. (215m). On the upper reaches of the mountain granuliltes are found within migmatites between the elevations of 800 ft. (246m) and 1000 ft. (308m). Exposures along the western flank of the mountain crop out between 700 ft. (215m) and 1000 ft. (308m). There layering is nearly horizontal, or gently dipping southwestwards, and occasionally eastwards. Units on the west flank of the mountain are commonly interlayered with and overlain by felsic igneous sills, or grade texturally into tough crystalline gneissic feldspathized schists.

The lithologies of the granulites are: calc-silicate granulite; quartz-biotite-plagioclase-microcline granulite; quartz-biotite schist with minor muscovite; impure quartzite; and tourmaline-bearing granulitic gneiss.

Outcrop exposure is rarely continuous for more than 65m along strike, and tends to be along joint surfaces sub-parallel to the strike of the foliation, but steeply dipping in the opposite direction to the direction of the dip of foliation. Outcrops tend to be low-lying and knoll-like; commonly there are relicts of pegmatite bodies, or felsic to intermediate sills overlying granulitic metasedimentary exposures.

Layering ranges from 1 cm to 10 cm, with occasional 10 cm layers. The average thickness is 5 cm for the calc-silicate-bearing units, and 2 cm for the flaggy and more schistose units. Grain sizes range from .3 mm to 1 mm, and microscopic textures range from protomylonitized (Higgins, 1972, p. 15) to annealed (Spry, 1969, p.222). The samples which show annealing tend to have a lower percentage of opaque minerals, while cataclastic specimens show alignment of opaques parallel or subparallel to the dominant fabric, or have a large number of bubbles, possible fluid inclusions and dustings of opaque minerals within grain boundaries.

Calc-silicate-bearing units may constitute as much as 30 percent of the granulites. The calc-silicate minerals are both disseminated in the matrix and contained in pods and bands. These pods and bands may appear as elongate lenses ranging from 5 cm to 1 cm or more in length. Pods also commonly range in size from 3 cm to 15 cm along the long ellipsoidal axis, and 3 to 7 cm along the short axis. They are commonly observed to occur at the juncture of two healed fracture systems or to be associated with fold patterns in the rocks. These will be seen at Stops 3 and 7. Thin sections of calc-silicate pods show high strain features such as undulatory extinction and ribbon texture of quartz, crushed grain boundaries of amphibole or pyroxenes and plagioclase as well as dislocations of plagioclase twin planes.

The metapelitic rocks crop out in a sliver-like band along the east and south sides of the study area between approximately 400-500 ft. (123-154 m) elevation in the northeast, and approximately 600 ft (185m) in the south. (See Geologic Map). The bulk of the metapelitic rocks are exposed above the 800 ft. (246 m) contour, intermingled with small patches of granulite contained within coarsely migmatitic micaceous quartzo-feldspathic matrix. Exceptions to this are small discontinuous exposures of granulities inter-layered with sills of two-mica granite. Because of the elevation discrepancies between the two areas where metapelites are exposed, those below 600 ft. (185m) will be termed the lower metapelitic sequence, and those above 600 ft. will be termed the upper metapelitic sequence.

In contrast to the granulites, the metapelites show positive and sharper topographic relief. Exposure is often continuous for long distances along strike along the scarp-like en-echelon surfaces of "master joints". Excellent exposure of the metapelites is found on the upper reaches of the south peak of Saddleback Mountain opposite the WENH microwave tower. Exposure of the lower metapelites was not readily available at the time of Freedman's field work. Exposure has since been made available by road cuts and excavations. Good exposure is available at the Camp Yavneh septic lagoon in Northwood, N.H., and at the junction of Coffeetown Road and N.H. Route 43 in Deerfield, N.H.

There is a high degree of internal deformation within the metapelites, with a wide variety of fold styles exhibited at different scales.

Layering within the metapelites ranges from 2 mm to 5 cm or more in thickness. The rock texture is generally medium to coarse grained, in contrast to the generally finer grained granulites. Porphyroblasts of staurolite, tourmaline, and/or garnet commonly lend the rocks a knotty texture following weathering of the outcrop. Layers composed of quartz and tourmaline only are common in distinct sections of the sequence. Besides these layers, compositional layering of the rocks is delineated by staurolite and/or garnet-rich zones, layers of intergrown micas and quartz, quartzo-feldspathic rich layers, or layers rich in sillimanite. Well-indurated quartzite layers up to 10 cm thick are traceable in some areas. Strong cataclastic rodding of quartz, crenulation of kink axes in micas, and sillimanite needle alignment are common lineations present in the metapelites.

The rock colors vary depending upon the relative amount of biotite present. Fresh surfaces tend to be shiny light silvery grey to mottled white to bluish black, depending upon the grain size and width of compositional banding. Sillimanite bearing lithologies have a characteristic satiny sheen. Staurolite and garnet may give the rocks a pinkish tinge. Weathering colors range from chocolate brown with yellow tinge to rusty-to-black. Micas cause the golden yellow weathering. Mineral assemblages are shown on Thompson AFM diagrams in Figure 3. Noteworthy textural characteristics are shown by several metamorphic minerals: garnet, sillimanite, staurolite, and opaques. Garnets found in the metapelites are commonly poikilitically embayed, fractured, and flattened in the plane of the dominant foliation. Sillimanite occurs in both fibrolitic and tabular forms, with some sillimanite rich rocks showing both forms together. The fibrolitic form of sillimanite tends to be concentrated in shear zones. Less sillimanite rich rocks tend only to contain fibrolite. The rocks exposed by the WENH Microwave tower contain muscovite whose texture is suggestive of replacement of sillimanite by muscovite, then regrowth of sillimanite. Rock staining indicates minor potassic feldspar in these rocks. Staurolite is almost without fail poikilitically intergrown with quartz, and is often contained preferentially in discrete, folded layers within the rocks. The crystals of staurolite commonly define lineation by preferred orientation, or define fold noses of minor structures. Opaque minerals are noteworthy because they may often comprise a major phase of the rock, or more than five modal percent. The opaques may outnumber other minor phases of the rock sample, even if they are not a major phase.

Two generations of biotite are documented from metapelitic samples, as well as two distinct populations of sillimanite.

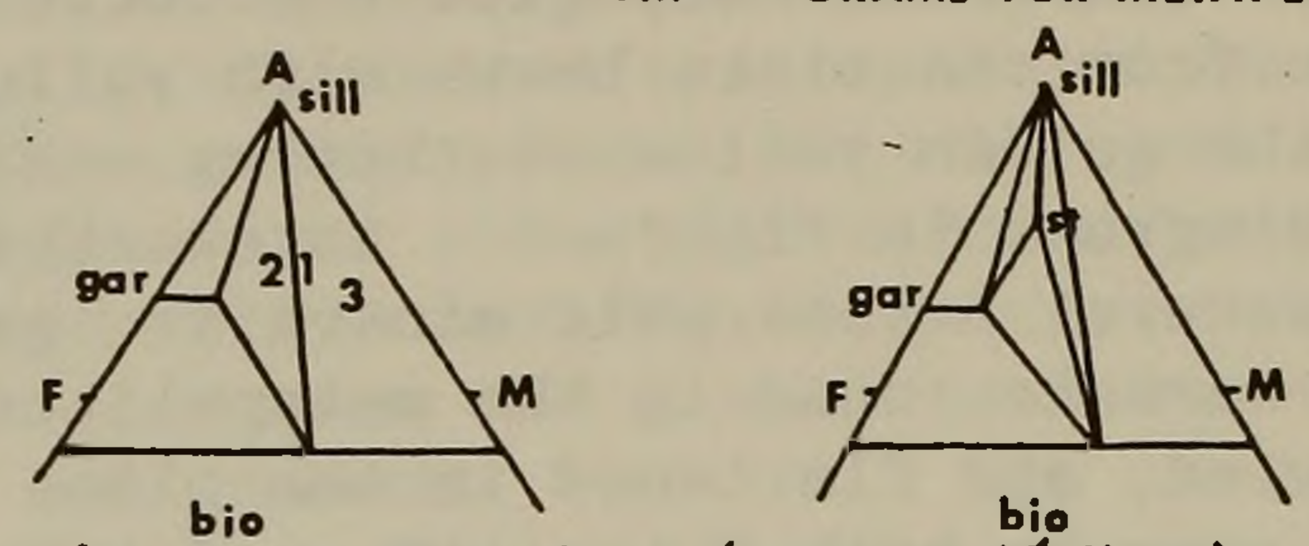
Significant portions of the upper metapelitic sequence are migmatitic, as are the rocks of the Camp Yavneh Lagoon. Portions of the quartzo-feldspathic material occur as veins and pods, and there is a gradual increase in quartzo-feldspathic content of the granulitic metasediments, along with a coarsening of fabric until the granulite is engulfed in a sea of more mobile matrix and left as a raft, or scholle to use the terminology of Mehnert (1968).

The mineral assemblages in the metapelitic rocks are compatible in metamorphic grade with the granulitic rocks. The stable mineral assemblages of both groups place them in the upper amphibolite facies of metamorphism (Eskola, 1920). Staurolite persists in the metapelites, albeit in segregated lenses throughout the sequence. This indicates that the P-T conditions of the rocks were sufficiently high enough to produce sillimanite in coexistence with potassic feldspar, but were below the staurolite breakdown temperature. These conditions would be fulfilled at about 4 Kb pressure, and between 550 and 600 degrees centigrade (Labotka, 1978).

There are relict minerals which indicate the rocks have undergone multiple periods of metamorphism. These are:

1. The overgrowth of diopside by amphiboles, and amphiboles on each other, to include core-rim reactions.

FIGURE 3: MODIFIED THOMPSON AFM DIAGRAMS FOR METAPELITIC MINERAL ASSEMBLAGES



Projections from Quartz, Muscovite (approx Mol % Units)

1. Quartz, oligoclase, albite, biotite, muscovite, sillimanite, opaques
2. Quartz, muscovite, biotite, garnet, sillimanite, opaques
3. Quartz, biotite, sillimanite, oligoclase, muscovite, chlorite (late), tourmaline, opaques
4. Quartz, biotite, muscovite, garnet, staurolite, chlorite (late), opaques,
5. Quartz, biotite, muscovite, sillimanite, garnet, staurolite, opaques, tourmaline, chlorite
6. Quartz, muscovite, biotite, opaques, garnet, staurolite
7. Quartz, oligoclase, muscovite, biotite, chlorite, opaques
8. Quartz, garnet, muscovite, biotite, sillimanite, opaques, microcline
9. Quartz, biotite, sillimanite, muscovite, oligoclase, garnet, opaques, microcline
10. Quartz, microcline, muscovite, biotite, staurolite, garnet, opaques

(8–10: Not projected)

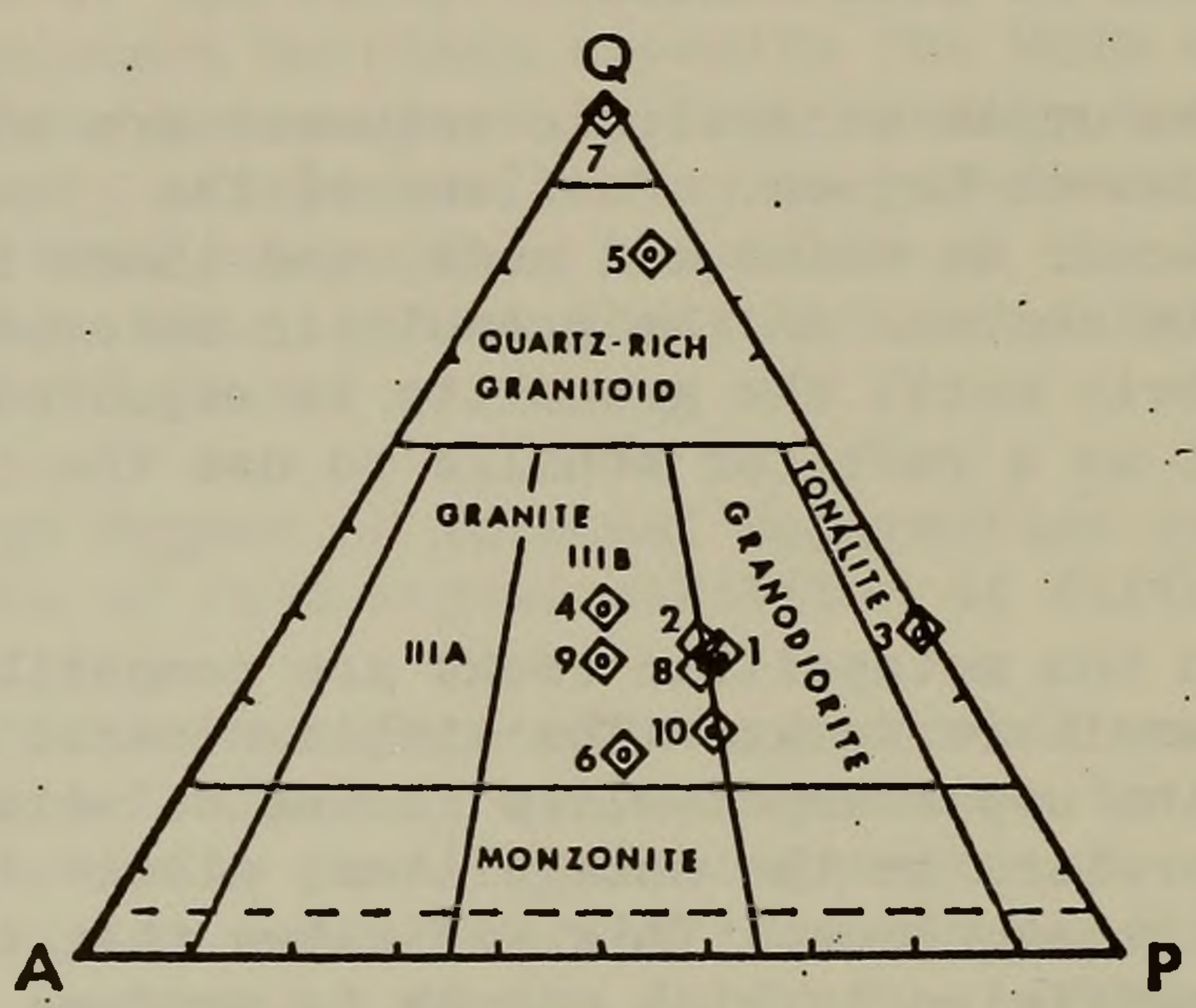


FIGURE 4
I.U.G.S. CLASSIFICATION OF FELSIC IGNEOUS ROCKS
(STRECKEISEN, 1979)

SAMPLES PLOTTED: SEE Whitaker, 1983

1. 666	5. 7189-1	9. 105G2
2. 62179-1	6. 7199-2	10. 105ssa
3. 7679-2	7. 889-2	
4. 7179-1	8. 106a1	

2. The presence of two populations of sillimanite, and possibly two generations of garnet in the metapelites.

3. Two generations of biotite in both metapelites and granulites: in some granulite samples grains are crossed, and extinct at distinctly different stage orientations, while the different biotite generations in the metapelites show differences in crystal habit, inclusion pattern and indices of refraction.

4. The flattening and embayment of garnet, with alteration of the rims to biotite in the metapelites.

Items 3 and 4 above indicate that metamorphism was accompanied by deformation.

The igneous rocks are predominantly felsic to intermediate. Mafic rocks are represented by dikes, ten of which have been positively located. The divisions of the felsic to intermediate rocks are:

1. Two-mica granite
2. Biotite rich granite-to-granodiorite
3. Muscovite rich granite
4. Pegmatite
5. Tonalite.

These lithologies are gradational with each other, but one type will tend to predominate over the others in a given domain. Muscovite-rich granites are dominant in the Southern Domain, but they grade to tonalites and biotite-rich granite. The biotite-rich granite to granodiorite predominates in the Northern Domains and the Northeastern Domain, and exists in narrow discontinuous bands along the eastern side of the study area parallel to the Saddleback Mountain Fault Zone. An increase in the biotite content of the igneous rocks, particularly in the eastern margin of the area is a common precursor to the discovery of a small enclave of granulitic metasediment, or a scholle. The only cross-cutting relationships between rocks of the felsic to intermediate category are of pegmatite dikes crossing two-mica granite, or biotite rich granite-to-granodiorite.

Figure 4 is a plot of the pointcounted normalized samples on the I.U.G.S. Q-A-P Triangle (Streckeisen, 1979). The majority of these samples plot in the granite field where they cluster near the granite-granodiorite boundary. One sample plots as a tonalite: the remaining two samples which are muscovite rich granite and pegmatite plot in the silexite, or quartz-rich granitoid field.

The mineralogy of these rocks indicates that they are peraluminous, as biotite, muscovite and garnet with accessory tourmaline are the only femic constituents.

The essential minerals are: plagioclase (var. oligoclase, An 20-26), microcline or orthoclase, quartz and micas. The ratios of the micas one to another is variable, but muscovite and biotite are ubiquitously intergrown. Myrmeckite and perthite are common, with myrmeckite being particularly common in more highly deformed zones of the rock. Garnets are common accessories, often occurring in two populations: one pink fine-grained (1-2 mm) cinnamin colored; the other darker, and larger (2-5 mm). Characteristic accessories are: apatite, sphene, zircon, opaques, and an amorphous red adiamantine-reflecting fracture filling which may be responsible for lending the rocks a pink color in outcrop.

Foliation is evident in almost all outcrops. Cataclastic features such as flaser texture, or dents-du-cheval may also be present. Ghost structure, or relict foliation (Pitcher in Newall and Rast, 1969) is evident in many outcrops, especially along the northern boundary of the study area. Contacts between igneous rocks and the metasediments indicate that the metasediments behaved in a ductile manner during the emplacement of the igneous units: the igneous rocks themselves have features indicating post emplacement shearing. Contacts between granodiorite and pelitic schist are less commonly seen in the field than contacts between granulite and felsic-to-intermediate lithologies: i.e., the muscovite-rich granite is commonly associated with the metapelites, or pegmatites.

There are over 100 bodies of felsic pegmatite exposed throughout the area. These tend to be oblately elliptical lenses ranging from 1 m in length to over 30 m, and lying subparallel or parallel to the local strike of the host rocks. They are commonly responsible for the localized steepening of dip, and/or deflection of the foliation trend. They may also bottom out as detatchment zones for the metasediments. Pegmatites occur within the metasediments, commonly along the contact between the metapelites and granulites, and within the igneous bodies, commonly close to or along the contacts with the metasediments. The pegmatite-metasediment contact may be the only portion of the contact exposed. Larger pegmatites 30 m or more in length crop out as knobs 3-15 m high above the surrounding topography, particularily along the eastern boundary. Many pegmatites are simple, but complex mineralogies occur, notably in the contact zones, showing high tourmaline or apatite content, as well as beryl. Borders between the pegmatites and country rock may be gradational, with gradual coarsening of the fabric of the host rock, an increase of micas in the host, and the presence of tourmaline laths, or zones of intergrown micas, staurolite or garnet. Structures such as slickensides, or rodding and mullion structures are common along the contacts. These contacts tend to show a higher percentage of opaques than the metasediments farther from the contacts. Tourmaline-rich zones occur near the contacts between the metasediments and the pegmatites, and in definite zones in metapelitic units, and in granulites near the Saddleback Mountain Fault Zone.

Ten dikes of dark-gray, red-brown weathering, slightly porphyritic basalt have been located. They range in width from .3-.6 m to an estimated 22 m width. Basalt float on the northwest side of Saddleback Mountain indicates that more dikes are present at depth, but these erode away preferentially, and are not represented in outcrop in direct proportion to their presence.

Quartz veins and stringers are ubiquitous in all metasedimentary and felsic igneous rocks of the area. Quartz segregations in the granulites tend to be ptygmatic and rolled, dimensionally on the order of 2-3 cm thick to 8 cm. These are commonly aligned en-echelon parallel or subparallel to the strike of the dominant foliation. Large crosscutting veins of commonly diffusion banded quartz occur within the metapelites and granites, often near the contacts between the two. These veins are usually fractured and commonly off-set.

Structures:

The pattern of the Geologic Map (Plate 1) indicates that the area shows alternation of igneous and metamorphic units with respect to the topographic surface. Plates 2, 2A and 3 provide structural information broken down by domains.

There are many minor folds within the study area. The earliest folding is isoclinal with recognizable folds ranging from a few centimeters to three or more meters. These folds are often difficult to discern in outcrop because they have been transposed and/or, are contained in the plane of the dominant foliation. Such folding is responsible for conflicting readings in facing direction within the same outcrop where grading of units may be present. Intrafolial folds and rotated sheath folds (Cobbold and Quinquis, 1980) are also present. These are common in metapelitic units and in the granulites near contact zones (Figure 5). Later folding is on various scales ranging from 10 cm to 10m or more, and refolds early isoclines. Interlayered pelitic and granilitic units will demonstrate differing deformational responses: granulites will warp, while pelites may be kinked, or isoclinally folded intrafolially. Folds with monoclinic geometry and complex asymmetric folds also occur. These styles will be examined in the field. There are two zones where crenulation cleavage (Gray, 1970) occurs (Stop 1B) along the southernmost trace of the Gulf Hill Fault, and on the northeastern border of the study area.

Fold superposition is seen in a number of localities (Stops 1D, 5, 7, 9). Metamorphic mineral growth is also associated with directed fabric orientation; thus "primary" features are commonly obliterated or masked, and cataclastic/tectonically induced properties of the rocks mimic them. Both brittle and ductile features are present in folding, and "late" brittle fracturing may affect the foliation orientation locally, or show cataclastic (ribbon texture) in thin section.

Jointing is common in all rocks of the area, but may become intense locally in stream beds, or fracture/fault zones. A rhombohedral to tetrahedral fracture pattern is common in the rocks of this area. Joint orientations are displayed on Plate 3.

The location of faulting in the Saddleback Mountain area was determined from accumulated lines of evidence such as: degree of cataclasis, shearing of veins, or pegmatites; abrupt change of lithologies along strike, or on localized detatchment zones; topographic evidence, and map and aerial photo linears; ground topography such as swamp/stream alignment and silicified zones, (see Plates) and also, fold styles. There is also unreduced magnetic data which substantiates faulting in two areas, and a 2° back azimuth compass anomaly in one. Mafic dikes also are aligned spatially with fracture traces. The fracture/faults of the Saddleback Mountain area from a

PLATE 2A: LINEATIONS: RODDING, ROSE DIAGRAMS AND EQUAL AREA FOLD AXIS PROJECTIONS

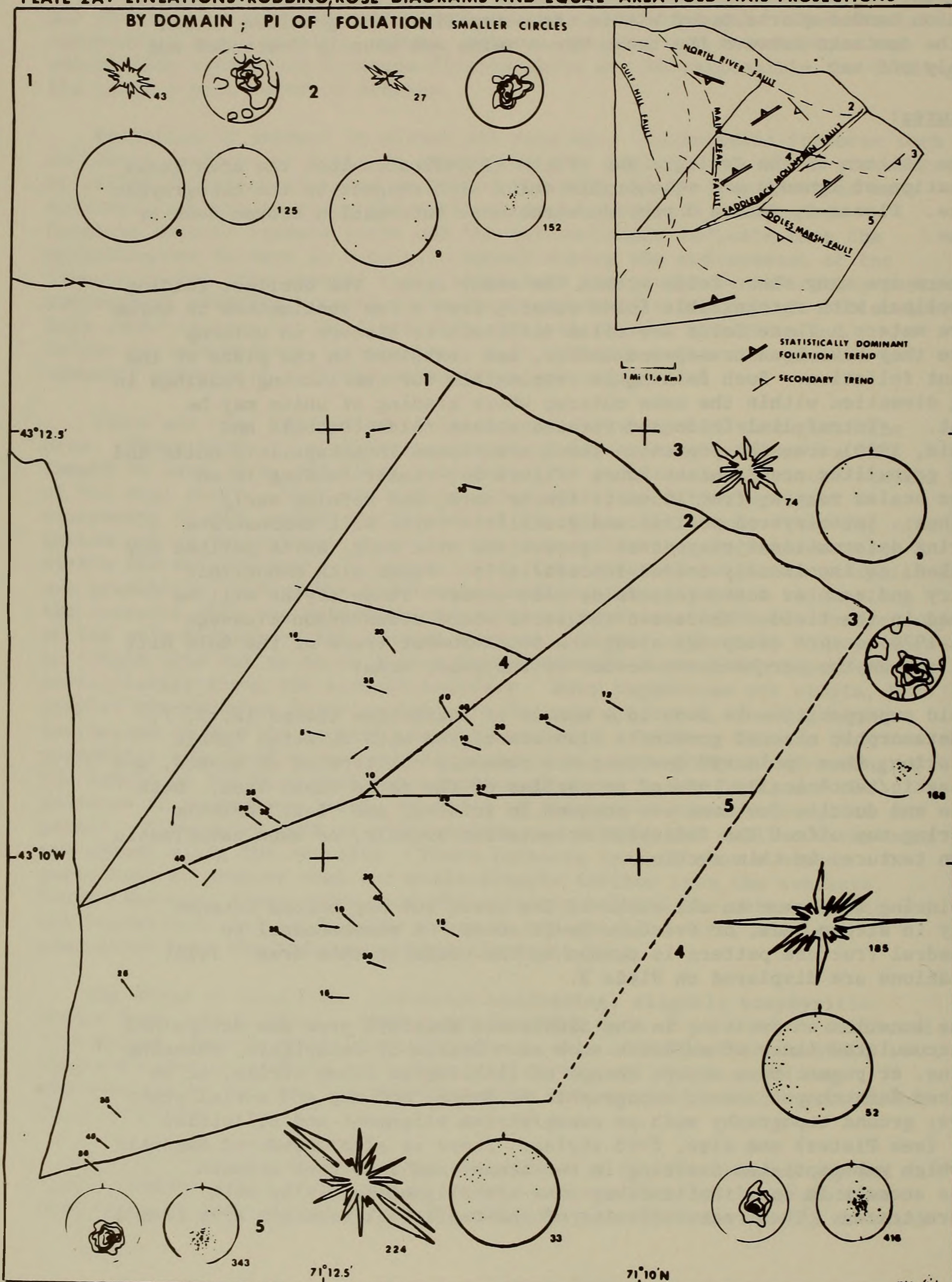


PLATE 2 : FOLD AXES AND LINEATIONS

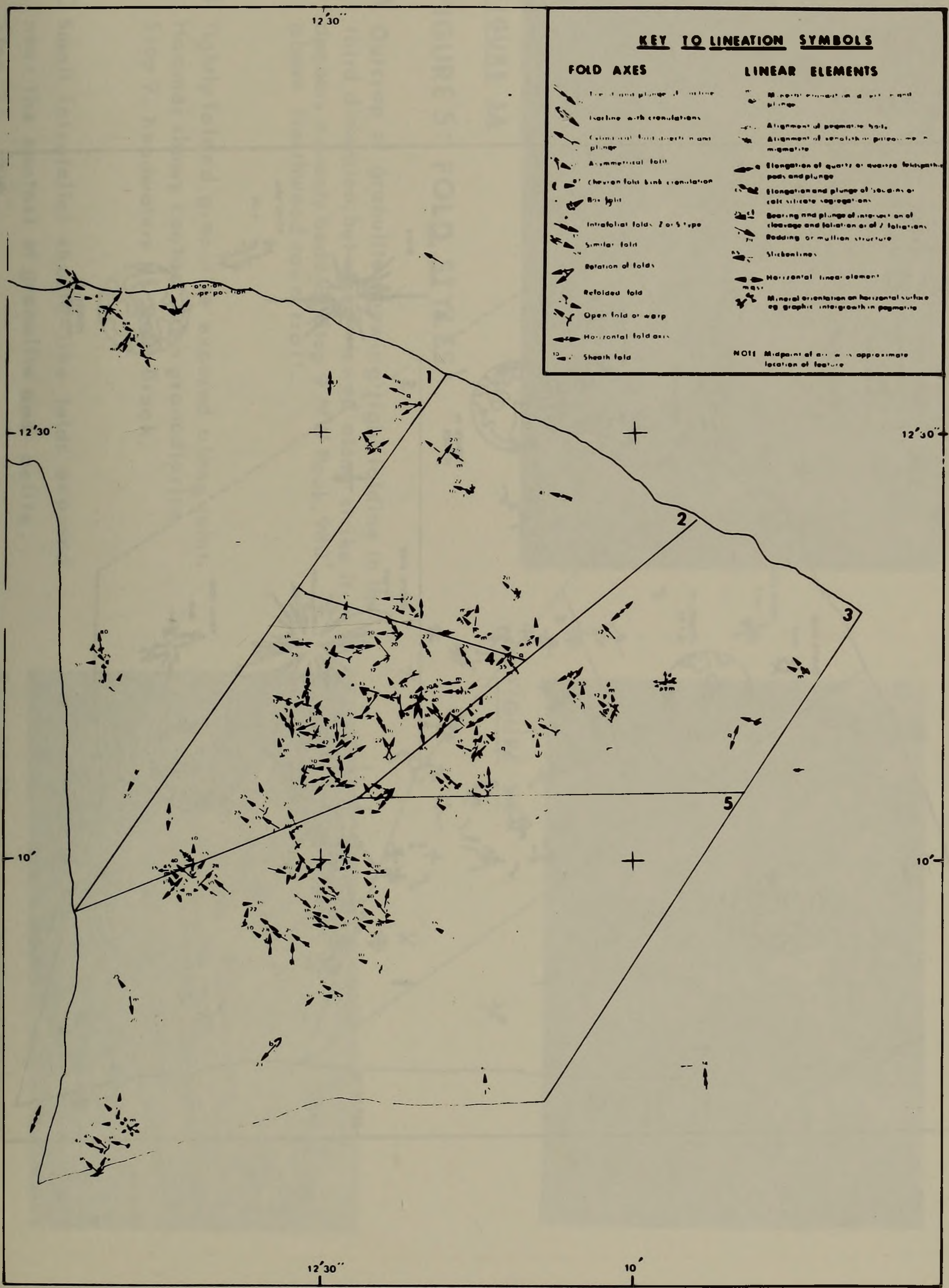


PLATE 3: JOINT PATTERNS, VEINS AND DIKES

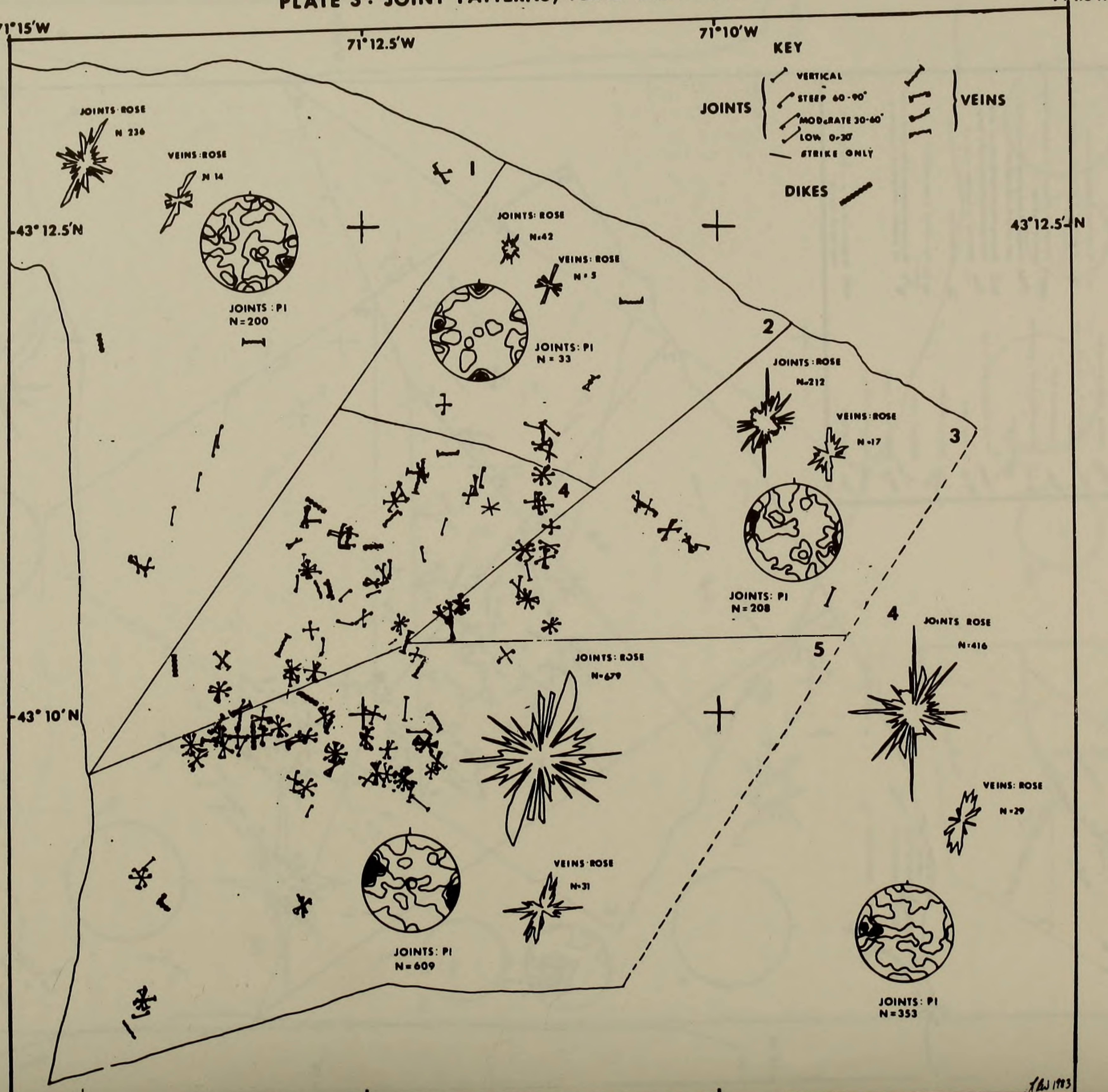


FIGURE 5A

FIGURE 5B

FIGURE 5: FOLD STYLES

A Outcrop of granulite showing tight folding in the third dimension, but when viewed along strike it appears eavenly bedded. Stop 9 NW Peak, 980′ above Northwood town trail.

B Tightly folded granulite exposed along joint. Hammer shows contact with granodiorite. Stop 9, headwaters of Bear Brook.

C Small intrafolial sheath-like folds exposed near the contact of granulite and pelite. Stop 12A.

FIGURE 5C

pattern similar to perianticlinal faults (Sitter, 1956) or fractures over diapirs.

Any interpretation of the structure of the area must explain the criteria above.

The following structural models were considered:

1. Structural terrace model of Freedman (1950) i.e., Saddleback lies close to the nose of a plunging fold on the northeast limb of a major synclinorium.

2. Migmatite complex.

3. Nappe above a master decollement.

4. Basin and Dome pattern produced by fold superposition.

5. Graben or Horst.

6. Diapir i.e., the metasedimentary mass might have been domed by the injection of magma rising from below/by a rising basement block.

7. Braided fault zone as described by Kingma (1958).

The favored model is that of the braided fault zone, (Model 7) because it can incorporate the greatest number of features observed in the field: i.e., the alternation of igneous and metamorphic units with depth; differing degrees of cataclasis; the presence of localized detatchment zones; minor folding; fracture orientation such as is caused by a piercement body; the potential presence of large and small scale horst and graben blocks. This model also explains the presence of migmatites. The braided fault would serve as a tectonic pumping mechanism, or migmatite mixer. Differences in slope produced by vertical movement along a fault plane could also potentially generate the gravity mechanism needed to produce a major decollement. Transfer of motion, or torque between two splays of the major fault could explain fold rotation and superposition and the change in the dominant foliation patterns. It could also explain the presence of multiple metamorphic and deformational events by differential heat transfer and motion. One last far-out thought: heat transfer might also be effected by basalt intrusions (Pajari, et. al, 1981). Note the presence of basalts near or in granites - this type of relationship was also reported by Trygstad (1981).

The basalt dike at Stop 1 indicates tectonic mobility upon emplacement. A radiometric age date (i.e., 40-39) for this dike would be highly desirable, because it would allow bracketing of the lastest episode of mobility for the area. Were this date to be anomalously early, or late, then the sequencing of events for this portion of southeastern New Hampshire will need to be reconsidered.

The geophysical modeling of the northern termination of the Massabesic gneiss, which is mapped directly east of the area (Anderson, 1978) implies that there could be interleaving of igneous and metasedimentary units at depth. Such interleaving is seen in the Saddleback Mountain area. Radiometric dating of the Saddleback Mountain units and the units directly east might resolve some of the questions concerning the structure and age of the Massabesic. An open question remains concerning the stratigraphic correlation of this area: what if the composition of the lithologies is more a function of tectonism and partial melting than original lithologic composition? If this might be true, then the rock units would be a function of the induced P-T-X conditions of tectonism, then metamorphic "formations" should not be assigned stratigraphies. This problem needs to be resolved by detailed geochemistry.

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Road Log

Mileage	
0	Starting point is Johnson's Dairy Bar, North side of N.H. Route 4 in Northwood, N.H. To get there from Danvers, Mass, take I-95 North to the Portsmouth, N.H. Interchange. Exit at the intersection with N.H. Route 4 and travel westwards through Durham, N.H. Cross the Lee, N.H. traffic circle where Routes 4 and 125 intersect, and continue westwards on Route 4. Johnson's Dairy Bar is approximately 14 miles west of Lee traffic circle on N.H. Route 4. Starting time is 8:30 A.M. Please be sure you have your lunch and are prepared to bushwhack. Turn eastwards onto N.H. Route 4 from the parking lot of Johnson's Dairy Bar.
0.1	(Stop 1 will be interspersed between several localities: It encompasses the NW domain of the map of the area.)
(1 hour)	Stop 1. Intersection of N.H. Routes 4, 107 North and Blakes Hill Road. Cataclastic two-mica granite is exposed in the cut on the Blakes Hill Road side of the intersection (south side of Route 4). The cataclastic foliation in the granite follows domains which are related to anastomosing fracture surfaces. Foliation directions are affected by proximity to movement surfaces (Figure 1RL-A); joint and foliation surfaces are commonly listric. There are varying degrees of deformation within the outcrop. A highly fractured boudinaged slightly porphyritic basalt dike intrudes the granite (Figure 1RL-B).
0.1	Turn southwards onto Blakes Hill Road.
0.8	Fork in road: left fork is Kelsey Mill Road, right fork Blakes Hill Road. Stay to the right.
2.0	View of Saddleback Mountain looking eastwards across field.
2.1	Intersection of Mountain Road and Blakes Hill Road.
2.7	Granites exposed under power lines.
2.8	Turn around and park at the top of hill: walk down the hill to the gravel pit for:
	Stop 1A. This gravel pit lies at the south end of the Gulf Hill Fault as it was mapped by Freedman. Glacial gravels are being worked for road metal but the bedrock is also being sold as gravel. The bed rock is a highly friable crenulation-cleaved and kinked quartz-mica

FIGURE 2RL Stop 1D

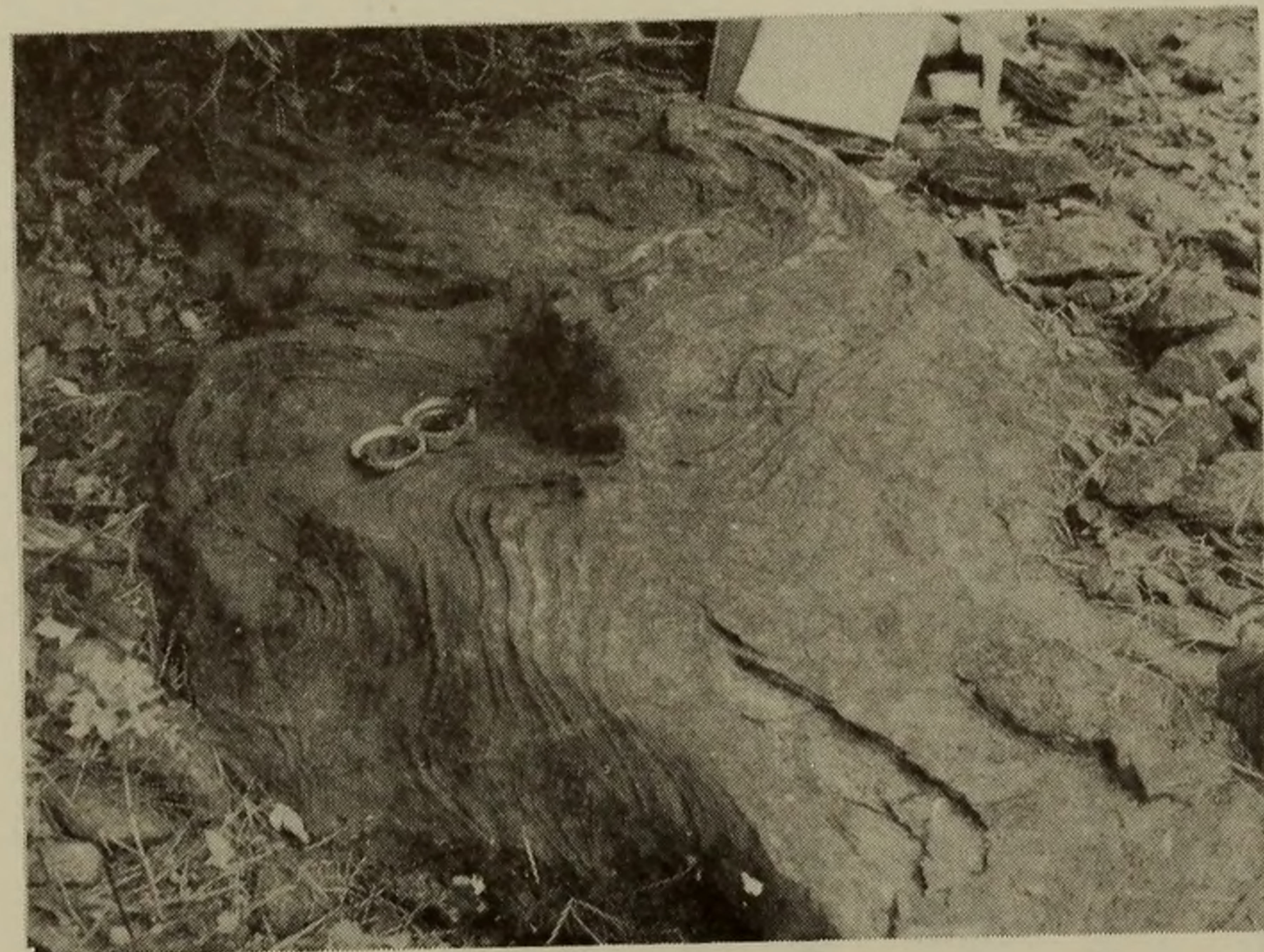


FIGURE 4RL Stop 7

FIGURE 5RL Stop 10

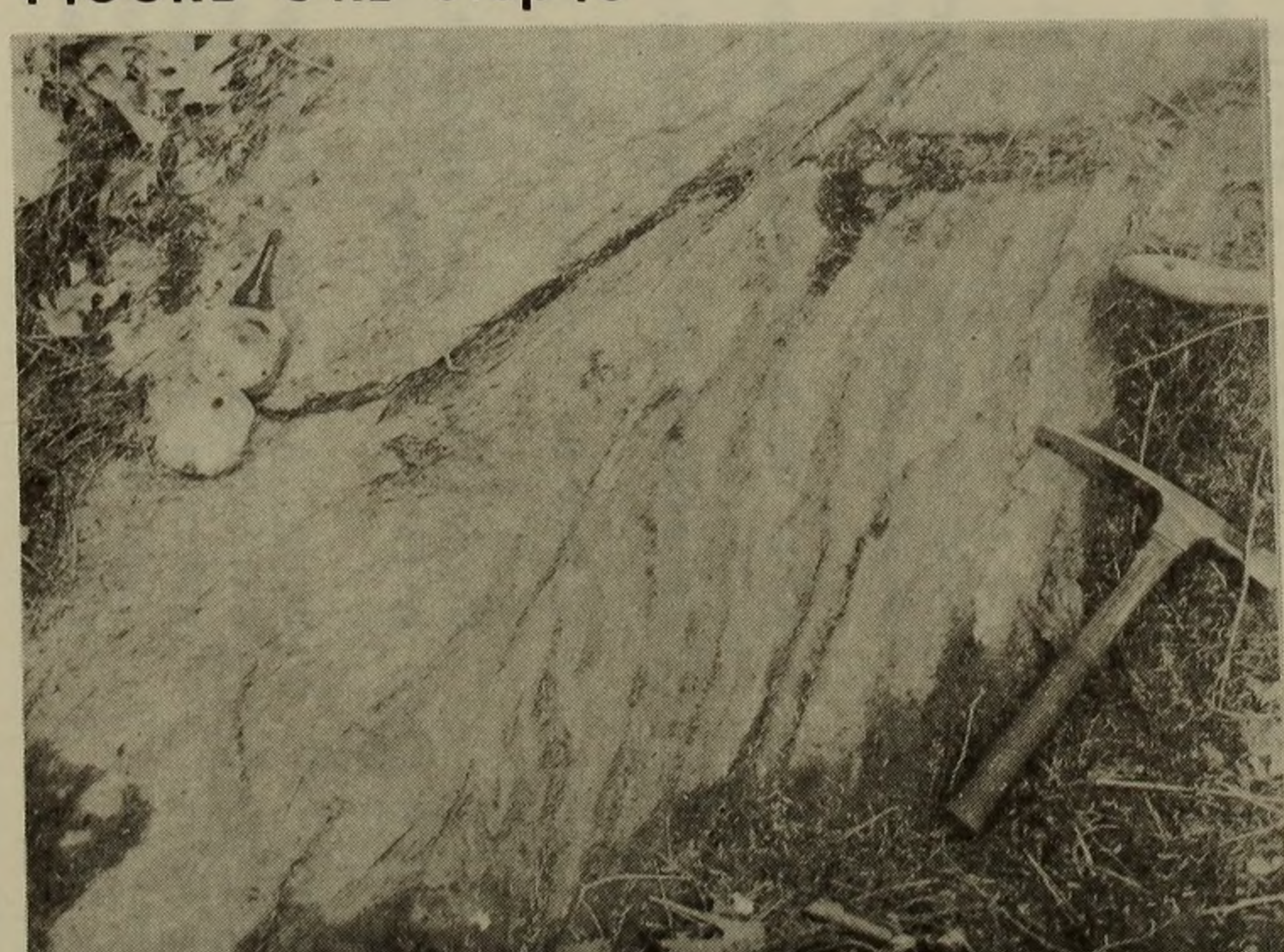
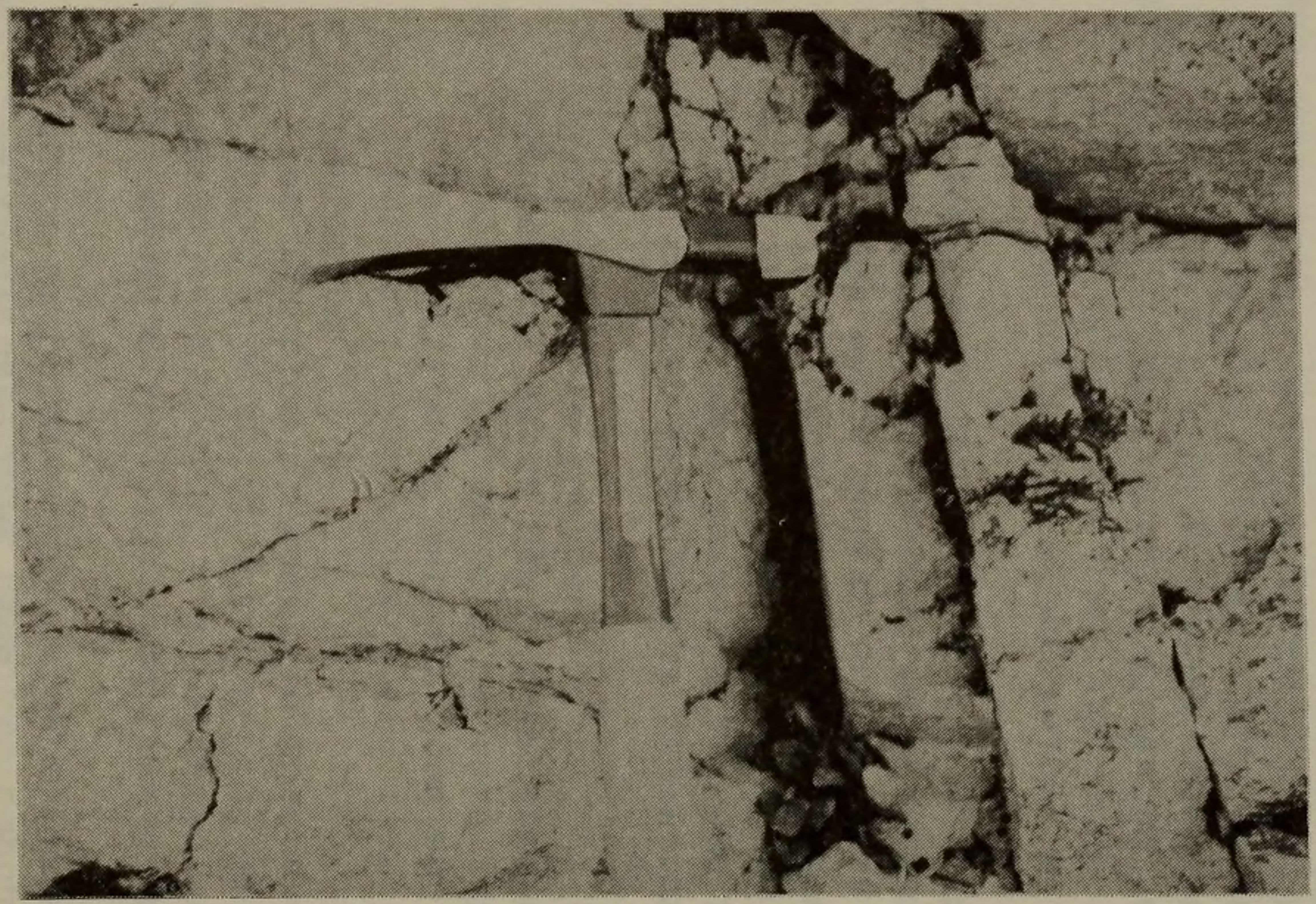


FIGURE 6RL Stop 11

FIGURE 1 RL

A



B

A. LOCALIZED REORIENTATION OF CATACLASTIC FABRIC OF GRANITE NEXT TO "BRITTLE" FRACTURE

B. FRACTURING AND BOUDINAGE OF BASALT AND GRANITE

Mileage	
	phyllonite. The average foliation of the rocks is variable depending upon the depth of exposure, because the minor structures are being exposed.
	Proceed up the hill, and travel northwards on Blakes Hill Road.
3.7	Pass junction of Mountain Road and Blakes Hill Road, Northwood.
3.9	Pass Junction of Harmony Road and Blakes Hill Road.
4.4	Cross area where power line traverse leads to the Gulf Hill Fault to the west.
5.0	Fork between Kelsey Mill and Blakes Hill Roads - take right fork onto Kelsey Mill Road heading eastwards.
5.2	Stop 1B. (Optional). Depending on conditions. North end of swamp where Kelsey Brook flows under Kelsey Mill Road. Note exposures of granite, gneissic schist (recrystallized mylonite?) and granulite.
	Proceed northeast along Kelsey Mill Road.
5.7 (5 min.)	Stop 1C. (Optional). Folds in schist in assocation with the contact with granite, exposures in the yard of the Northwood Oil Company, junction of Kelsey Mill Road and N.H. Route 4.
	Turn eastwards onto N.H. Route 4.
6.6	View of west face of Saddleback Mountain looking southeastward from Harvey Lake on south side of the road.
7.5	Junction of Harmony Road and N.H. Route 4. Turn southwards onto Harmony road on south side of the road.
8.15	Turn around in turn around area of M.E. Johnson residence, head northwards on Harmony Road.
8.5 (30 min.)	Stop 1D. (Optional). Dependent upon conditions. Exposure is along the shore line of Harvey Lake. If the water level of Harvey Lake is low enough, the contact zone between schist and garnetiferous granulite will be exposed, along with a folded outcrop of granulite showing development of micas on slip surfaces, fold superposition, healed cross fractures and minor thrust surfaces within the fold outcrop. If conditions do not permit viewing in, i.e., the outcrop is submerged, Figure 2RL will have to suffice.
8.8 (20 min.)	Junction of Harmony Road and N.H. Route 4.

Mileage

Stop 2. Park cars on Harmony Road, go around the corner to outcrop on south side of NH Route 4.

This outcrop shows the contact between schist, granulite and granite. An example of a "juiced zone of movement?" There are tightly folded minor folds with NW-SE axial trend.

Turn right onto N.H. Route 4 and head eastwards.

12.7 View of Northeast side of Saddleback Mountain looking southwards from Northwood Ridge which we have been traveling along.

12.75 View of Mt. Pawtuckaway to the south.

12.9 Junction of NH Routes 4 and 43. Turn right onto Route 43 and go southwards.

14.0 Junction of N.H. Route 43, Lucas Pond Road on east and Mountain Road on west along east flank of Saddleback Mountain.

14.4 Junction of Old Deerfield Road and Mountain Road, Northwood, N.H. Turn left onto Old Deerfield Road and head south .15 miles. Elevation 574'.

14.55 Stop 3. Outcrop of folded calc-silicate granulite exposed at elevation 580' approximately 60 yards west of Old Deerfield Road.

Thin sections of samples from this exposure reveal cataclastic properties (fracturing and millings of feldspars, pyroxene and amphibole phenocrysts). Quartz is sutured, also showing ribbon texture. Diopside is overgrown by amphiboles, and amphiboles are of two generations, and/or overgrown by biotite, indicating a complex structural and thermal history for these rocks. The calc-silicate pods may represent original compositional layering, but these are now transposed into rolled segregations. Folding is complex; the entire outcrop plots in a monoclinic, or kink mode. (Figure 3RL).

14.7 Exit Old Deerfield Road to NH Route 43, turn left, head north on Route 43.

14.95 Exposure of granulites in road cuts.

15.1 Junction of Woodman Road and Route 43. Turn right onto Woodman Road head southwest.

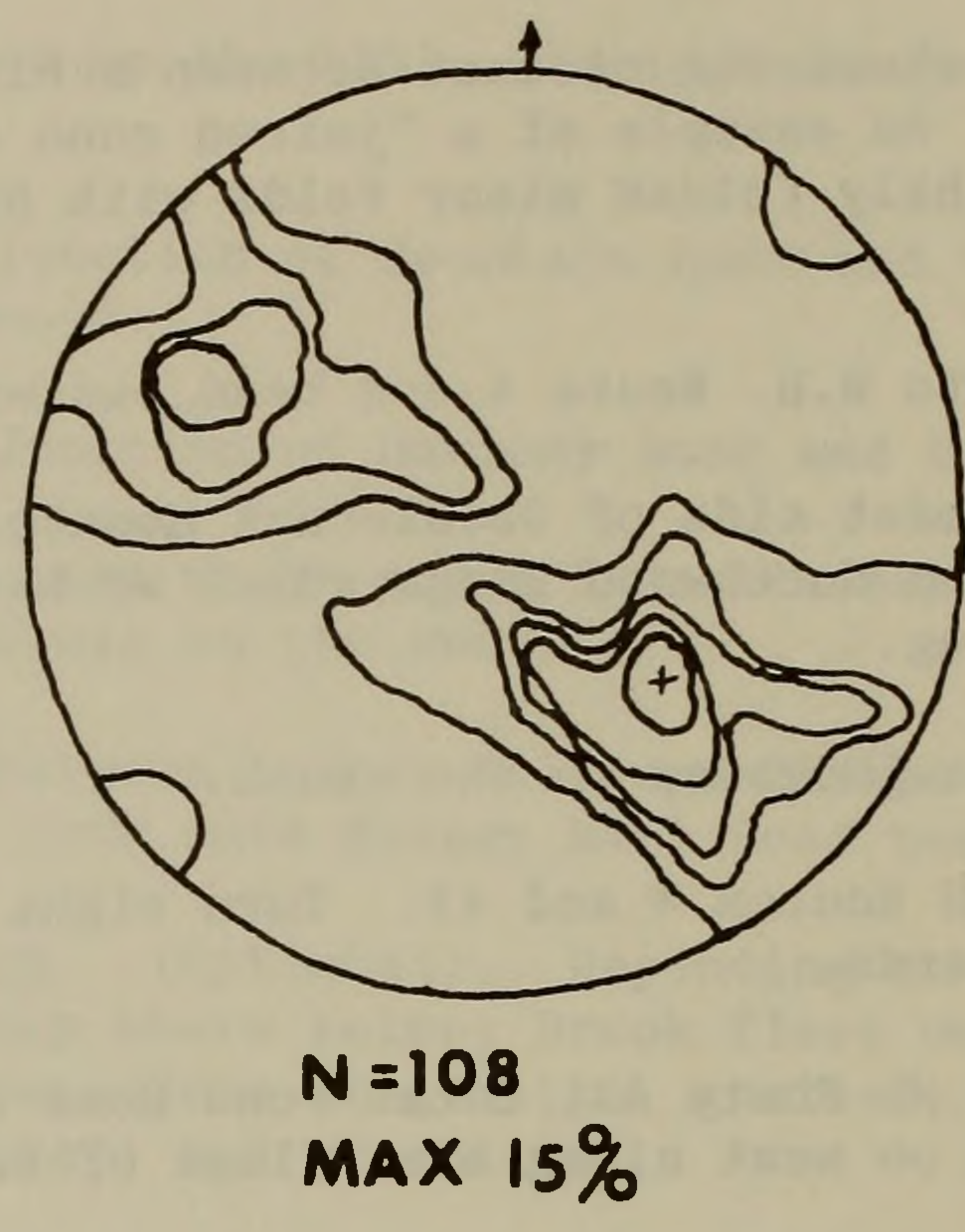


FIGURE 3RL OUTCROP OF FOLD .1 MI SOUTH OF THE INTERSECTION OF MOUNTAIN ROAD AND OLD DEERFIELD ROAD, NORTHWOOD, N.H., WITH PI DIAGRAM OF FOLIATION MEASUREMENTS (STOP 3)

Mileage

15.2	Turn left onto service road opposite first trailer on right on Woodman Road. Park cars.
(30 min.)	Stop 4. Walk eastwards down trail to Camp Yavneh Lagoon.
	Exposures here are of silicified pegmatites and granular sillimanite-rich gneissic schist. There are two generations of sillimanite in these rocks: tabular and fibrolitic as well as two generations of biotite. This is an area of structural rotation of foliation. There is also a NW oriented rodding in this exposure.
15.3	Turn around, head back to the intersection of N.H. Route 43 and Woodman Road. Turn left onto Route 43, head southwards.
15.55	Stop 5. Road cut of granulites: note, directly north and west are exposures of pegmatites and biotite-rich granodiorite. Isoclines are present in these rocks even though not apparent at first. Rock staining enhances minor structures, which are delineated by the presence of potassic feldspar.
	Continue southwards on NH Route 43.
16.1	Outcrop of gneissic schist exposed on west side of Route 43.
16.2 (30 min.)	Stop 6. Masonry supply yard - exquisite exposure of folds in association with fractures and contact with biotite rich granite - granodiorite. Excavations for the foundation of the masonry supply warehouse revealed the changing structural orientation. This exposure in the yard of the masonry supply warehouse and the outcrop at NH route 43, as well as some in the Waterville Camp Ground indicate that there is a splay of the Saddleback Mountain Fault running directly through this area. Brittle and ductile features, as well as features indicative of subsolidus melting, and, or chemical mobility (lit-par - lit injection).
16.6	Proceed southwards on NH Route 43.
	Exposure of sillimanite-rich schist in outcrop on NH Route 43 near the entrance to Doles Marsh Wildlife refuge.
17.5	Deerfield, N.H. Junction of Coffeetown Road and NH Route 43.
19.0	Junction of Parade Road and N.H. Route 43, Deerfield, NH. (This is the turn off for Stop 10 later in the day).

Mileage

	Route 43 changes direction to westerly. Continue on 43.
19.2	Exposure of granite pegmatite.
19.7 (30 min.)	Stop 7A. Exposure of granulite in road cut on north side of road. Contact with speckled biotite-rich granitic(?) rock similar to that seen at Stop 6. Move cars .2 miles down N.H. Route 43 to Stop 7B.
19.9	Stop 7B. Exposure of granulite, granite and basalt dike in road cut opposite the intersection of Mountain View Road, and N.H. intersection of Mountain View Road and N.H. 43, Deerfield, N.H., elevation 600' (Figure 4RL).
19.95	Junction of N.H. Route 43 and Mountain View Road.
20.1	Note silicification of pegmatites. Beryl-bearing pegmatites are exposed in the yard of the cape at the turn of Route 43. Note the fracture patterns associated with folding of the foliation planes of the granulites metasediments, and the development of coarse micas along shear surfaces.
	Continue southwards on N.H. Route 43.
21.2	Junction of N.H. Route 43, and N.H. Route 107 N-S and south Parade Road. Turn southwards onto 43-107 south. (There is a mafic dike buried on the north end of the lot of the Quonsett Hut at the junction of Parade Road and N.H. Route 43-107. This dike is highly fractured and is deflected indicating that it was moved upon emplacement. There is a high degree of sausiterization in the thin section of this dike and development of secondary calcite pyrrhotite. (Pyrrhotite forms fracture fillings.)
21.4	Cross Lamprey River on Route 43.
21.9	Junction of James City Road and Route 43 (N.H. Historical marker).
22.3 (30 min.)	Stop 8. (Also rest stop. Facilities graciously provided by the American Legion.) Deerfield American Legion Hall - Contact between gneissic schists and pegmatites. Pegmatites are zoned, there are rotating directions of feldspar aligment, and shears in the large feldspar phenocrysts-graphic granite was exposed in the excavation alignment of graphic intergrowth has spatial distribution akin to fracture orientation. Rimmed garnets in pegmatites. Walk .1 mile S on 43 exposure of schists which are folded. Pseudo-cross bedding is produced by

Mileage

fracturing in the rocks. Thin sections show evidence of retrogression in these rocks. This outcrop is in alignment with the trace of the Gulf Hill Fault.

Compare these rocks to the outcrop of the Camp Yavneh Lagoon at Stop 4.

Turn around, (note - last chance to buy lunch at one of the two country stores in the vicinity of the American Legion Hall.)

Proceed northwards on N.H. Route 43-107.

23.2 Recross Lamprey River.

23.4 Junction of N.H. Route 43-107 (DEFINITELY LAST CHANCE TO STOCK UP AT STORE).

Take N.H. Route 43 northwards.

24.4 Pass outcrop of Stop 7 on right.

24.5 Junction of N.H. Route 43 and Mountain View Road, Deerfield, N.H.

Turn left onto Mountain View Road. Follow Mountain View Road up Saddleback Mountain.

25.8 Elevation 900'. Turn around at road to tower. Park cars.
(3 hours)

Stop 9. (Lunch) - take lunches and field packs, walk up to WENH Microwave tower (Elevation 1100'). (Note, the elevation of the top of Saddleback Mountain reported on the 1981 7 1/2 minute Northwood Quadrangle is incorrect, total elevation is 1175'). Eat lunch and begin treck across the top of Saddleback Mountain.

Views of Gulf Hill, Fort and Nottingham Mountains to the west, Blue Hills to northwest (on a clear day Mt. Monadnock can be seen to the southwest).

The rocks exposed at the microwave tower are gneissic schists of variable composition often with abundant tourmaline. (See description in text). We will examine these rocks, then view the contacts between these rocks and igneous units, examine structures within biotite-rich granite to granodiorite, and structures within granulitic rocks on the northern side of the uppermost peak of the mountain and in the saddle of the mountain. The tranverse begins at approximately 030 azimuth from the south peak of

Mileage

the mountain. The contact between granite and gneiss occurs at the north end of the south peak in association with small enclaves of granulitic metasediments. Isoclinal folding/fracturing mimicking it is seen in the granites here. The traverse changes then to almost due east to the top of Saddleback Mountain's highest peak where tourmaline rich gneissic schists are exposed. A northwesterly traverse is then taken across the west flank of the highest peak. The contact between schist and granulite occurs in an approximately E-W trending direction. Granulites showing complex folding and fracture patterns are exposed on the west flank of the highest peak, (interlayered with granites on the north end), and on the saddle. The northwesterly traverse will take us through granulites, then granite, and back down through granulites, gneissic schist. At the top of the north west peak, granite pegmatite with quartz veining is exposed. The Town of Northwood Nature trail will be followed in a westerly direction, descending to the valley of the NW trending Lamprey River tributary known as Bear Brook and crossing it at approximately the 700 foot contour.

From there, a logging trail which trends approximately S25°E (155° Azimuth) will be followed. Along this traverse are migmatites with rotated granulite enclaves, and restites showing reaction rims. Exit the trail onto Mountain View Road at approximately 880-900' elevation by point where cars were parked.

Proceed southwards along Mountain View Road.

27.1 Junction of Mountain View Road, and NH Route 43, Deerfield, NH.

Turn right onto NH Route 43.

27.7 Junction of N.H. Route 43 and north end of Parade Road, Deerfield. Turn right and head southwards on Parade Road for .2 miles.

27.9 Stop 10. Junction of logging trail and Parade Road, Deerfield, NH.

(15 min.) Be careful parking cars; this is by a blind corner in the road.

This outcrop shows transposition structures characteristic of ductile shear at the borders between porphyritic granite and gneissic schist (Figure 5RL).

Turn around, head northwards toward NH Route 43.

Mileage	
28.1	Junction of Parade Road and N.H. Route 43. Turn right onto N.H. Route 43, head northwards.
29.6	Junction of Coffeetown Road and N.H. Route 43.
(15 min.)	Stop 11. Elevation 600'. Exposure of crenulated and rodded tourmaline-rich gneissic schist with granulite layers exposed in road cut at the corner of Coffeetown Road and Route 43. Also, refolding of ptygmatic folds in the yard of trailer .1 mi. north of road cut. (Figure 6RL).
	Proceed northwards on N.H. Route 43.
	The remaining stops are optional-depending upon time. If the trip ends here, return to Danvers. may be by heading southwards on NH 43-107S until it intersects NH Route 101 East. Follow 101E until it intersect I-95. Take I-95 south to Danvers.
30.5	Outcropping of sillimanite-rich schist at entrance to Doles Marsh Wildlife Refuge.
	Turn around, head northwards on N.H. Route 43.
31.5	Turn left off of Route 43 onto spur of Old Deerfield Road .1 mile north of turn off to Doles Marsh Conservation area.
	Stop 12. Folded schist in association with speckled biotite-rich granodiorite.
	Proceed northwards on Old Deerfield Road.
31.8	Turn left, park and proceed up old trail.
	Stop 12A. Follow trail westwards - trail will be following part of the trace of the Saddleback Mountain fault. Note contacts between "schists" and granulites, and intense fracturing in stream beds near traces of E-W fault. Folds resembling sheath folds described by Cobbold and Quinquis (1980). (See Figure 5 of text.)
	Return to N.H. Route 43 north, follow it to N.H. Route 4, turn right, head eastwards towards Lee, Durham and Portsmouth. Take I-95 south to Danvers, Mass. from Portsmouth, N.H. interchange.