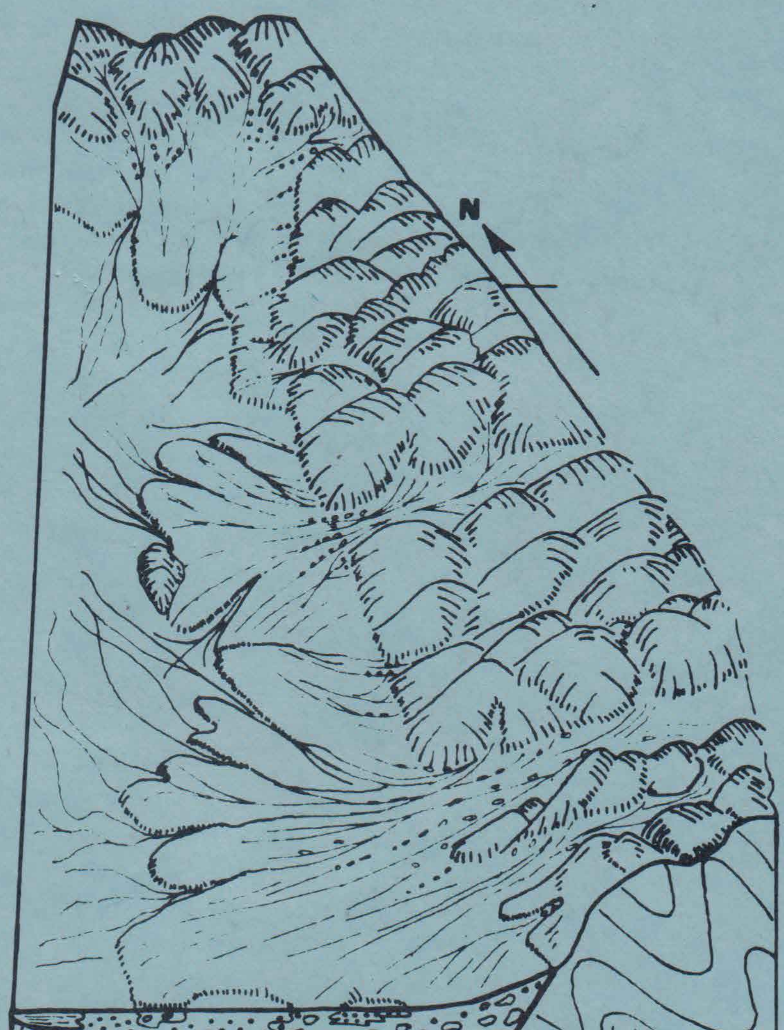
SEDIMENTARY HISTORY OF UPPER TRIASSIC ALLUVIAL FAN COMPLEXES IN NORTH—CENTRAL MASSACHUSETTS

BY

JAMES M. WESSEL



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Contribution No. 2

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ABSTRACT

Upper Triassic Mount Toby Conglomerate and Turners Falls Sandstone consist of intertonguing conglomerate, sandstone, and mudrock that were deposited in a subsiding fault trough. Dispersal trends determined from primary structures and gravel fabric indicate that sediment transport was primarily from east to west. Moving average diagrams of pebble sizes suggest the presence of three major alluvial fan complexes.

Planar crossbedded units have an average thickness of 5.6 inches and a mean foreset inclination of 15.2°. The small angle of foreset inclination may result from development of crossbedding in the upper part of the lower flow regime. Association of the crossbedding with planar beds, parting lineation, and antidunes supports this hypothesis.

The Mount Toby Conglomerate and Turners Falls Sandstone differ significantly in composition in the northern and southern parts of the basin. Conglomerates in the northern part of the basin contain abundant metamorphosed mafic igneous rock fragments, whereas conglomerates in the southern part are richer in metamorphosed granitic rock fragments.

Sedimentary structures, textures, and facies geometry indicate that four depositional environments are represented: (1) alluvial fan, (2) fluvial (subdivided into streams developed on fan complexes and streams heading in fan bays), (3) flood plain, and (4) lacustrine.

Textures, structures, and authigenic minerals suggest a semi-arid Late Triassic climate in this part of the Connecticut Valley.

INTRODUCTION

Triassic redbeds in the Connecticut Valley have fascinated geologists for one hundred and twenty years. Previous work (see Krynine, 1950, for bibliography) has yielded a detailed knowledge of the structural and stratigraphic framework of the depositional basin, but little data has been accumulated on paleocurrents, petrography, facies distribution, and general sedimentological history. This investigation of the Mount Toby Conglomerate and Turners Falls Sandstone in the northernmost preserved Triassic basin of the Connecticut Valley was undertaken to (1) determine paleocurrents and associated dispersal trends; (2) analyze the composition and texture of the rock suite; and (3) reconstruct the depositional environments.

The rocks lie entirely in the Connecticut lowland of the New England Province (Thornbury, 1965, p. 167). This lowland is bordered by the Worcester Plateau to the east and the Berkshire Plateau to the west. Intensely folded Lower Paleozoic metamorphic rocks underlie the plateau areas.

To present and compare the data, the study area has been divided into three provinces: (1) a Southern Province that includes the Mount Toby Conglomerate and Turners Falls Sandstone in the area south of Montague and Taylor Hill (Fig. 1); (2) a Northern Province, composed of the sedimentary rocks that crop out northward from Montague and Taylor Hill (Fig. 1) and to the area northeast of the village of Gill where the Triassic rocks pinch out against older crystalline rocks (Fig. 1); and (3) the Northfield Province comprising the small northern block of Triassic sediments separated from the main section (Fig. 1)

Figure 1. -- General geologic map of the study area (modified from Willard, 1951).

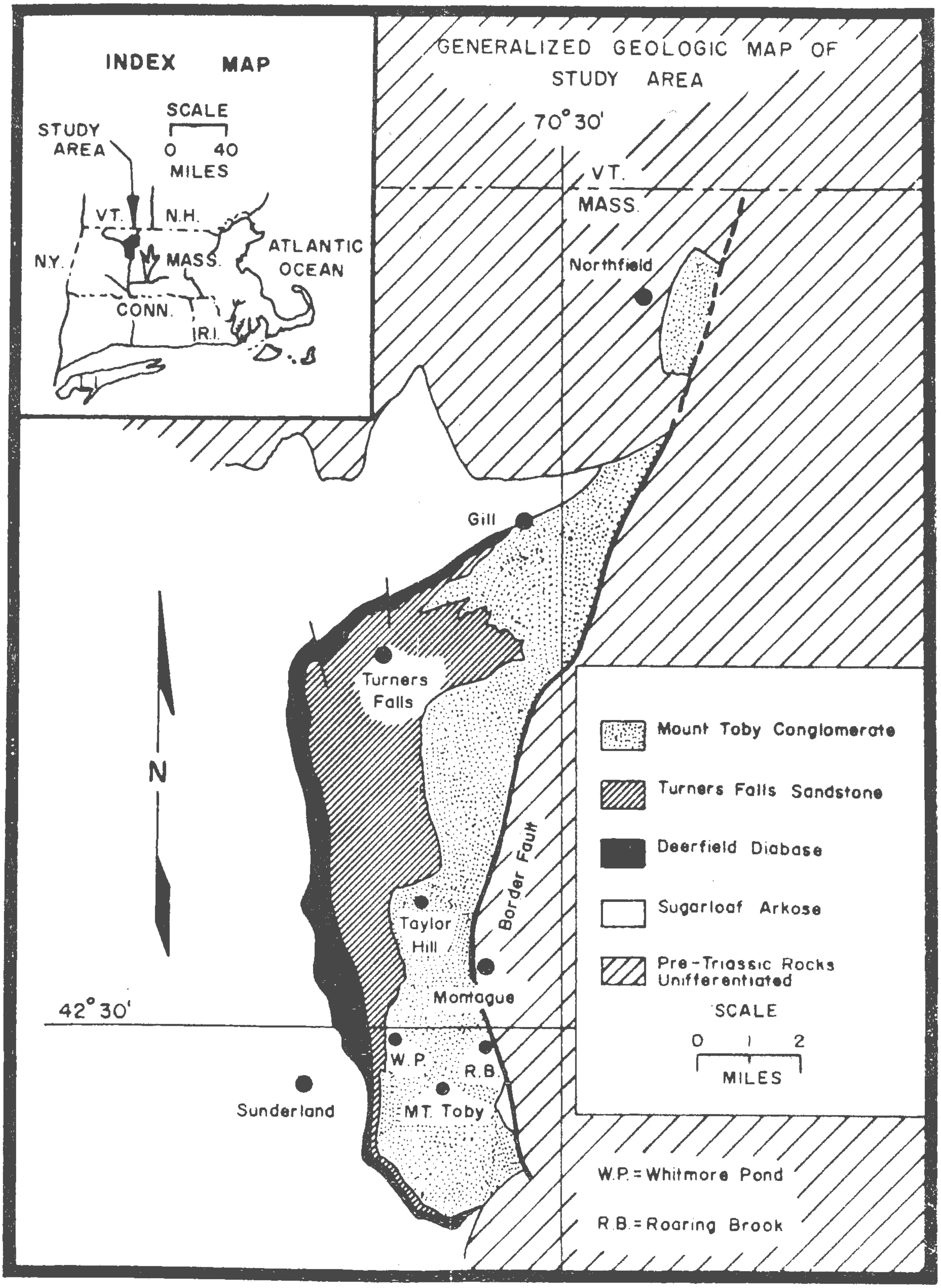

INDEX MAP
SCALE
0 40
MILES
STUDY AREA
VT.
N.H.
NY.
MASS.
ATLANTIC OCEAN
CONN.
R.I.
GENERALIZED GEOLOGIC MAP OF STUDY AREA
70° 30'
VT.
MASS.
Northfield
Gill
Turners Falls
Taylor Hill
Border Fault
Montague
42° 30'
W. P.
R.B.
MT. Toby
Sunderland
N
Mount Toby Conglomerate
Turners Falls Sandstone
Deerfield Diabase
Sugarloaf Arkose
Pre-Triassic Rocks Unifferentiated
SCALE
0 1 2
MILES
W.P. = Whitmore Pond
R.B. = Roaring Brook

Figure 1

ACKNOWLEDGMENTS

The author wishes to thank Miles O. Hayes, the principal advisor, for his many helpful suggestions and criticisms; Peter Robinson for his suggestions and advice concerning the conglomerate clasts and regional geologic setting; Gregory W. Webb for his advice on the stratigraphic aspects of the problem; and Leo Hall for his helpful criticisms and suggestions regarding the petrography and regional geology. Bryce M. Hand of Amherst College also served on the Thesis Committee and made many helpful suggestions regarding fluid dynamics of the depositional environment. A grant from Sigma Xi to defray the costs of some of the thin sections is also gratefully acknowledged.

STRATIGRAPHY

The Turners Falls Sandstone and the Mount Toby Conglomerate of north-central Massachusetts compose a complex of intertonguing mudrocks, sandstones, and conglomerates approximately 2000 feet thick. These eastward dippling rocks are exposed in a north-south trending belt sixteen miles long and four miles wide (Fig. 1). Sedimentary structures, lebensspuren and lithic associations indicate a continental origin for these deposits (Krynine, 1950, p. 15). Plant and fish and fossils contained in the rocks suggest that the rocks are Upper Triassic (Lull, 1953, p. 15; Russell, 1892).

Turners Falls Sandstone

The Turners Falls Sandstone (Emerson, 1898, 1917; Willard, 1951; and Balk, 1956) consists of interbeds of reddish-brown to gray pebbly sandstone; coarse to medium-grained sandstones; red, fine-grained siltstones; and red to black mudstones. Silty micrite beds and small amounts of coal are present at some horizons. The formation ranges from one to 1000 feet in thickness

A variety of organic and inorganic sedimentary structures are present, the most notable of which are dinosaur footprints, burrowed zones, cross-bedding, ripple marks, parting lineation, and load casts. Fossil fish have been reported and small amounts of plant detritus are present in a few beds.

Mount Toby Conglomerate

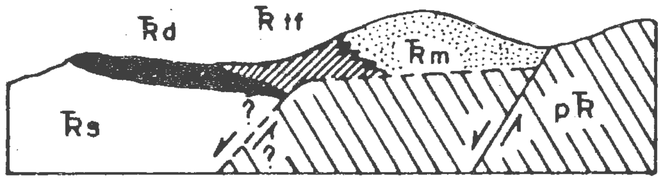
The Mount Toby Conglomerate (Emerson, 1917; Reynolds and Leavitt, 1927; Willard, 1951 and 1952; and Balk, 1956) is reddish-brown to gray-brown thick-bedded pebble to boulder polymicitic conglomerate. Local lenses and beds of pebbly sandstone and coarse sandstone occur within many of the conglomerate horizons. Although directional structures are generally absent or poorly developed in the conglomerate, the finer interbeds of coarse sandstone contain abundant crossbeds and parting lineations. Cut and fill, graded bedding, and imbrication are typically developed in the conglomerate. Grain size varies from 2 mm up to 1.8 m; however, roundness varies only slightly throughout the section. The thickness of the Mount Toby Conglomerate cannot be directly determined due to complex facies changes, but it probably ranges from 200 to 1000 feet (Willard, 1951).

The Mount Toby Conglomerate is interbedded with the Turners Falls Sandstone. Along its eastern boundary the Mount Toby Conglomerate is separated from older pre-Triassic crystalline rocks by a normal fault, which defines the east side of the basin. The basal contact of the unit is complex and difficult to determine precisely. It rests on older crystalline rocks along its eastern limits, but towards its central portion it probably directly overlies older Triassic rocks (Fig. 2).

Willard (1951) described three subdivisions in the Mount Toby Conglomerate: (1) fine to thick-bedded conglomerate, (2) talus breccia, and (3) autochthonous breccia. The distinction between the fine to thick-bedded conglomerate and the talus breccia appears to be based on grain size, pebbl

Figure 2. -- Generalized geologic east-west cross section in the vicinity of Montague (Fig. 1). Slightly modified from Willard (1951)

GENERALIZED GEOLOGIC
EAST-WEST CROSS SECTION
OF THE
STUDY AREA
NEAR MONTAGUE



Ꞧm		MOUNT TOBY CONGLOMERATE
Ꞧtf		TURNERS FALLS SANDSTONE
Ꞧd		DEERFIELD DIABASE
Ꞧs		SUGARLOAF ARKOSE
pꞦ		PRE-TRIASSIC ROCKS UNDIFFERENTIATED

0 1
miles

Figure 2

angularity, and clast composition. However, little variation in clast angularity and composition across the basin was identified in this study. Thus a distinction between bedded conglomerate and talus breccia has not been made. The autochthonous breccia, however, is an important phase of the Mount Toby Conglomerate and will be discussed in a separate section.

A small isolated section of Triassic conglomerate with interbeds of pebbly sandstone is exposed one mile north of the main section of Triassic sediments in the Northfield area (Fig. 1). Balk (1956) mapped this unit as Mount Toby Conglomerate but did not discuss the basis of correlation between the two areas. The composition of these rocks (see Table 1, stations marked Northfield), their structural relationship to the main border fault, and their general sedimentological characteristics are all similar to the main section of the Mount Toby Conglomerate. This suggests that the two areas were probably once connected and that the correlation across one mile of older crystalline rocks is valid.

Regional Tectonic Setting

Trassic sedimentary rocks of the Connecticut Valley are separated from the older crystalline rocks to the east by a north-trending fault zone, commonly called the "great Border Fault" or "eastern border fault" (Krynine, 1950), and here called the Border Fault. According to Balk (1956) and Willard (1951) the fault zone dips steeply west, but the vertical displacement along the fault is unknown. However, Peter Robinson (oral communication, 1966) reports a stratigraphical throw of 25,000 feet in the area east of the Mount Toby highland. No evidence has been identified for strike-slip displacement along the fault.

Topography of the Basin Floor

The basin floor on which these late Triassic sediments accumulated is one of irregular relief. The topography in the Triassic was characterized by small inselbergs and fault scarps. Emerson (1917, p. 102) suggested the presence of "a great hill in Triassic time" in the vicinity of Taylor Hill (Fig. 1). At this locality, large (25-50 cm) angular fragments of granite gneiss are imbedded in a siliceous matrix. Some of the clasts may be mechanically weathered joint blocks (Fig. 3). Wessel and others (1967, p. 162) postulated that this area was an inselberg during Triassic time.

Another inselberg was described by Emerson (1917, p. 100-101) at Whitmore Pond just north of the town of Sunderland (Fig. 1). A pre-Triassic greenish-black phyllite is exposed along a small west-dipping fault. Clasts of Triassic conglomerates that crop out near this fault are identical in composition to pre-Triassic crystalline rocks exposed along the fault. The textural characteristics of the surrounding conglomerate indicate that this area was also a topographic high through at least part of the duration of Triassic sedimentation.

Minor Faults

Faulting has displaced Triassic strata in several areas (see Fig. 1 for location of larger faults). Emerson (1898), Bain (1932), and Willard (1952) all identified these faults. Willard identified two faults on the west side of the Mount Toby highland on the basis of juxtaposition of conglomerate and sandstone. The present author examined these areas and found no structural discordance between the units and a complete absence of slickensides. Thus the best interpretation of these abrupt changes in sediment types appears to be changes in facies and not structural displacements. In the Greenfield quadrange northeast of Turners Falls, several conglomerate-sandstone contacts that appear to be facies changes were mapped as faults by Willard (1952).

Figure 3. -- Angular clasts derived from the postulated inselberg at Taylor Hill. Fragments are granitic and display a strong foliation (F).

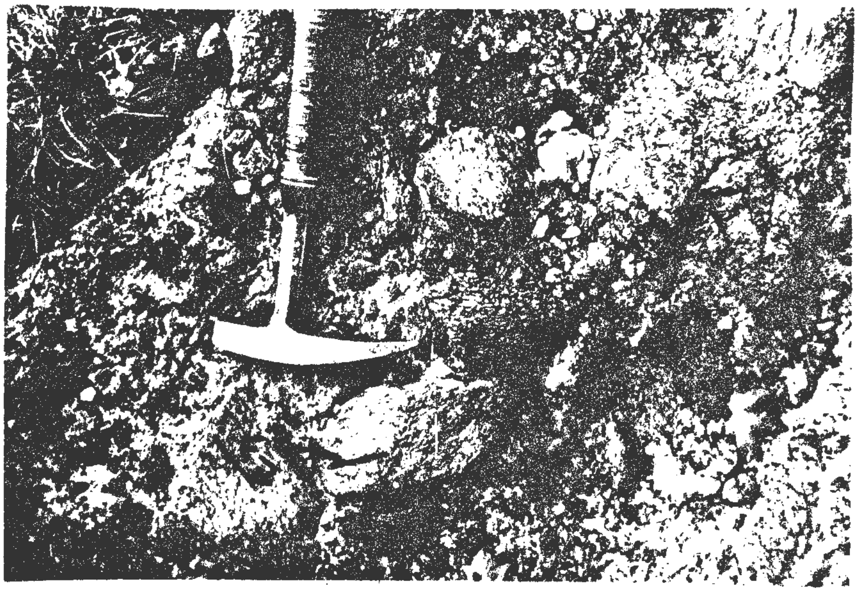


Figure 3

SEDIMENTARY STRUCTURES

General Statement

Organic and inorganic sedimentary structures are abundant in the Turners Falls Sandstone and the Mount Toby Conglomerate. Primary directional structures were used to determine paleocurrent patterns, paleoslope, direction of sediment supply, and depositional environments. The non-directional primary structures were used to interpret other aspects of the general depositional setting including plasticity of sediment before burial and time interval of sub-aerial exposure.

Sampling of directional structures was controlled by the availability of outcrop. The study area is small enough that over 90 percent of the bedrock exposures were visited and measurements were made on every directional structure that was observed. The field data are plotted on a 1/4 x 1/4-mile grid. The small grid density provides an accurate geographic position of the paleocurrent trends.

Directional Structures

Crossbedding---Crossbedding is the most abundant directional structure in the study area (Fig. 6). The majority of crossbeds occur as planar units in single sets (Fig. 5); festoon crossbedding is rare.

Azimuth of dip and size of the crossbedded units were measured at thirty-eight stations. Unit thickness of planar crossbeds is 2.0 to 24.0 inches (Fig. 6) and mean scale is 5.6 inches. However, scale sorting is poor (Fig. 6) and shows no consistent trends within the basin. The variation in planar crossbedding depends on three factors: water depth, bottom configuration, and amount of sediment supply (Schwarzacher, 1953, p. 325).

Fluvial crossbedding foreset inclinations in undeformed sediments normally range from 18° to 25° (Potter and Pettijohn, 1963, p. 79). An

Figure 4. -- Histogram showing abundance of directional sedimentary structures in the study area. Based on an attempt to measure all directional structures exposed in outcrop in the area.

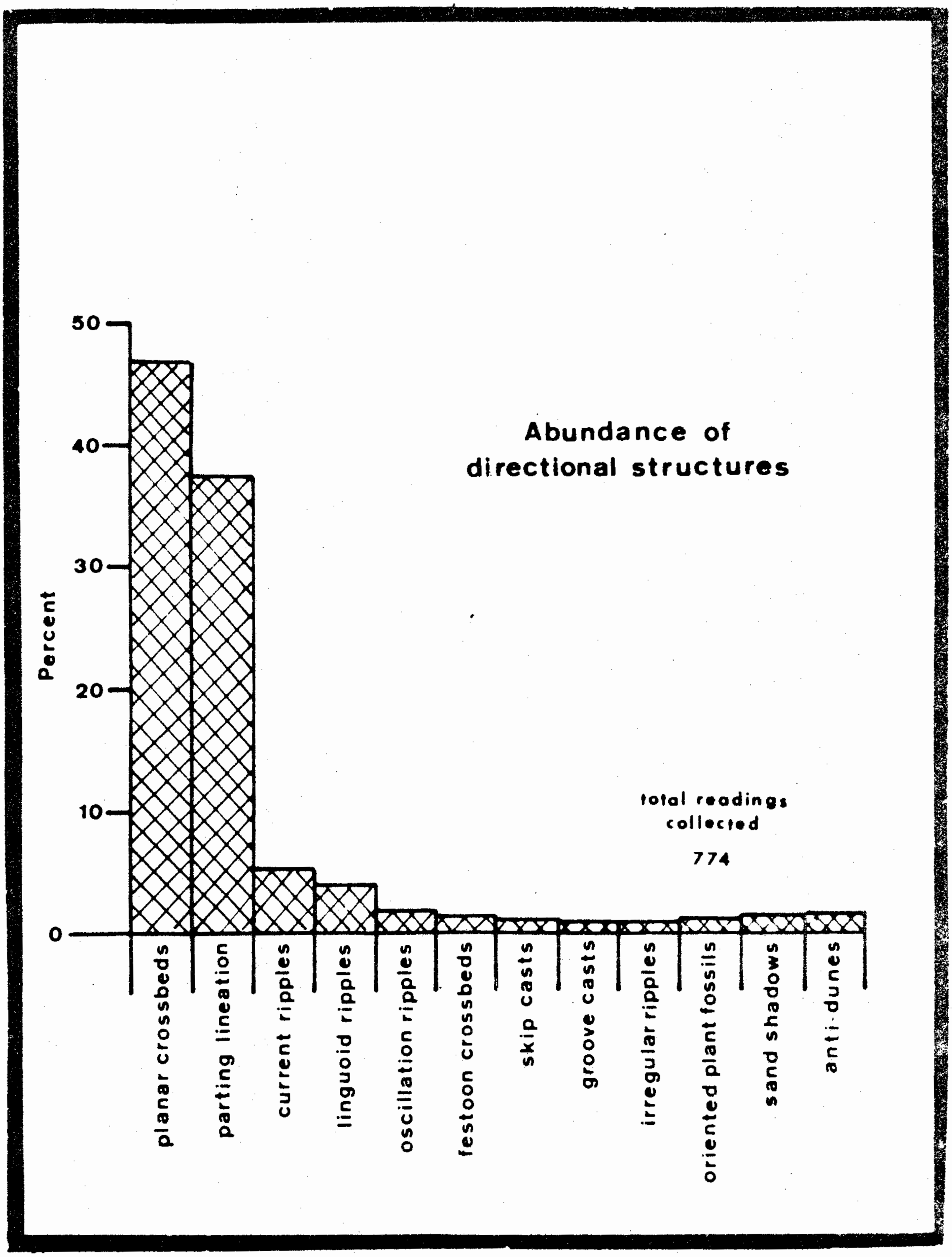

Abundance of
directional structures
Percent
50
40
30
20
10
0
total readings
collected
774
planar crossbeds
parting lineation
current ripples
linguoid ripples
oscillation ripples
festoon crossbeds
skip casts
groove casts
irregular ripples
oriented plant fossils
sand shadows
anti-dunes

Figure 4

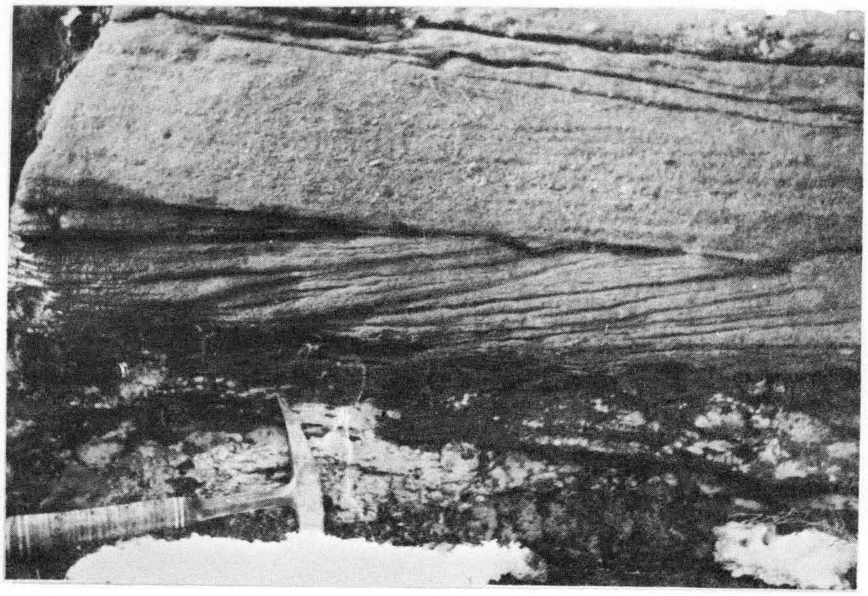


Figure 5

Figure 5. -- Planar crossbedding in an exposure of the Turner Falls Sandstone north of Sunderland. Note small scale, low foreset inclination, and plane beds above the crossbedded unit.

Figure 6. -- Histogram of crossbedding scale for 329 readings taken at 38 stations.

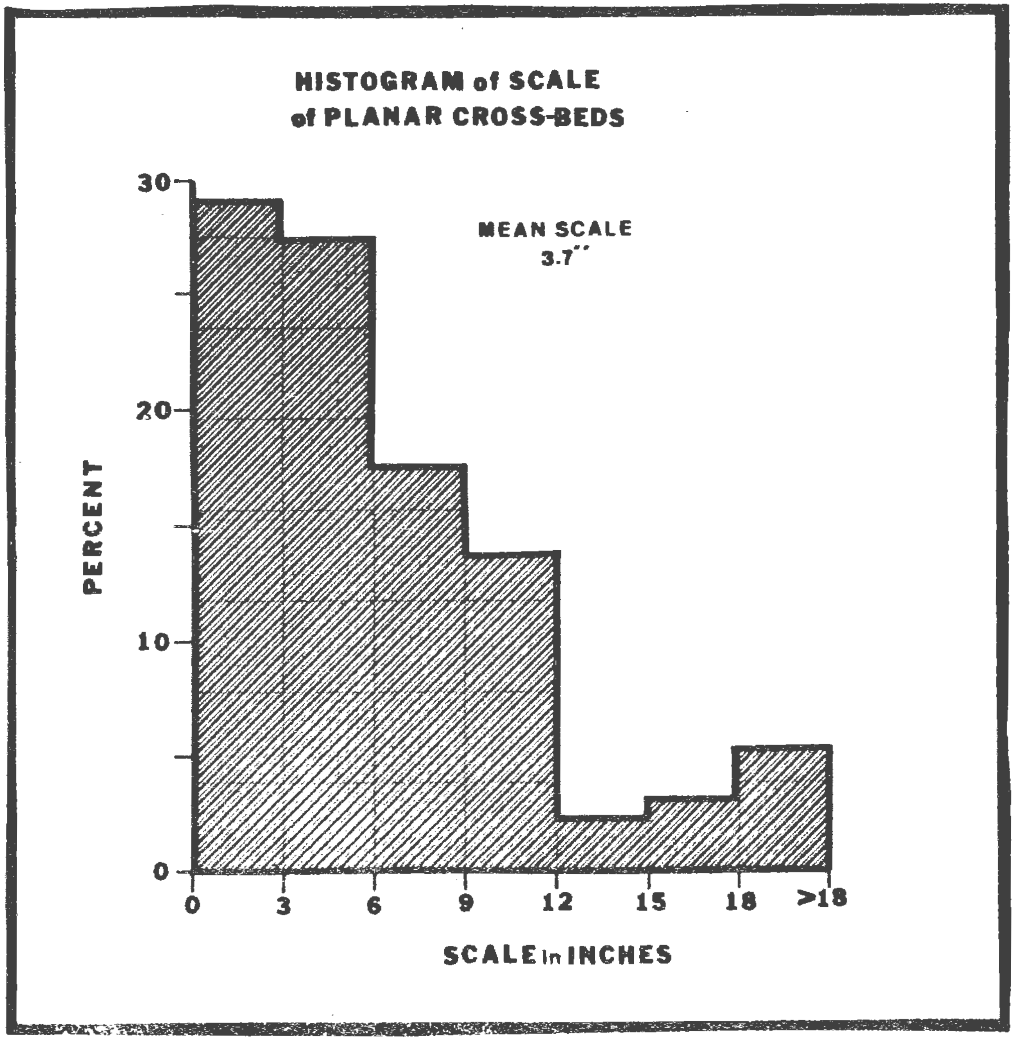

HISTOGRAM of SCALE
of PLANAR CROSS-BEDS
MEAN SCALE
3.7"
PERCENT
30
20
10
0
0
3
6
9
12
15
18
>18
SCALE in INCHES

Figure 6

analysis of tilt-corrected foresets (Fig. 7) in the study area shows that the angle of inclination may vary from 4° to 36° with a mean value of 15.2°. Furthermore, 30.6 percent of foresets have inclinations less than 12° (Fig. 7). McKee (1957, p. 133-134) states that the angle of foreset inclination is a function of grain size and shape, sorting, velocity of water, and depth of water. Klein (1956, p. 189) suggests that low angle foresets are controlled by the texture of the substrate and water velocity (low angle foresets are produced in higher velocities of the lower flow regime). Flume experiments indicate that the foreset inclination of dunes tends to develop a transition stage during tranquil flow. A series of low angle foresets (less than 12°) are formed before the dunes are finally washed out and plane beds are produced (Bryce M. Hand, oral communication, 1966). Allen (1965, p. 64) reported low angle foresets from the "finer facies" in alluvial fans. Power (1961, p. 604) found a maximum foreset inclination of 25° in the Coso Formation (Pleistocene, California). The attitude of foresets in the Coso Formation is from 25° to horizontal (plane) beds in the same sedimentation unit. Thus data from recent field studies and flume investigations suggest that the planar crossbeds in the Mount Toby Conglomerate and Turners Falls Sandstone were deposited under high velocities at the upper limits of the lower flow regime.

The lack of well-developed and abundant festoon crossbeds in the study area does not permit analysis of their environmental significance. Festoon crossbeds were used only as directional indicators. Direction was determined from the direction of plunge of the trough axes.

Ripple marks. -- Current and oscillation ripple marks are present in many horizons of the sand and mud facies in the Turners Falls Sandstone and Mount Toby Conglomerate.

Figure 7. -- Histogram of foreset inclinations of 320 planar crossbeds measured at 38 stations.

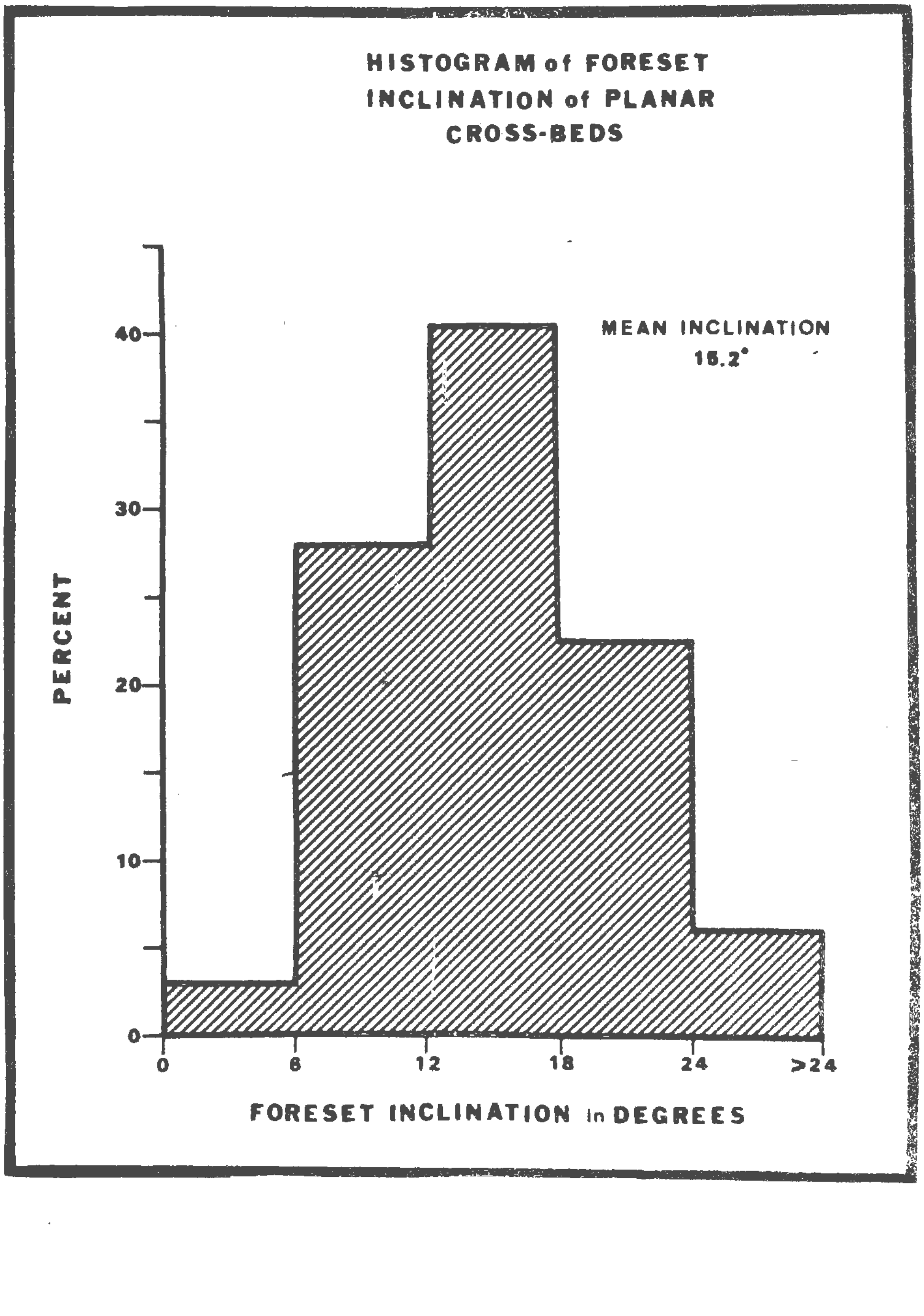

HISTOGRAM of FORESET
INCLINATION of PLANAR
CROSS-BEDS
MEAN INCLINATION
15.2°
PERCENT
40
30
20
10
0
0
6
12
18
24
>24
FORESET INCLINATION in DEGREES

Figure 7

Several varieties of current ripples are present in the study area (Fig. 4). The simplest form consists of straight crests with an asymmetric profile (Fig. 8). The wave length of these ripples varies from one to five inches as determined by 38 readings. Asymmetric ripples with markedly curved crests are abundant in many localities (Fig. 9). The steepest side indicates the downcurrent direction of transport. The wave length of 30 of these structures was determined and varies from three to seven inches. Bucher (1919, Fig. 1) called this type of ripple cuspate or linguoid. Occurrence of cuspate ripples has been noted after flash floods in the peripheral parts of playa lakes in the Great Basin by D.B. Matz (oral communication, 1966). Irregular asymmetric ripple marks of the type described by Doeglas (1962, Fig. 13, p. 176) are present in a few horizons (Fig. 10). The hydrodynamic conditions involved in the formation of these structures is unknown. All of the various asymmetric ripples were treated as directional vectors parallel to the main current direction; field notation included strike or direction of crest orthogonal, type of ripple mark, and wave length of ripple mark.

Wave length and strike of ridge crest of 23 oscillation ripple marks were measured (Fig. 11). Preliminary data from other areas indicate that the strike of the ridge crests of oscillation ripples is approximately parallel to the depositional strike (Potter and Pettijohn, 1963, p. 97). The scarcity of this ripple type suggests the possibility that large water bodies were ephemeral features during the deposition of Triassic rocks in this part of the Connecticut Valley.

Parting Lineation. --- Parting lineation is sub-parallel linear, shallow grooves and ridges on parting surfaces in laminated rocks where the parting surface cuts across one or more of the laminations. The

Figure 8. -- Ripples with straight crests and asymmetric profiles in the Turners Falls Sandstone east of Turners Falls.

Figure 9. -- Linguoid ripple marks in the Turners Falls Sandstone near Turners Falls.

Figure 10.-- Irregular or horseshoe ripple marks in the Turners Falls Sandstone northeast of Turners Falls.

Figure 11.-- Oscillation ripples in the Turners Falls Sandstone at Turners Falls.

Figure 8

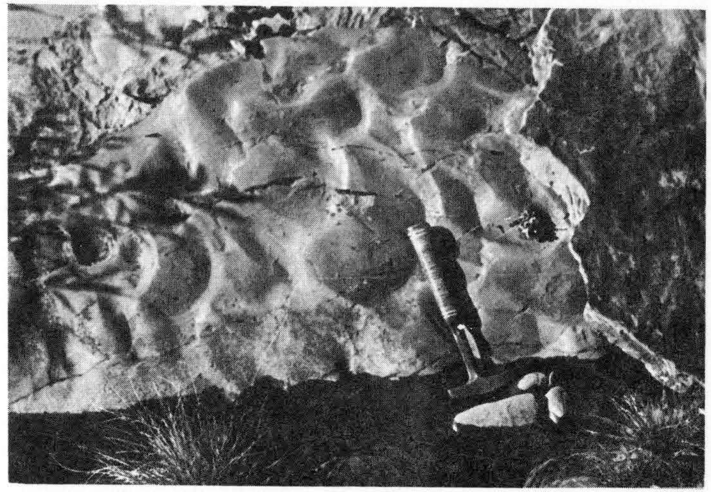


Figure 9

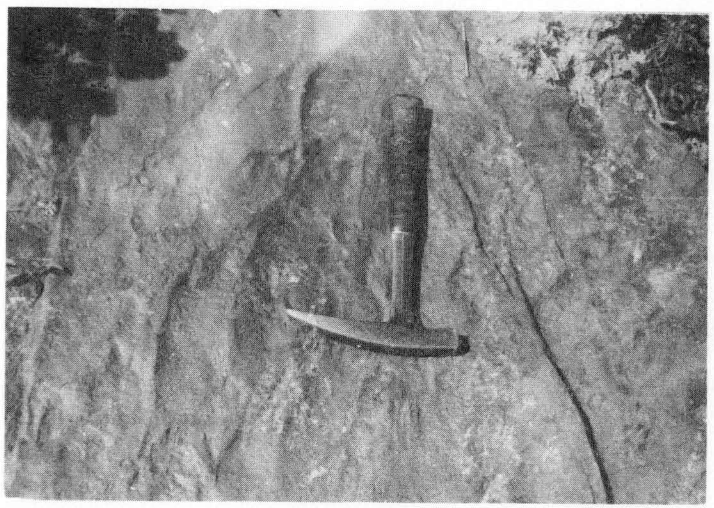


Figure 10

Figure 11

lineation is made up of a series of sub-parallel, step-like ridges (McBride and Yeakel, 1963, p. 780). Stokes (1947) used the term "current lineation" to describe the same feature. McBride and Yeakel (1963, p. 779) identified two types of parting lineation: (1) "parting plane lineation, which is characterized by parting that persists over a wide area on a single lamination," and (2) "parting step lineation, which includes parting developed over several adjacent laminations." Both types are present in the study area (Figs. 12 and 13).

Parting lineation is related to grain fabric. Allen (1964, p. 95) suggested that a preferred parallel orientation of sand grains and grain imbrication are the important properties controlling its formation. The parting lineation develops parallel to oriented elongate sand grains.

The exact hydrodynamic conditions governing the formation of particle alignment are not completely understood. Sorby (1908) indicated that alignment develops in the lower flow regime but Allen (1964) has shown that alignment develops in the lower part of the upper flow regime.

Parting lineation occurs in three depositional settings: (1) on plane beds associated with linguoid rippled surfaces; (2) on plane bed units of sandstone two to three feet thick interlayered with mudrock; and (3) in sandstone lenses within the conglomerate facies.

Applying the concept of flow regime as presented by Simons and others (1965), and Harms and Fahnestock (1965), it is evident that most of these lineations form under upper flow regime conditions because they commonly occur on plane beds that form in the lower portions of the upper flow regime. The occurrence of plane beds interlayered with mudrock is puzzling, but it is possibly related to sheetwash deposition on a flood plain.

The standard deviation of the azimuths of parting lineation display

Figure 12. -- Parting step lineation found in the Turners Falls Sandstone northeast of Turners Falls.

Figure 13. -- Parting plane lineation found in a sandy facies of the Mount Toby Conglomerate on the west side of the Mount Toby highland.

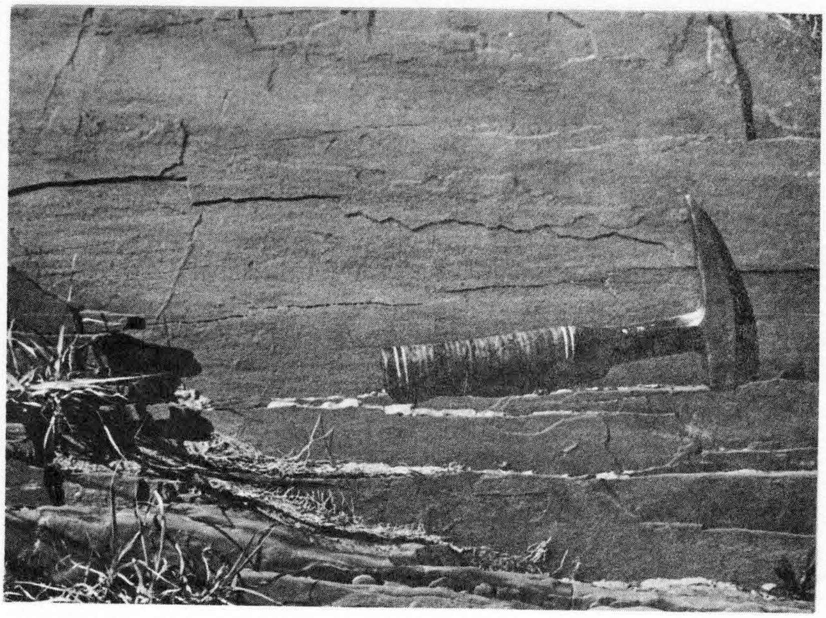


Figure 12

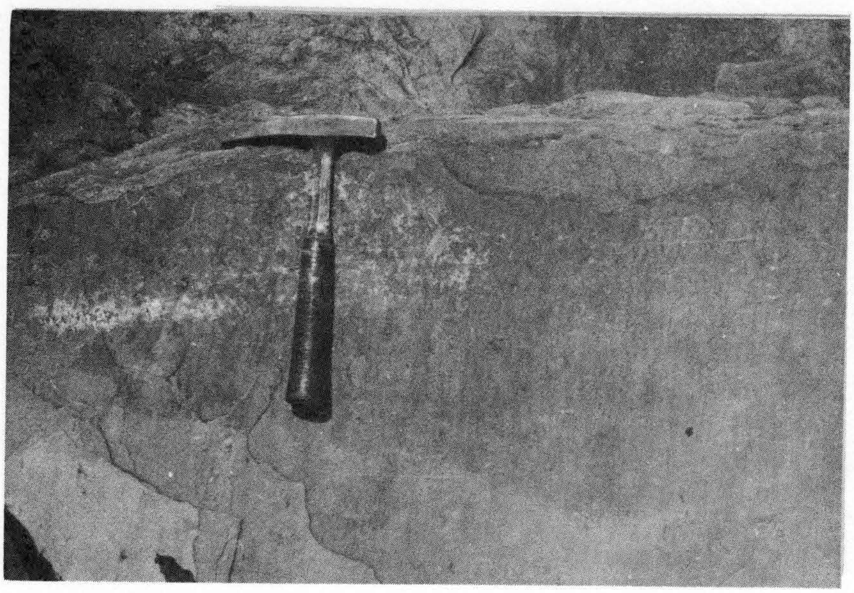


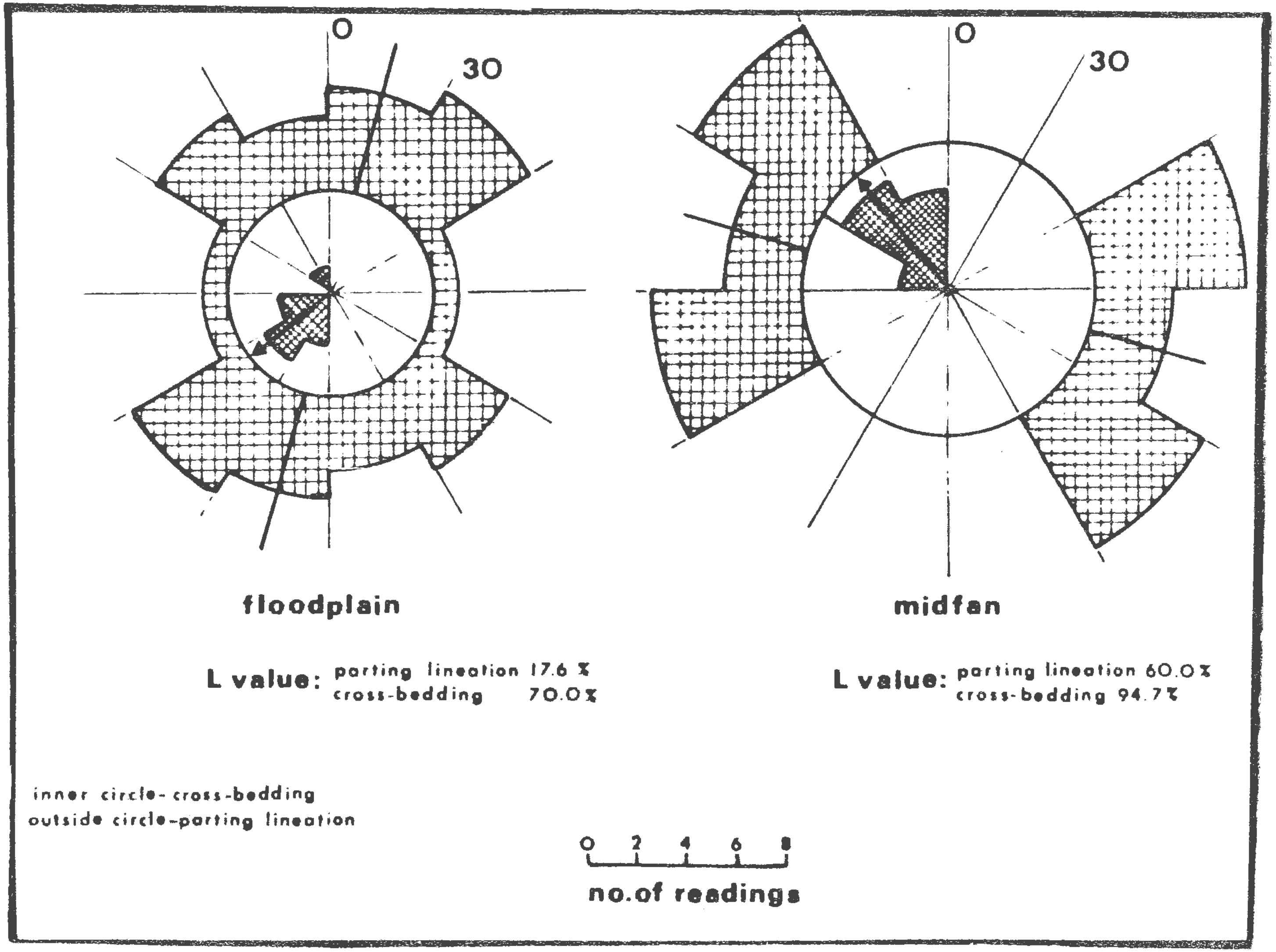
Figure 13

a greater variability than the directions indicated by crossbedding (Fig. 14). This variability probably reflects the fluid mechanics involved in the formation of the structure. Turbulent zones or threads move along the substrate in several different directions even though the main current direction is essentially constant. This is especially true in the plane bed phase of the upper flow regime where any grain orientation that is developed will be highly variable. This phenomenon is similar to gusting wind moving snow on a highway or pavement where the main wind direction remains constant but individual gusts are highly variable in direction.

Sandstone beds in the conglomerate facies display parting lineation that is not as variable in mean orientation as that present in the coarse silt and sand facies (Fig. 14). This suggests that the parting lineation developed in coarser units is confined to discrete channels, whereas that produced in finer facies is formed in broad and poorly defined channels or flood plains, perhaps during sheetwash deposition.

Ripple drift cross-lamination.---The term "ripple drift" was originally defined as "all structures that are the effect of the action of ripples on drifted material" (Sorby, 1859, p. 143). Sorby, (1908), subsequently recognized that there may be more than one type of ripple drift depending on the depositional environment. Walker (1963, Table 11, p. 180) defined three distinct types of ripple drift cross-lamination and inferred the conditions under which each type forms. The structure is confined to fine sand or silt beds, and forms by the succession (climbing) of a ripple onto the stoss slope of the ripples immediately downstream. There is a net accumulation of sediment during its formation (Walker, 1963, p. 178).

Figure 14.---Rose diagrams comparing azimuthal relationships of parting lineation and crossbedding in flood plain and alluvial fan (midfan subenvironment) sediments. L values are a measure of the standard deviation (higher values indicate less dispersion). Inner circle represents crossbedding and outer circle represents parting lineation.



O
30
floodplain
L value: parting lineation 17.6 %
cross-bedding 70.0 %
O
30
midfan
L value: parting lineation 60.0 %
cross-bedding 94.7 %
inner circle- cross-bedding
outside circle-parting lineation
0 2 4 6 8
no.of readings

Figure 14

Although ripple drift cross-laminations are rare in the study area, they are thought to be quite diagnostic of environmental conditions. They usually form because of rapid decreases in current velocity under lower flow regime conditions (Walker, 1963; McKee, 1965). They occur in abundance in alluvial channels, on flood plains and on deltaic plains (Coleman and Gagliano, 1965, Table 1, p. 147). From these discussions it appears that ripple drift cross-lamination in the Triassic rocks of the study area was formed in braiding or meandering channels subject to periodic flooding. The scarcity of these structures limits their usefulness as directional indicators.

Antidunes.--Antidune refers to a form of ripple that travels upstream due to erosion of sand from the lee slopes and deposition on the stoss slopes (Gilbert, 1914, p. 31). Kennedy (1961) concluded that antidunes are a bed feature in phase with surface waves whether they move upstream, downstream, or remain stationary. The preceding definitions are based on flume studies and according to Gilbert (1914, p. 241), "it seems unlikely that these features could be preserved" in the rock record. However, Power (1961) demonstrated the presence of antidune (or backset beds) in the Pleistocene Coso Formation in California. The Coso is an alluvial fan deposit. More recently, Wessel and others, (1967, p. 159-161) postulated that antidunes are preserved in the Mount Toby Conglomerate. On the basis of these structures, Hand and others, (1968) reconstructed the angle of the paleoslope (5^{o} to 7^{o}) and suggested that sheetwash was the depositing agent. This discovery of backset bedding has prompted more detailed study of the sedimentary structures of the Mount Toby Conglomerate and the Turners Falls Sandstone and several other exposures of backset beds have been found (Fig. 15). It appears that the presence

Figure 15. -- Backset bedding (arrow) formed by migrating antidunes. Paleoslope and main flow direction is from right to left.

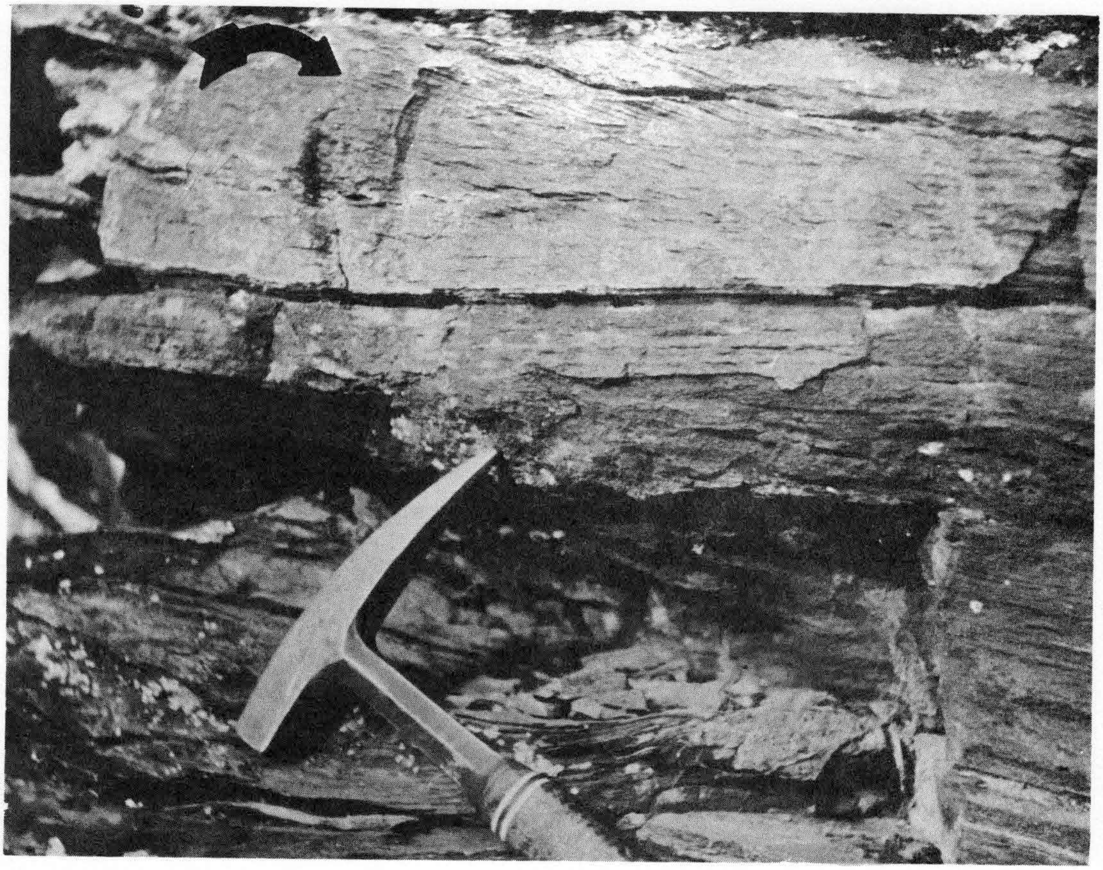


Figure 15

of backset bedding in many exposures is related to a definite sedimentary cycle represented by three distinct units: (1) a sand or silt unit containing plane beds displaying parting lineation and, in places, linguoid ripples at the base; (2) a backset-bedded unit; and (3) an overlying conglomerate unit (Fig. 16). The entire sequence is presumably deposited under upper flow regime conditions with the finer units being deposited during early stages of sheetwash flooding. Two possible mechanisms of preservation are proposed: (1) meandering or braiding channels subject to rapid migration in which flow can be suddenly terminated; (2) very rapid burial. The latter case is supported by the fact that large volumes of sediment are moved during sheetflooding (Blissenbach, 1954; Blackwelder, 1929; McGee, 1897) and that backset beds in the present study are commonly overlain by conglomerate.

Micro cross-lamination.---The absence of any directional structures is a conspicuous feature of large sections of the mudrock facies. Sawed slabs of fourteen oriented mudrock specimens were inspected in the laboratory for cross-lamination in order to determine current trends. Only two of these slabs and one thin section displayed cross-lamination. Thus, the usefulness of the structure as a directional indicator is greatly limited because of the difficult mode of study and the apparent sparse occurrence. Cross-lamination, where it does occur, probably reflects low velocity currents on a flood plain or in a nearshore lacustrine environment.

Other directional structures.--- Less widespread sedimentary structures used for reconstructing paleocurrents include oriented plant debris, groove coasts, and sand shadows. Sand shadows are cone-shaped structures with the cone tip consisting of pebbles that grade into finer particles in the

Figure 16. -- Hypothetical upper flow regime sequence based on field evidence. Note that backset beds appear to be preserved by rapid burial under coarser debris.

TRIPARTITE DIVISION
of
UPPER FLOW REGIME
DEPOSITS

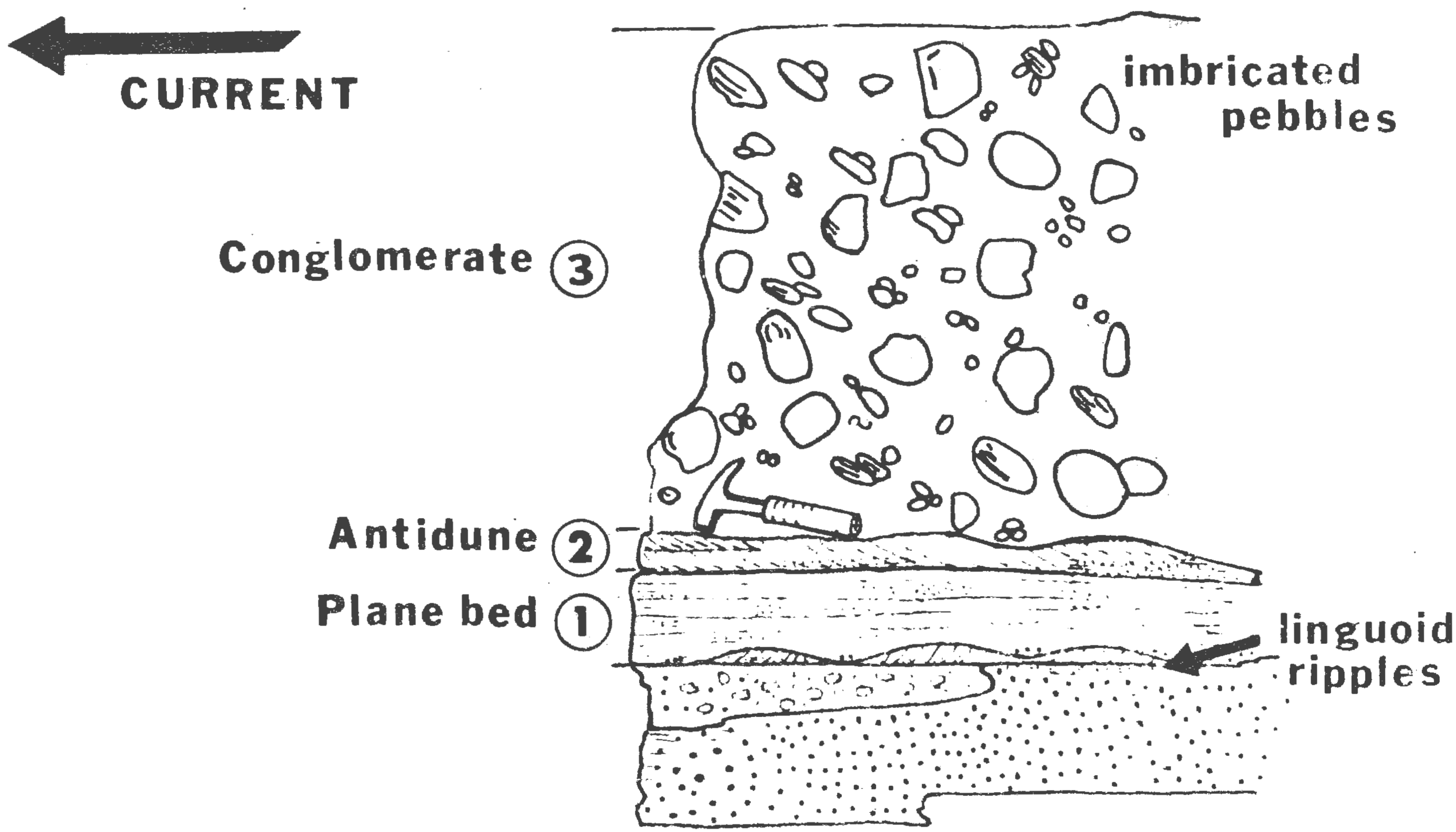


Figure 16

cone proper. The coarser tip of the cone points upstream. Potter and Pettijohn (1963, p. 295, Plates 15A and 15B) call similar features current crescents.

Dispersal Trends

Method.---The frequency of tilt-corrected one-way directional structures was plotted on rose diagrams and grouped into 30° classes. The mean direction was determined by analysis of the vector mean (Pettijohn and others, 1965, 1965, p. 145, Table 12-13). After calculating the mean direction of one-way structures, the two-way directional structures (parting lineation, tool marks, and oriented plant debris) were assumed to represent the trends of the one-way structures and were regrouped into the rose diagrams used for the directional mean of the one-way structures. A new mean was calculated and the data were used to construct a paleocurrent map (Fig. 17).

Interpretation.---The broad pattern of sediment dispersal was from east to west (Fig. 17). However, the dominant northwest trend of paleocurrents in the southern part of the basin and the southwestern trend in the northern part of the basin indicate that deposition occurred on a gently downwarped surface, with the greatest amount of downwarping occurring in the central portion of the basin. Thus, Late Triassic sedimentation in this part of the Connecticut Valley took place in an interiorly drained basin, or bolson.

Non-Directional Structures

The Turners Falls Sandstone and the Mount Toby Conglomerate contain abundant structures that lack directional significance. However, these structures are indicators of environmental conditions in the basin at the time of, or shortly after, deposition. These features include

Figure 17. -- Paleocurrent trends in the sandstone facies of the Turners Falls Sandstone and the Mount Toby Conglomerate. Based on 320 crossbedding, 300 parting lineation, and 45 ripple mark readings. Arrows represent mean paleocurrent direction at 38 stations.

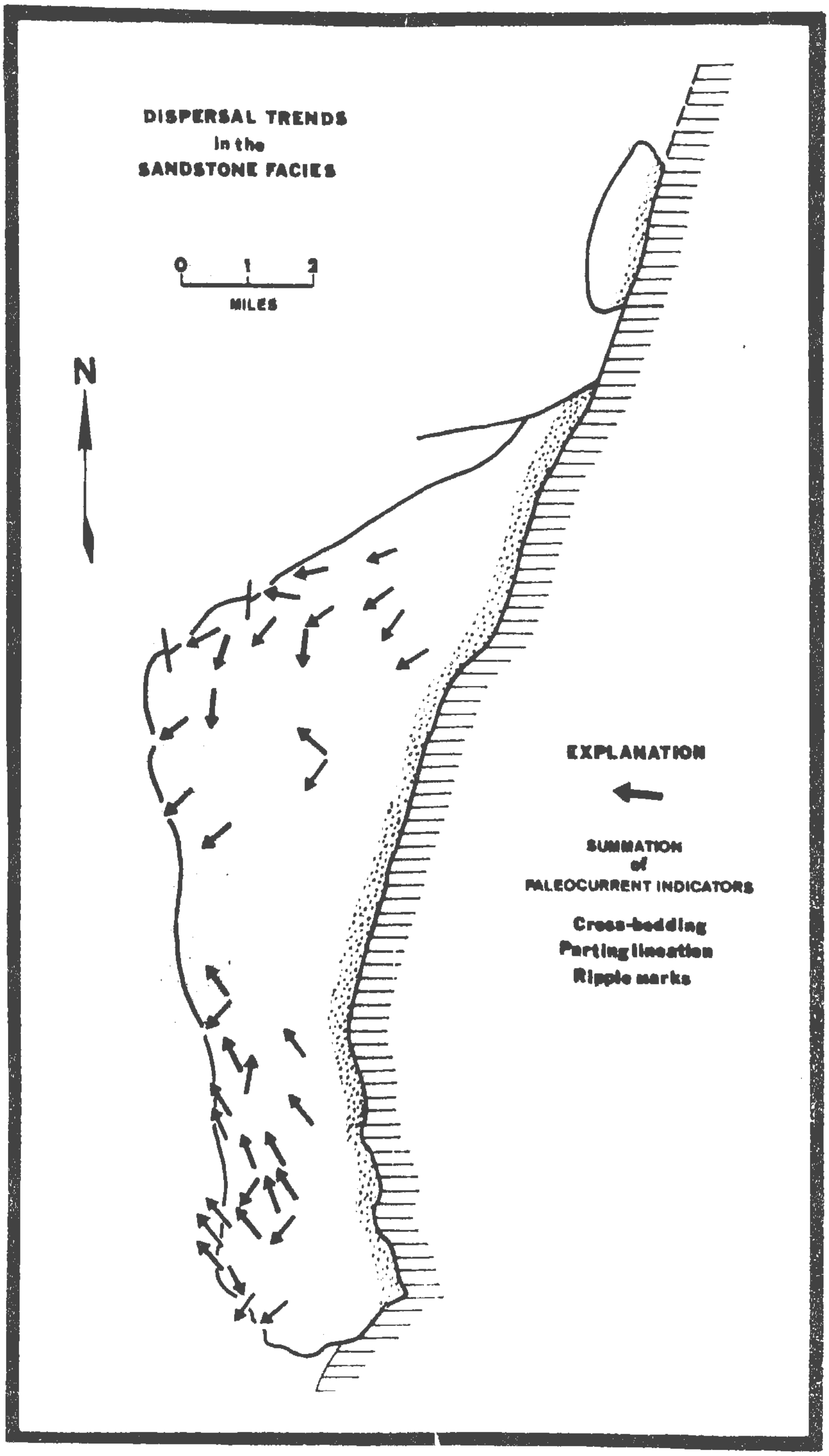

DISPERSAL TRENDS
in the
SANDSTONE FACIES
0 1 2
MILES
N
EXPLANATION
SUMMATION
of
PALEOCURRENT INDICATORS
Cross-bedding
Parting lineation
Ripple marks

Figure 17

deformational structures, mudcracks, horizontal laminations, scour and fill, and lebensspuren.

Deformational features.---

1. Slump structures--Slump structures are common in several horizons in the Turners Falls Sandstone and the Mount Toby Conglomerate. Slumping is usually restricted to sands or coarser facies. It is characterized by a slight downward sagging or bowing of coarse sandstone beds eight inches to four feet thick and one foot to ten feet in length. The down-warping or sagging seldom exceeds eight inches. This type of slumping has been observed by the author in many glacial outwash deposits in the Connecticut Valley, and it appears to represent a response to rapidly accumulating overburden. The fluid content of the sediment during this type of slumping is probably low.

2. Load casts--Load casts are developed at several locations. They are primarily confined to the interface between conglomerate and sandstone (Fig. 18) but they are locally present in the mudrock facies (Fig. 19). The formation of these structures could result from rapid, unequal loading on a water-saturated plastic layer. Deposition of a few feet of sand or gravel on a mud may account for their formation.

3. Ball and pillow--Ball and pillow structures (pseudonodules) occur in medium to coarse sandstone beds as kidney or pillow-shaped balls approximately nine inches thick and eighteen inches wide (Fig. 20). The mechanics of formation of the structure is not completely known. However, Potter and Pettijohn (1963, p. 162) suggest their formation is related to a sudden foundering of a sand or sand and mud bed by thixotropic transformation produced by a shock.

4. Convolute lamination--Ten Haaf (1956, p. 19) described convolute lamination (bedding) as sets of wavy or contorted laminae whose deformation

Figure 18. -- Load casts developed in a sandstone unit of the Turners Falls Sandstone north of Sunderland.

Figure 19. -- Load casts developed in mudrock of the Turners Falls Sandstone east of Turners Falls along the Connecticut River.

Figure 20. -- Ball-and-pillow structure in a sandstone bed in the Turners Falls Sandstone north of Sunderland. Note the lack of deformation in underlying and overlying units.

Figure 21. -- Convolute lamination in sandstone layers of the Turners Falls Sandstone north of Sunderland. Main current direction and paleoslope is right to left.

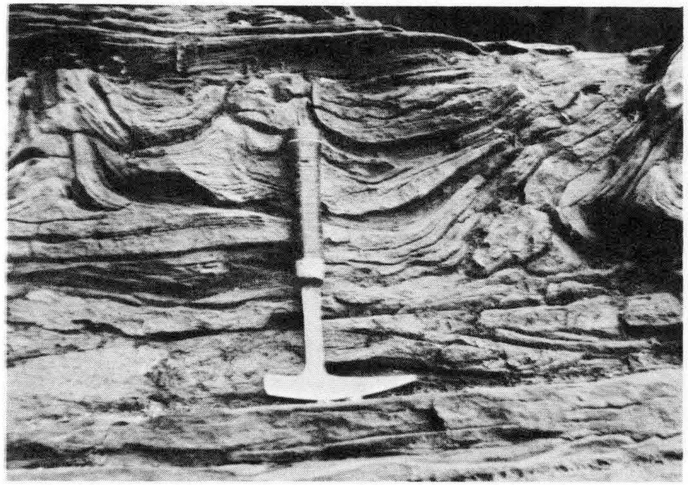


Figure 18

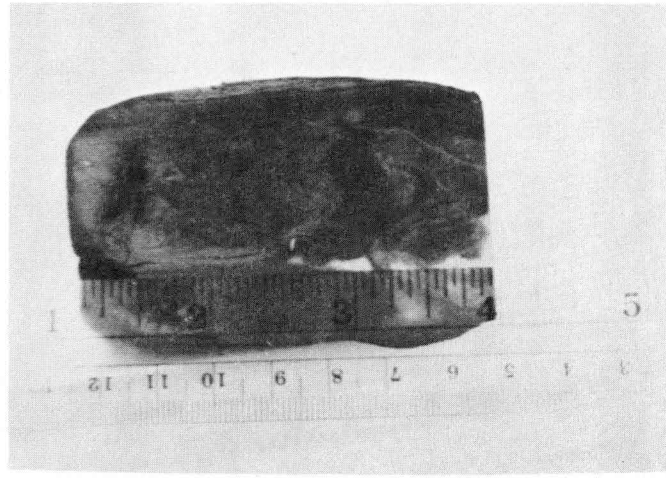


Figure 19

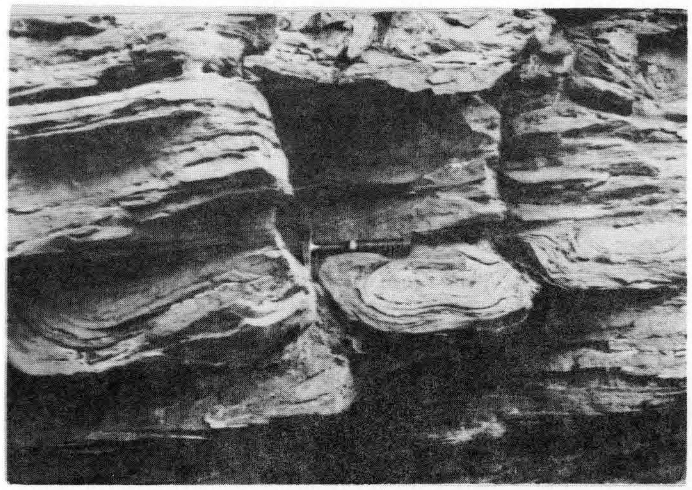


Figure 20

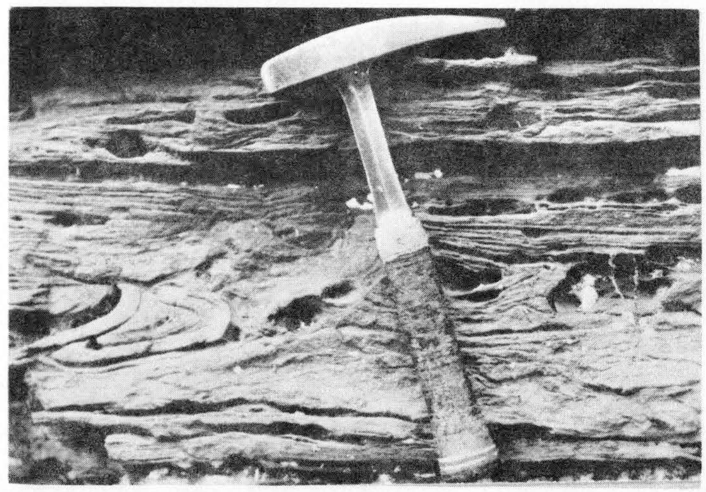


Figure 21

characteristically dies out upward and downward within a given bed (see Fig. 21). This structure is not common in any of the rocks in the area of investigation.

The formation of this structure has been attributed to the action of both slumping and current action. Sanders (1960, p. 409) states that they represent a decollement type of adjustment to increasing velocity. Frazier and Osanik (1961, p. 132) found that convolute laminations associated with recent point bar deposits may develop sub-parallel to the current direction. McKee and others, (1967, p. 840) suggested that convolute structures are developed during late stages of flooding when current velocities have slowed down and sediment is in a quicksand condition. The association of the structure with climbing ripples in modern flood plains suggests that it may be formed during periods of declining stream velocities.

Non-deformational structures.---

1. Mudcracks and raindrop impressions--Both of these structures are present in the mudrock facies. Mudcracks may form in a variety of environments, including flood plains, point bars, lagoons, and playa lakes. In the study area mud-cracked layers commonly alternate with fine sand layers, and the sand often contains fragments of the underlying mud, indicating that the mud-cracked surface was susceptible to erosion as the next sediment layer washed over it. This suggests that the muds were subjected to extended periods of drying.

Raindrop impressions are abundant in many of the mudrocks. Twenhofel (1950, p. 490) noted that these features do not form in very fluid mud and that their preservation requires rapid drying and hardening.

2. Scour-and-fill--Scour-and-fill is shown in figure 22. This type of structure is very abundant in the Turner Falls Sandstone and the Mount

Figure 22. -- Scour-and-fill structure developed in a fine conglomerate-pebbly sandstone on the west side of the Mount Toby highland in the Mount Toby Conglomerate.

Figure 22

Toby Conglomerate. It occurs in all facies, but it is best developed in coarse sandstone and fine conglomerate. The formation of this structure is attributed to sudden increases in volume and velocity of an aggrading stream. The stream erodes new channels in the sediment beneath, and when the velocity is decreased, these new channels are filled. Flood periods can account for these sudden changes of stream regimen and, in drier climates, where much of the drainage is intermittent, the temporary passage of water though arroyos is an ideal environment for development of scour-and-fill.

Blissenbach (1954, p. 186) showed that "channel and fill" is a very important process in alluvial fan environments. He also demonstrated that the most common type of "cross-stratification" on alluvial fans is due to the filling of scour channels cut into the underlying deposits.

3. Plane beds--Plane bed structures in sandstones were discussed above with respect to the occurence of parting lineation. Plane beds are probably the most abundant structure in the sandy units, although no quantitative summary was made. Plane beds form in the lower stage of the upper flow regime (Harms and Fahnestock, 1965), and in the study area were probably formed by high velocity currents in very shallow water during periods of sheetflow.

4. Parallel laminations--Parallel laminations are ubiquitous features in the mudrocks (Fig. 23). They are persistent over large areas and are formed by alternations of sand and mud and of dark and light mud layers caused by differences in organic constituents (Fig. 24). They vary from 1.0 mm to 2.0 mm in thickness and seldom display cross-lamination. Pettijohn (1957, p. 163) indicates that such laminations are the result of variations in the rate of supply or of deposition of the different materials. Rubey (1930, pp. 40-41) attributed the variations to changes in the quantity

of silt, clay, and organic material and to changes in the rate of accumulation of these materials as the result of pulsating currents. The changes may be cyclic "with intervals of a day, a season, or some longer period." Aperiodic storms in the distant source area could account for alternation of particle sizes, inasmuch as grain-size variations related to stream capacity are ultimately reflected in the mud facies. The well-preserved laminations probably indicate deposition in a lacustrine environment of various Eh and pH potentials (Rubey, 1930, p. 44). The laminations are flaky and this texture is interpreted as due to rapid drying of the sediment (Fig. 24).

5. Concretions--Many black laminated mud-rock beds contain concretions (Fig. 25). The concretions are of the clay-ironstone type and the vary in size from one to three inches long and one to two inches wide.

6. Lebensspuren--There is abundant evidence of animal and plant life during the late Triassic of the Connecticut Valley. Both the Turners Falls Sandstone and the Mount Toby Conglomerate contain plant and fish fossils, dinosaur tracks, and burrows. Hitchcock (1858), Newberry (1898), and Lull (1915, 1953) give excellent accounts of the flora and fauna of the Triassic in Connecticut and Massachusetts.

North of Sunderland along the east bank of the Connecticut River, a sequence of black shales containing fish remains is exposed. Two genera and four species were identified in these shales (Lull, 1953), but the fossil remains do not give any conclusive evidence as to the chemical composition of the water in which the fish lived. However, other fossils at the same locality, including mollusks, plants, and an aquatic insect larvae, indicate that it was a non-marine environment.

Hitchcock (1858) and Lull (1915, 1953) carried out extensive investigations of the fossil tracks and footprints preserved in the Triassic of

Figure 23.--Parallel laminations in the mudrock facies of the Turners Falls Sandstone south of Turners Falls. Laminations reflect differences in organic content of the mud layers.

Figure 24.--Laminations developed in the "flaky shale" of the Turners Falls Sandstone at Turners Falls. The flaky nature of the rock probably reflects a thorough and repeated drying of the unit before lithification. Looking parallel to strike.

Figure 25.--Concretions in the mudrock facies of the Turners Falls Sandstone near Turners Falls.

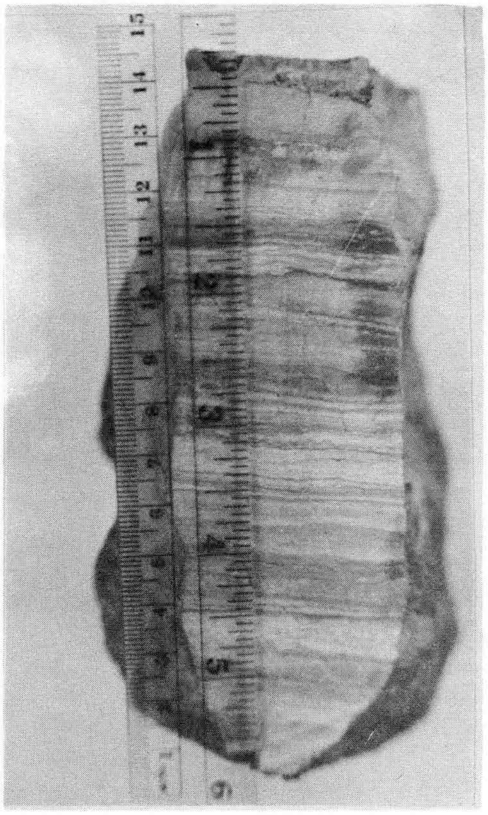


Figure 23

Figure 24

Figure 25

the Connecticut Valley. In the study area, they described two orders, two sub-orders, four families, seven genera, and seven species of dinosaurs.

Burrows are abundant in many of the mudrocks. They are characterized by elliptical outlines in which coarser and darker material is concentrated in the burrow (Fig. 26). Two burrow types can be distinguished on the basis of size. The first type consists of small elliptical pods averaging 1.0 cm long and 0.5 cm wide, and the second type is rod-shaped with an average length of 6.0 cm and width of 1.0 cm. No skeletal remains were found in any of the burrows, and no descriptions are available in the literature concerning the type of organism that produced the structure. The internal structure of many beds has been destroyed by burrowing activity.

DIRECTIONAL ANALYSIS OF THE CONGLOMERATE

Introduction

Those properties that indicate either a line of movement or direction of movement and are specified by azimuth are called "directionals" (Potter and Pettijohn, 1963, p. 4). Unfortunately, directionals such as parting lineation, crossbedding, and ripple marks are generally confined to mud, sand, and fine conglomerate facies. Conglomerate makes up over forty-five percent of the Turners Falls Sandstone and Mount Toby Conglomerate and most of this conglomerate is devoid of directionals. Therefore, the interpretation of dispersal patterns of the conglomerate is based on particle size, gravel fabric (including imbrication), and roundness.

Gravel Fabric

Potter and Pettijohn (1963, p. 23) define fabric as the "spatial arrangement and orientation of fabric elements". A fabric element may be

Figure 26. -- Burrow structures in the Turners Falls Sandstone near Turners Falls.

Figure 26

a "single crystal, a detrital fragment, a fossil, or any component that behaves as a single unit with respect to the applied force" (Potter and Pettijohn, 1963, p. 23). The basic fabric element of sedimentary particles is the long axis or A axis. In most cases the long axes lie either parallel to or perpendicular to the transport direction.

Several studies of Holocene sediments show that shape may be important in determining the final resting position of the long axis. Schlee (1957, p. 163) pointed out that particles approaching spherical shapes may come to rest with their long axis in any direction, hence only disc-or rod-shaped pebbles should be used in directional investigations of gravels. Lane and Carlson (1954) showed that elongated pebbles commonly are arranged with their long axis perpendicular to flow direction. Most studies concerned primarily with gravel fabric have been limited to glacial and fluvial deposits. Rapp (1959, 1960), the only worker to study the fabric of talus and avalanche boulder tongues, found that the A axis of oblong boulders is parallel to the direction of slope in talus and in avalanche tongues. The gravel fabric associated with streamflood and sheetflood conditions, the environments of most interest in this study, is unknown. Thus, it appears, on the basis of these few studies, that the long axis is a significant indicator of slope and transport direction.

Method of Measurement

The apparent long axes of approximately 10,000 clasts, at over 200 localities, were measured for azimuthal orientation. The sampling procedure was determined by the availability of outcrop, the size and type of rock exposure, and size of clasts. Outcrops of conglomerate composed of particles less than 30 mm in diameter were not used because the long axis is too difficult to define. Larger clasts were measured because they do not reflect bottom irregularities and current flucuations as much as finer constituents do. Those clasts with an apparent ratio of long axes of less than 1:1.3 were not used.

To avoid bias, a string was placed across the outcrop and orientations of the trend of apparent long axis of the larger unequant clasts were measured with a Brunton compass. The azimuths of 50 long axes were recorded as they were encountered along the string traverse line and two or more traverses were commonly necessary. Sample areas studied are about 12 square yards. Because shape is a difficult property to determine in outcrop; it was omitted.

Trends of long axes of oriented pebbles show a line of movement or a two-dimensional orientation. All measurements are therefore made in a range of 180°, and if a histogram of 360° is desired, the azimuth of each grain is plotted twice. A resultant vector calculated by this system would be zero. To remedy this, Krumbein (1939, p. 686-693) doubled the angles of th observation vectors before computing the north-south and east-west components of the vectors. His procedure is outlined below:

N-S component = $n \cos 2\theta$
E-W component = $n \sin 2\theta$

$$\tan 2\theta = \frac{\Sigma\, n \sin 2\theta}{\Sigma\, n \cos 2\theta} \qquad \overline{\theta} = 1/2 \arctan \frac{\Sigma\, n \sin 2\theta}{\Sigma\, n \cos 2\theta}$$

where:

θ = azimuth from 0° to 360° of each group observations (usually the mid-point of each class is used) and in this study 20° classes were used (fig. 28).

$\overline{\theta}$ = azimuth of resultant vector.

n = number of observations in each group.

Curray (1956, pp. 118-127) pointed out that the above calculations fail to compute the magnitude of the resultant vector, which is a measure of standard deviation. Thus he introduced two additional steps to measure the standard deviation.

$$r = \sqrt{(\Sigma\ n\ \sin\ 2\theta)^2 + (\Sigma\ n\ \cos\ 2\theta)^2}$$

$$L = \frac{r}{n}\ 100$$

where:

r = magnitude of resultant vector.

L = magnitude of resultant vector in terms of percent.

These calculations were performed on grouped data from this study using a desk calculator. Curray (1956, p. 126) developed a table to test the statistical significance of the results against a model of randomness. The table is a modification of the Rayleigh test of significance using the L value and n (number of observations). The calculated vector means obtained were all tested by this method in the study and were found, with but two exceptions, to fall within 0.05 or less level of significance as prescribed by Curray (1956, p. 125).

The L value is well-suited for graphical presentation, inasmuch as magnitude of the number decreases with increasing dispersion of the grouped data. The average L value of the conglomerate is about 35 percent.

Analysis

There is generally good agreement between gravel fabric vectors in the conglomerate facies and directional vectors in the sandstone facies (Figs. 17 and 27). The dispersal trends as indicated by the gravel fabric vectors suggest that deposition took place in an interiorally drained basin or bolson. In the vicinity of Northfield the conglomerate fabric vectors suggest that the source area lay to the north and northwest (Fig. 27).

Figure 28 illustrates six of the current rose diagrams constructed from fabric analyses. All pebble shapes were used in these diagrams. Bluck (1965, p. 228, fig. 4) shows the same type of diagrams for fabric

Figure 27. --Gravel fabric diagram showing mean orientation of A axes at over 200 stations. L value determines the length of the vector mean line.

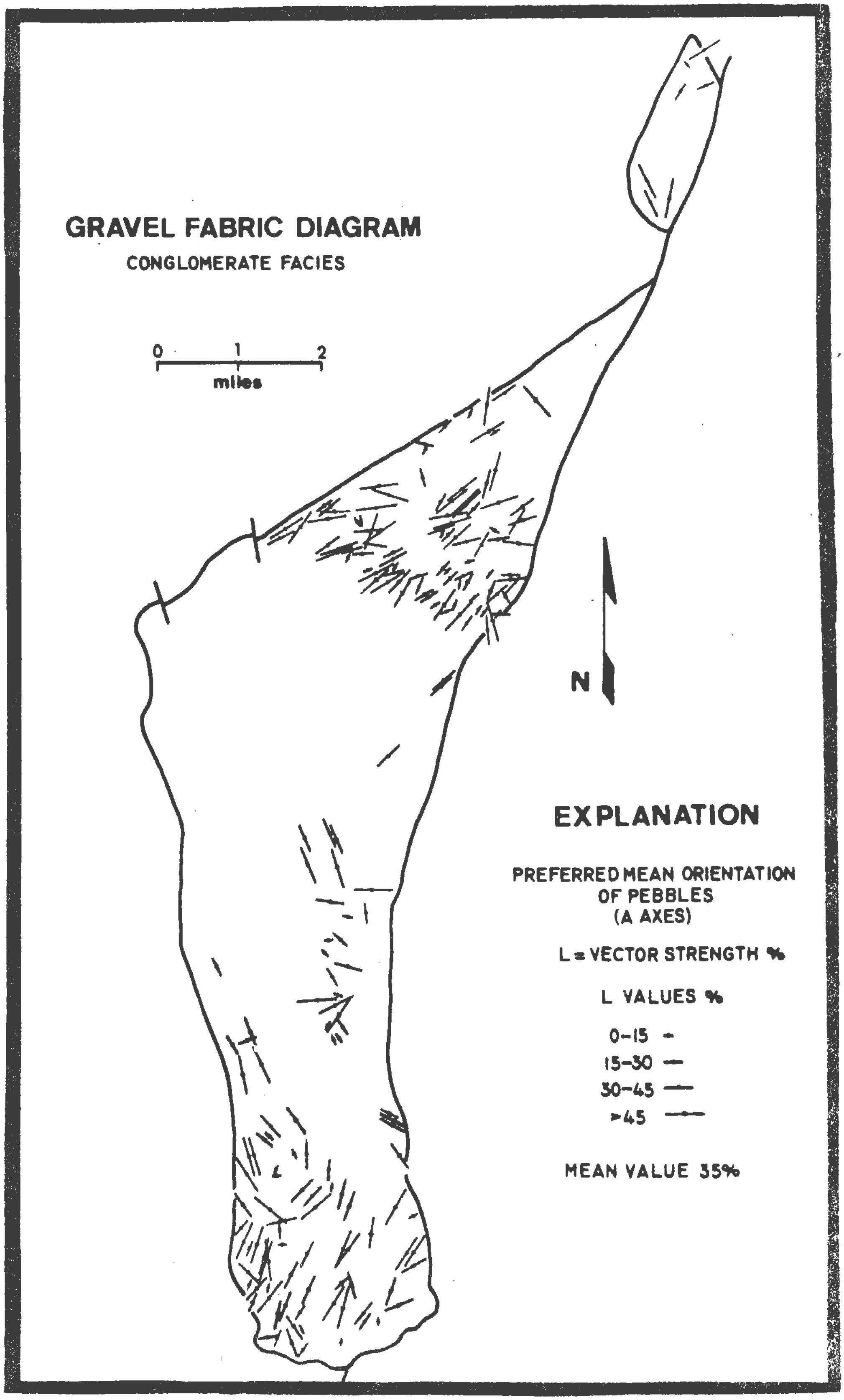
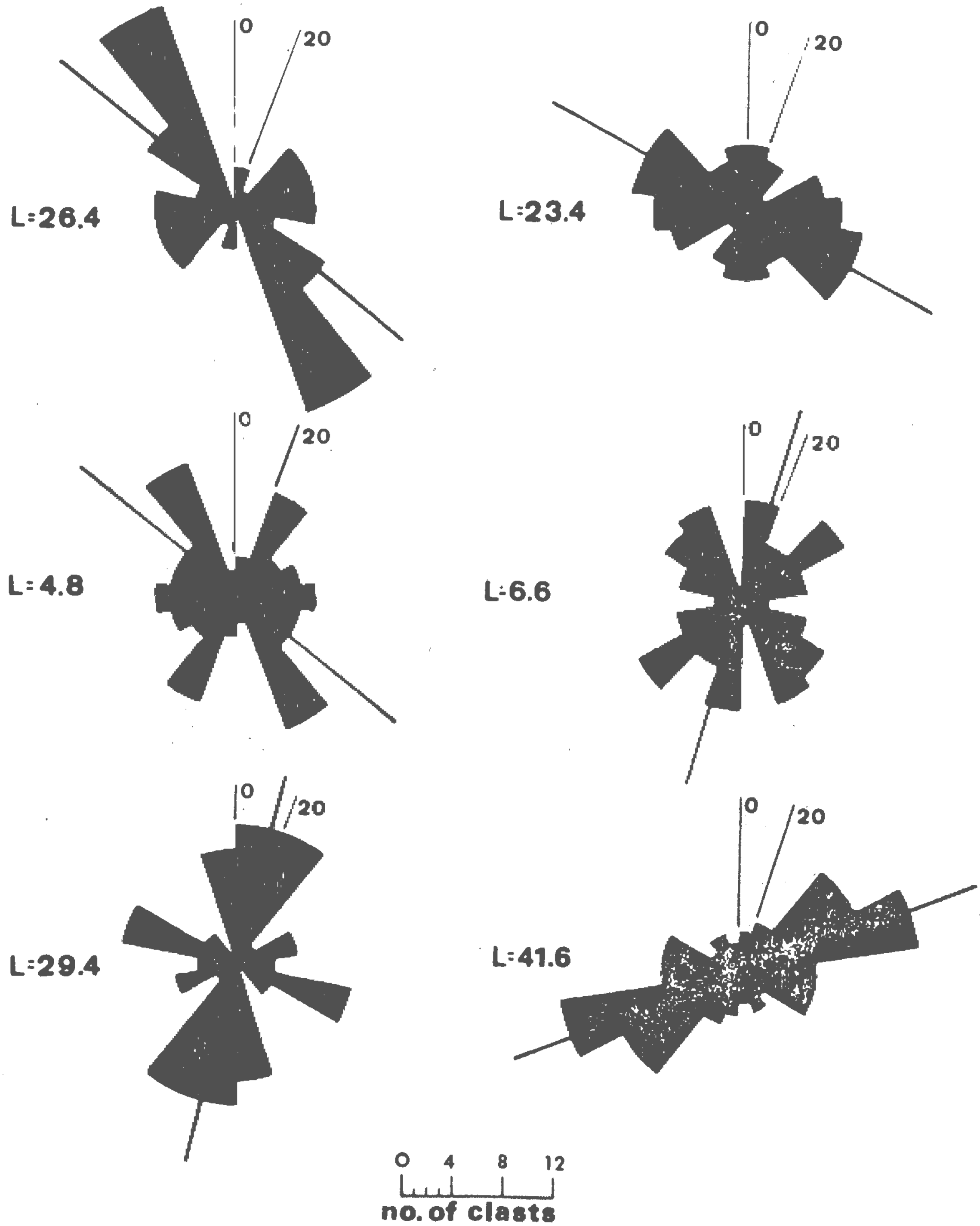

GRAVEL FABRIC DIAGRAM
CONGLOMERATE FACIES
0 1 2
miles
N
EXPLANATION
PREFERRED MEAN ORIENTATION
OF PEBBLES
(A AXES)
L = VECTOR STRENGTH %
L VALUES %
0–15
15–30
30–45
>45
MEAN VALUE 35%

Figure 27

Figure 28.--Representative rose diagrams of gravel fabric. The roses were constructed using 50 A-axes of conglomerate. The vector mean is shown by the heavy dark line.



0
20
L=26.4
0
20
L=23.4
0
20
L=4.8
0
20
L=6.6
0
20
L=29.4
0
20
L=41.6
0 4 8 12
no. of clasts

Figure 28

roses of Triassic conglomerates in South Wales but Bluck measured orientations only of those pebbles he considered to be discs or rods. The similarity of current roses in this study, in which all shapes were used, to those presented by Bluck, suggests that shape need not be considered in determining the relation of the orientation of the A-axis to the directed force.

Imbrication is another property useful for directional analysis of conglomerate units. The maximum projection plane of most pebble shapes dips up-current (Schlee, 1957, p. 171). Where exposure permitted, the direction of dip of 25 flat or platy clasts was measured at thirty-eight stations. It was found that large percentages of the clasts dip toward the eastern edge of the basin. The average angle of dip of 16°. Blissenbach (1954, p. 189) found pronounced imbrication in stream and streamflood deposits associated with alluvial fans. Results of this study appear to show a similar pattern, as the conglomerate at the distal, more fluvial, portions of the fans displays a higher percentage of imbrication (Fig. 29).

Particle Size

The downcurrent decline in grain size is a well-established fact in some environments. Blissenbach (1954, p. 182) found that coarser gravels predominate near the fan apex, with intermediate sizes occurring in the central portion of the fan and silts and clays at the base. Bluck (1964, p. 397) described the same relationship on an alluvial fan in southern Nevada.

In the conglomerate facies of the study area, the long axis of the ten largest clasts was measured at over 220 stations to determine if there

Figure 29. -- Imbrication relationships across the basin. Based on measurement of direction of dip of apparent maximum projection plane (on east-west vertical face) of 25 of the largest clasts at 37 stations. Percentages refer to percent of the total of the 25 largest clasts, regardless of attitude. Note that the percentages increase in a westerly direction. This probably reflects more stream deposition in western parts of the basin.

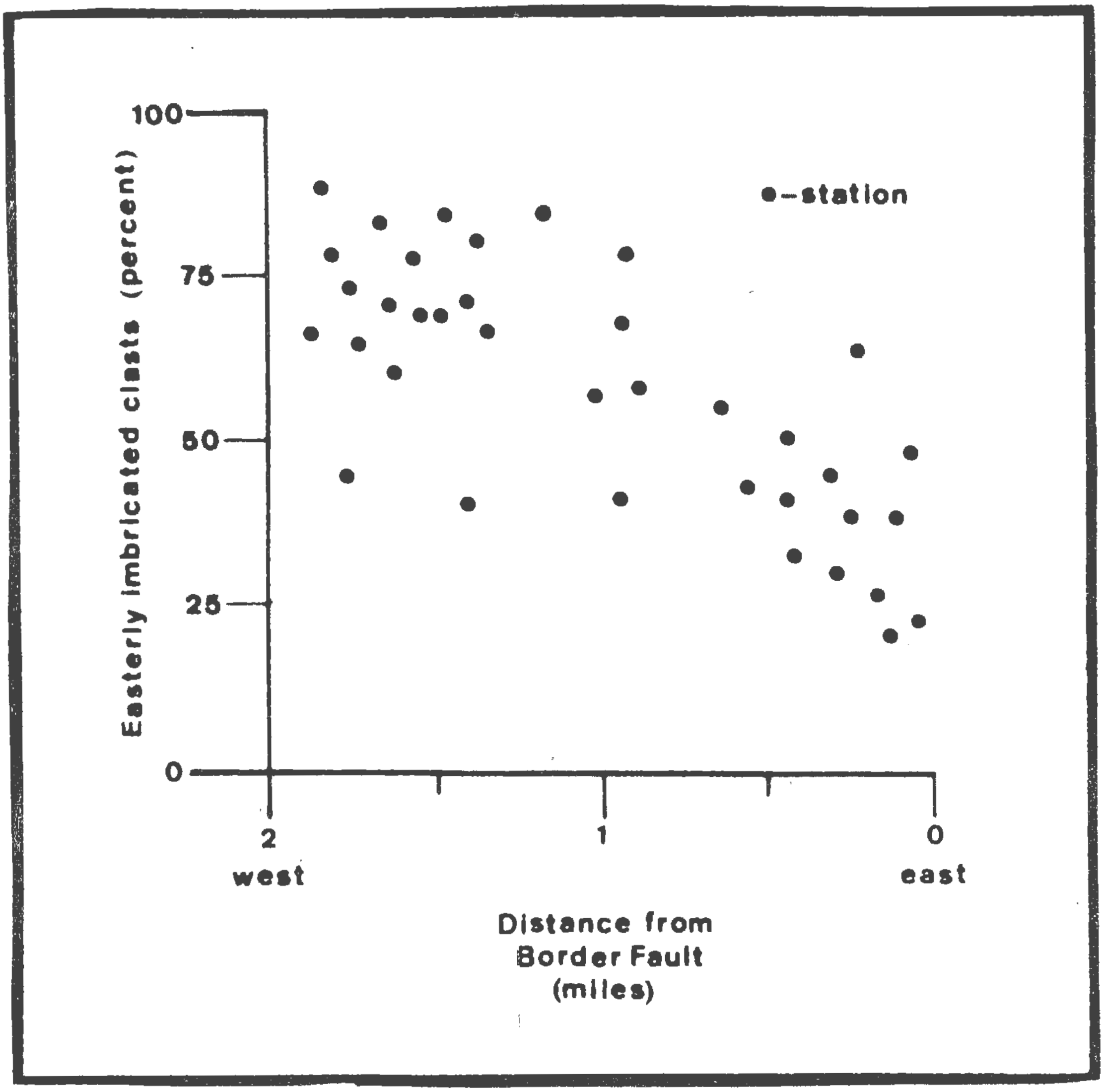

100
75
50
25
0
Easterly imbricated clasts (percent)
●–station
2
west
1
0
east
Distance from
Border Fault
(miles)

Figure 29

was a decrease in particle size away from the eastern escarpment. The ten largest pebbles were averaged in order to reduce the chances of an extraordinarily large pebble giving an excessive value. The data were plotted using a moving average on a one-quarter-mile grid. The technique used is modeled after the method suggested by Pelletier (1958, Fig. 2). The resulting averages are contoured at 100 mm intervals (Fig. 30). The decrease in grain size from east to west clearly indicates an eastern source for the sediments.

The distribution of clast size shows that three main fan complexes can be distinguished along the eastern escarpment. A large fan complex is present at the Mount Toby highland. Another fan complex is developed in the northern part of the basin. In the Northfield area, the coarsest fragments occur west and northwest of the Border Fault, suggesting that the source for this material lay to the north.

Roundness

The significance of roundness in a paleocurrent study is uncertain. However, Blissenbach (1954, p. 184) found that roundness increases away from the fan apex on an alluvial fan in Arizona. Roundness behavior in the conglomerate facies of this study was evaluated by visual comparison of Krumbein's pebble charts (1941, p. 68) to over 10,000 clasts at 200 stations. Mean roundness, or the graphic mean, (Folk, 1965, p. 45) was determined separately for foliated fragments (phyllite and schist) and for granular clast types (granite, vein quartz, and gneissic rocks). There is a slight increase in roundness from east to west across the basin. For all rock types, mean roundness at 35 stations along the eastern escarpment is Mz = .50; at 75 stations in the central part of the basin mean roundness is Mz = .52; and along the western margin at 55 stations mean roundness is Mz = .54. Although there is a slight increase in

Figure 30. -- Moving average diagram of mean size of 10 largest clasts (in mm) occurring in outcrop. A 100 mm contour interval was used. Three major alluvial fan complexes (arrows) can be recognized: (1) Mount Toby Fan Complex; (2) Montague Fan Complex; and (3) Northern Fan Complex.

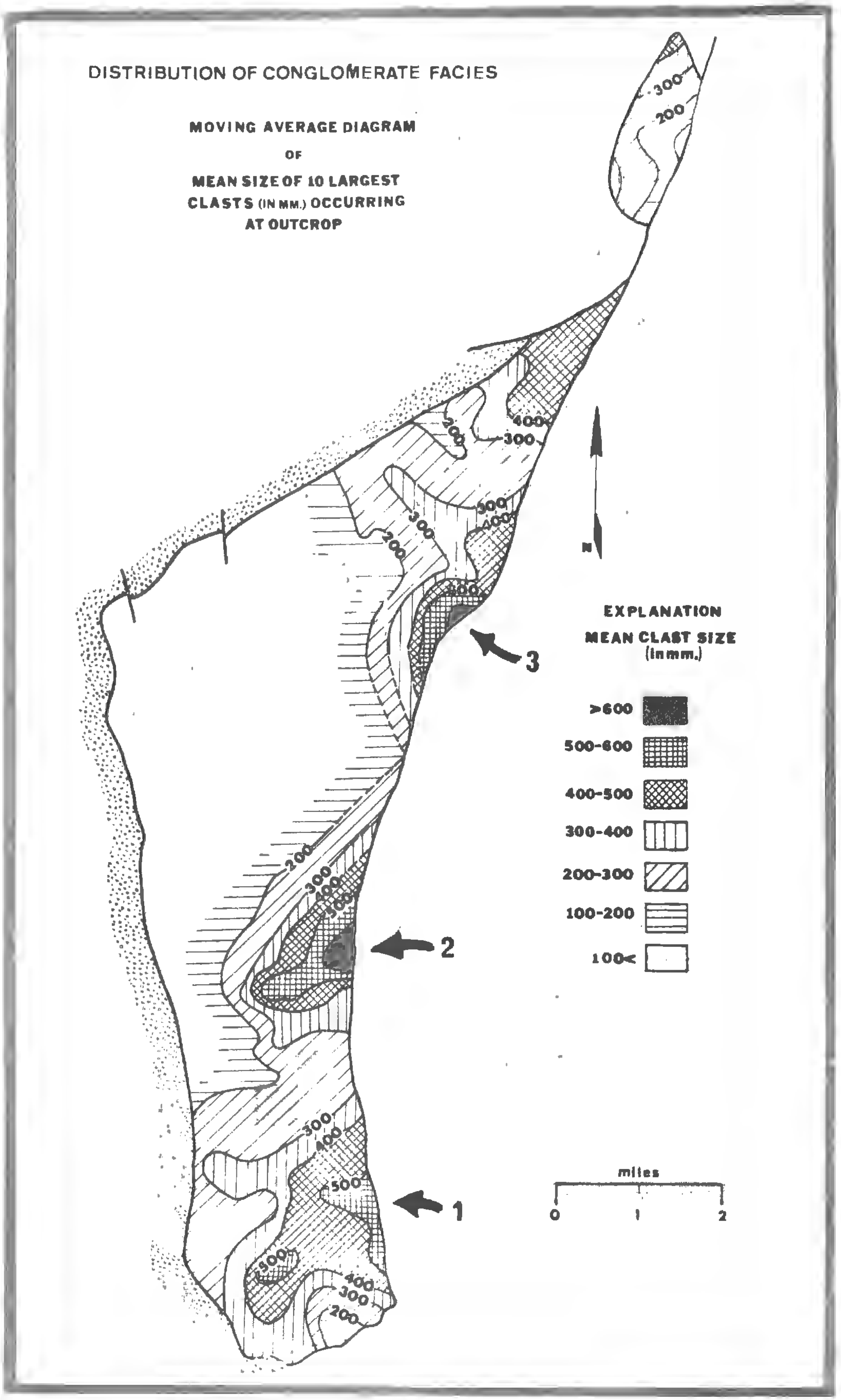

DISTRIBUTION OF CONGLOMERATE FACIES
MOVING AVERAGE DIAGRAM
OF
MEAN SIZE OF 10 LARGEST
CLASTS (IN MM.) OCCURRING
AT OUTCROP
EXPLANATION
MEAN CLAST SIZE
(in mm.)
>600
500-600
400-500
300-400
200-300
100-200
100<
miles
0
1
2
N
1
2
3

Figure 30

roundness across the basin, the small change from east to west indicates that rounding is not an effective process on alluvial fans. This probably reflects the influence of exfoliation on clast rounding as suggested by Lawson (1912, p. 327).

PETROGRAPHY

Variations in mineral composition and texture of the entire rock suite were identified. For discussion purposes, the individual facies are divided into three groups: conglomerate, sandstone, and mudrock.

Conglomerate

Over forty-five percent of the section is conglomerate. This facies is too coarse to sample for detailed laboratory analysis, therefore a thorough field study was undertaken at 154 stations (Table 1). Field data include: determination of clast type, size grouping of clasts, and roundness of clasts. To avoid sampling bias, a string was placed across the outcrop and approximately 125 clasts were counted at each station. If megascopic field classification of a particular fragment was not possible, a portion of it was removed and then classified in the laboratory using a binocular microscope.

A check list (Fig. 31) was constructed to facilitate identification of the rock clasts in the conglomerate. Percentages of different clasts occurring at each station are presented in Table 1. As a means of comparing conglomerate variations within the basin, the clast lithologies were divided into three textural and compositional groups: (1) a felsic group composed of granite, granite gneiss, gneiss, pegmatite, and feldspar; (2) a mafic group composed of meta-diabase and diorite; and (3) a foliated metamorphic group including phyllite, granulite, schist, amphibolite, and metavolcanics. There is little variation in vein quartz throughout the

Figure 31. -- Sample pebble chart. Numbers represent the roundness value (After Krumbein, 1941) of a clast having the specified composition (e.g., a clast of vein quartz with roundness of 0.5 occurring within the indicated size range).

date ....   location....

clast size in mm.

clast comp.	>150	130-150	110-130	90 – 110	70 – 90	50 – 70	30 – 50	<30
vein quartz				.5				
garnet phyllite								
granulitic phyllite								
granite								
bio.& mus. granite								
granite gneiss								
gneiss								
mica schist								
granulite								
meta volcanics								
amphib – olite								
hnbld.dior. & meta diab.								
sil.schist								
quartzite								
pegmatite								
misc.								

Figure 31

conglomerate facies and it has been omitted from the composite analysis.

These groups are plotted on ternary diagrams for the Northern and Southern Provinces as a means of showing the difference in clast lithology between the two regions. A moving average diagram for each province was constructed using a square grid with a grid spacing of ten percent. The number of stations in the grid were counted and then plotted at the center point of the grid on ternary graph paper. These plots were then contoured on a five percent interval (Fig. 32). There is good compositional separation between clasts in the Northern and Southern Provinces. Although the foliated metamorphic rock content is almost identical in the two provinces, the Northern Province contains more mafic rock types than the Southern Province and felsic rock fragments are more abundant in the Southern Province (Figs. 32 a and 32 b). Northfield Province clasts are more dioritic and granitic than clasts in the other two provinces (Table 1).

Mica schist clasts were examined in thin section for minerals indicative of metamorphic grade. This was done to see if sediment dispersal patterns in the alluvial fan complexes showed any relationship to metamorphic isograd boundaries in the pre-Triassic rocks. The pre-Triassic rocks show increasing metamorphic grade from north to south, and the sillimanite isograd occurs east of the Mount Toby highland (P. Robinson, oral communication, 1966). The sample locations and metamorphic mineral compositions of the clast thin sections are shown in Table 2. Sillimanite, which is restricted to the clasts of the southern province, is the only definitive isograd indicator found in any of the clasts. This agrees with the occurrence of the sillimanite zone in the pre-Triassic rocks east of the Southern Province. The correlation of metamorphic

Table 1. -- Composition of the conglomerate facies. No - Northfield Province; N - Northern Province; and S - Southern Province.

TABLE 1

STATION	Province	vein quartz	black & garnet phyllite	granulitic phyllite	granite (undiff.)	biot. & musc. granite	granite gneiss	gneiss (undiff., felsic)	mica schist	siliceous schist	granulite	amphibolite	hornblende diorite & meta-diabase	meta-volcanics (felsic)	quartzite	pegmatite	feldspar
Y11A	N	29.8	12.4	9.3	11.3	-	19.6	5.2	-	3.1	4.1	1.0	-	-	4.1	-	-
Y12A	N	9.4	18.9	9.4	7.1	7.9	5.5	3.9	-	1.6	-	.8	11.0	-	13.4	2.4	-
Y14A	N	18.1	11.4	9.5	8.5	1.9	8.6	2.9	-	2.9	1.0	2.5	11.4	-	8.5	5.7	-
Y14A	N	14.7	10.7	17.6	5.9	5.9	3.9	2.9	-	2.9	-	4.9	7.8	1.9	20.6	-	-
Y14B	N	14.0	22.0	17.0	8.0	4.0	9.0	4.0	-	2.0	2.0	-	12.0	-	6.0	-	-
Y15B	N	17.6	14.7	15.7	6.9	6.9	4.9	-	-	3.9	2.9	4.9	8.8	-	8.8	-	-
Y16A	N	19.0	15.0	13.0	12.0	1.0	7.0	4.0	-	3.0	4.0	1.0	11.0	-	10.0	1.0	-
Y17A	N	15.7	16.8	17.6	5.9	2.9	4.9	6.9	-	3.9	1.0	2.9	7.8	-	12.7	1.0	-
Y17B	N	17.5	16.4	9.3	8.2	7.2	6.2	4.1	-	-	5.1	5.1	9.3	-	11.3	-	-
Y19A	N	19.4	18.0	12.5	5.6	4.2	9.7	5.6	-	5.6	-	4.2	8.3	-	6.9	-	-
Y19B	N	15.7	9.7	11.2	17.2	6.0	7.5	3.7	-	-	2.2	9.0	6.7	-	11.2	-	-
Y19C	N	13.3	18.4	12.3	8.2	5.1	13.3	2.0	-	3.1	-	-	11.2	2.0	3.1	-	-
Y20A	N	6.9	26.9	5.9	8.9	5.9	4.9	3.9	-	6.9	1.9	8.9	10.9	4.9	2.9	-	-
Y20B	N	14.0	19.0	11.0	9.0	6.0	5.0	3.0	-	10.0	2.0	6.0	9.0	-	6.0	-	-

TABLE 1 (Continued)

STATION	Province	vein quartz	black & garnet phyllite	granulitic phyllite	granite (undiff.)	biot. & musc. granite	granite gneiss	gneiss (undiff., felsic)	mica schist	siliceous schist	granulite	amphibolite	hornblende diorite & meta-diabase	meta-volcanics (felsic)	quartzite	pegmatite	feldspar
Y20C	N	11.0	12.0	21.0	-	10.0	8.0	-	1.0	8.0	8.0	9.0	5.0	1.0	3.0	3.0	-
Y20D	N	9.6	19.2	17.3	4.8	6.7	8.6	3.8	-	2.9	-	3.8	8.6	4.8	5.8	3.8	-
Y21A	N	13.0	13.0	9.1	2.6	5.2	7.8	-	3.9	3.9	2.6	6.5	15.6	6.5	5.2	5.2	-
Y21B	N	12.1	4.3	14.6	7.8	-	7.8	6.9	2.6	4.3	5.2	1.7	12.9	3.4	6.0	0.9	-
Y21C	N	14.6	9.7	18.6	5.3	1.8	14.6	6.2	3.5	8.8	.9	7.1	8.8	-	2.6	-	-
Y21D	N	18.0	15.0	14.0	5.0	-	5.0	4.0	-	10.0	Tr.	4.0	15.0	6.0	4.0	-	-
Y22A	N	34.8	25.6	24.8	-	-	-	-	-	1.8	1.8	0.9	2.8	7.3	-	-	-
Y23A	N	19.0	19.0	-	7.1	-	7.1	9.5	-	11.9	-	3.6	10.7	6.0	4.8	-	1.2
Y23B	No	31.8	-	-	12.3	-	12.7	-	-	-	-	-	18.2	4.5	0.8	15.4	-
Y24A	No	5.4	7.1	5.4	22.3	8.0	4.5	15.2	-	-	-	4.5	22.3	5.4	-	-	-
Y26A	No	8.5	11.0	4.3	6.1	1.2	1.8	1.8	20.1	4.3	.6	2.4	10.4	6.7	-	20.7	-
Y26B	No	19.4	1.8	10.2	10.2	-	2.8	1.8	-	-	-	11.1	12.0	6.5	-	24.1	-
Y26C	No	13.4	-	4.5	8.0	-	3.6	7.1	-	9.8	.9	2.7	17.9	10.7	-	21.4	-
Y27A	No	6.3	6.9	3.4	6.3	2.0	5.8	-	2.0	1.5	3.4	8.8	21.0	6.3	1.0	24.4	1.0

TABLE 1 (Continued)

STATION	Province	vein quartz	black & garnet phyllite	granulitic phyllite	granite (undiff.)	biot. & musc. granite	granite gneiss	gneiss (undiff., felsic)	mica schist	siliceous schist	granulite	amphibolite	hornblende diorite & meta-diabase	meta-volcanics (felsic)	quartzite	pegmatite	feldspar
Y27B	No	4.1	7.4	8.3	16.5	-	11.8	-	-	.8	2.5	4.3	16.5	5.8	-	23.1	-
Y27C	No	14.5	12.8	3.4	14.5	1.7	21.3	1.7	-	9.4	-	5.1	6.0	6.8	.8	1.7	-
Y27D	No	12.1	26.6	8.1	4.8	1.6	16.9	3.2	-	6.4	1.6	4.8	7.3	5.6	-	9.8	-
Y28A	N	6.4	25.3	2.5	10.8	-	19.6	6.4	-	5.7	1.3	1.3	15.8	4.4	-	0.6	-
Y28B	N	10.6	24.2	3.8	15.2	0.8	13.6	8.3	-	3.8	3.8	1.5	8.3	6.1	-	-	-
Y28C	N	8.3	37.6	1.5	8.3	2.3	11.3	4.5	-	1.5	3.0	-	15.8	6.0	-	-	-
Y29A	N	14.4	27.3	5.3	1.9	-	13.6	5.3	1.5	2.3	3.8	-	9.8	6.8	-	0.8	-
Y29B	N	22.3	30.4	-	8.9	-	10.7	7.1	-	3.6	-	-	5.4	8.0	1.8	1.8	-
Y29C	N	22.1	18.6	7.1	24.8	-	6.2	1.8	0.9	5.3	1.8	-	2.6	6.2	1.8	0.9	-
Y30A	N	24.8	17.7	6.2	20.1	-	2.6	5.3	0.9	2.6	1.8	1.8	8.8	7.1	-	-	-
Y30B	N	32.4	20.2	4.4	13.2	-	6.1	9.6	0.9	0.9	2.6	-	3.5	3.5	2.6	-	-
Y30C	N	13.6	20.4	17.7	13.6	-	6.8	1.4	-	2.1	3.5	0.7	13.6	5.4	1.4	-	-
Y31A	N	16.0	25.9	17.3	2.5	1.2	3.1	4.3	0.6	9.3	8.0	0.6	3.7	4.9	2.5	-	-
T3A	N	13.9	15.3	23.6	10.4	-	4.2	1.4	-	6.2	3.5	4.2	8.3	6.9	2.1	-	-

TABLE 1 (Continued)

STATION	Province	vein quartz	black & garnet phyllite	granulitic phyllite	granite (undiff.)	biot. & musc. granite	granite gneiss	gneiss (undiff., felsic)	mica schist	siliceous schist	granulite	amphibolite	hornblende diorite & meta-diabase	meta-volcanics (felsic)	quartzite	pegmatite	feldspar
T3A'	N	18.7	15.4	11.0	13.2	-	6.6	2.2	1.1	5.5	4.4	3.3	7.6	6.6	4.4	-	-
T3B	N	19.3	13.3	17.0	8.9	-	2.2	5.2	-	3.0	5.9	1.5	15.6	3.7	-	0.7	-
T4A	N	15.2	18.8	16.7	4.3	-	4.3	1.4	1.4	3.6	8.0	6.0	9.4	4.3	6.0	-	0.7
T5A	N	14.2	17.2	18.6	6.0	-	4.5	3.7	0.7	2.2	3.0	30.0	14.2	7.3	5.2	-	-
T5B	N	18.6	13.4	21.6	6.0	-	4.5	4.5	-	5.2	3.7	2.2	12.7	3.7	3.7	-	-
T6A	N	15.4	18.4	15.4	8.1	0.7	6.6	4.4	-	2.2	1.5	3.7	13.2	6.6	2.9	-	0.7
T6B	N	13.1	20.2	19.6	7.1	1.8	6.0	2.4	0.6	2.4	4.2	2.4	14.3	3.6	2.4	-	-
T6C	N	17.8	19.5	19.5	3.4	-	4.2	1.7	-	6.8	3.4	3.4	12.7	5.1	2.5	-	-
T7A	N	19.5	18.6	23.9	8.0	-	2.6	9.4	0.9	2.6	3.5	1.8	9.4	4.4	3.5	-	-
T8A	N	15.3	26.0	17.6	7.6	-	3.1	3.8	-	3.8	2.3	1.5	8.4	6.9	3.8	-	-
T9A	N	15.1	18.9	15.1	8.5	1.9	8.5	1.9	-	2.8	1.9	2.8	12.3	4.7	4.7	-	-
T11A	N	15.7	20.7	21.5	8.3	-	4.1	6.6	1.6	3.3	2.5	-	12.4	-	3.3	-	-
T11B	N	11.9	24.6	20.3	5.1	1.7	4.2	5.1	-	1.7	3.4	0.8	14.4	5.1	1.7	-	-
T21A	N	15.8	14.3	21.8	7.5	-	3.8	6.8	-	5.3	2.2	-	18.0	2.2	2.2	-	-

TABLE 1 (Continued)

STATION	Province	vein quartz	black & garnet phyllite	granulitic phyllite	granite (undiff.)	biot. & musc. granite	granite gneiss	gneiss (undiff., felsic)	mica schist	siliceous schist	granulite	amphibolite	hornblende diorite & meta-diabase	meta-volcanics (felsic)	quartzite	pegmatite	feldspar
T12B	N	14.8	24.6	9.8	5.7	-	4.1	2.4	-	7.4	5.7	4.1	9.8	4.1	7.4	-	-
T13A	N	14.2	19.6	14.2	6.8	2.0	8.8	4.0	0.7	6.1	4.0	4.0	13.5	4.0	0.7	-	0.7
T13B	N	16.7	17.5	11.7	5.8	0.8	4.2	5.8	1.6	3.3	3.3	4.2	15.8	4.2	5.0	-	-
T14A	N	14.8	22.1	13.9	6.6	-	2.4	6.6	0.8	3.3	3.3	1.6	17.2	1.6	5.7	-	-
T14B	N	16.0	21.8	16.8	5.9	1.7	1.7	4.2	-	3.4	6.7	-	18.5	0.8	2.5	-	-
S10A	N	16.8	21.8	8.4	7.6	2.5	3.4	4.2	-	4.2	4.2	0.8	17.6	4.2	1.7	0.8	-
S11A	N	11.8	25.2	11.8	4.2	-	2.5	5.0	1.7	5.0	3.4	2.5	17.6	5.0	0.8	1.7	1.7
S15A	N	20.3	25.6	11.3	3.8	0.8	0.8	2.2	1.5	4.5	2.2	1.5	15.8	6.8	1.5	1.5	0
S15B	N	14.8	24.2	11.7	7.0	0.8	2.3	4.7	0.8	5.5	2.3	2.3	12.5	7.0	1.6	1.6	0.8
S17A	N	14.0	28.1	14.9	5.0	2.5	2.5	3.3	-	4.1	2.5	1.6	10.7	6.6	2.5	1.6	-
S17B	N	12.2	21.4	13.7	4.6	0.8	3.0	2.3	-	8.4	3.8	2.3	16.0	5.3	4.6	1.5	-
S17C	N	14.9	28.9	12.3	5.3	1.8	4.4	2.6	-	3.5	4.4	0.9	15.8	4.4	0.9	-	-
S18A	N	13.6	22.1	15.0	6.4	2.9	5.0	4.3	1.4	4.3	1.4	2.1	7.9	12.1	-	1.4	-
S18B	N	11.6	24.8	11.6	6.9	1.6	5.4	2.3	1.6	4.6	4.6	1.6	11.6	9.3	2.3	-	-

TABLE 1 (Continued)

STATION	Province	vein quartz	black & garnet phyllite	granulitic phyllite	granite (undiff.)	biot. & musc. granite	granite gneiss	gneiss (undiff., felsic)	mica schist	siliceous schist	granulite	amphibolite	hornblende diorite & meta-diabase	meta-volcanics (felsic)	quartzite	pegmatite	feldspar
S20A	N	16.7	22.0	11.4	6.1	1.5	5.3	1.5	-	1.5	3.8	3.0	14.4	10.6	2.3	-	-
S20B	N	15.1	22.3	11.8	5.8	-	4.3	3.6	2.9	1.4	2.9	2.2	13.7	13.7	0.7	0.7	-
S22A	N	18.6	24.8	9.3	6.2	-	3.1	3.9	-	6.2	1.6	1.6	10.0	12.4	2.3	-	-
S22B	N	19.0	29.8	9.9	4.1	0.8	2.5	2.5	1.6	1.6	3.3	1.6	9.1	9.1	5.0	-	-
S24A	N	12.4	26.4	10.7	7.4	-	5.8	4.1	-	5.8	1.6	1.6	11.6	9.1	3.3	-	-
S24B	N	15.8	22.6	7.5	4.5	0.8	2.2	3.0	-	6.0	3.0	2.2	14.3	15.0	3.8	-	-
S24C	N	16.8	26.0	11.8	-	-	2.5	3.4	-	5.0	3.4	1.7	12.6	14.2	2.5	-	-
S25A	N	13.3	21.9	12.5	7.0	1.6	5.5	3.1	-	1.6	3.1	0.8	12.5	14.8	1.6	-	0.8
S25B	N	5.5	24.6	17.8	6.8	1.4	2.7	2.1	-	4.1	2.7	1.4	16.4	11.0	2.7	0.7	-
S25C	N	9.4	19.7	22.4	7.1	1.6	5.5	2.4	-	1.6	1.6	1.6	18.1	10.2	0.8	-	-
S27A	S	11.7	18.8	10.2	14.8	-	4.7	4.7	2.3	2.3	0.8	8.6	8.6	10.2	1.6	0.8	-
S27B	S	13.2	17.0	13.9	7.8	0.8	6.9	-	2.3	1.6	0.8	9.3	6.9	13.2	3.9	-	-
S29A	S	16.3	26.4	9.3	6.2	0.8	2.3	2.3	-	1.6	1.6	12.4	7.8	9.3	2.3	1.6	-
S29B	S	18.9	20.5	9.4	10.2	-	2.4	3.2	-	1.6	1.6	15.0	3.9	9.4	2.4	1.6	-

TABLE 1 (Continued)

STATION	Province	vein quartz	black & garnet phyllite	granulitic phyllite	granite (undiff.)	biot. & musc. granite	granite gneiss	gneiss (undiff., felsic)	mica schist	siliceous schist	granulite	amphibolite	hornblende diorite & meta-diabase	meta-volcanics (felsic)	quartzite	pegmatite	feldspar
S29C	S	14.8	17.2	8.2	11.5	-	7.4	3.3	2.5	1.6	5.7	13.2	3.3	9.0	1.6	0.8	-
02A	S	3.8	25.2	3.8	17.6	-	3.0	3.0	3.0	-	12.2	17.6	5.3	4.6	0.8	-	-
03A	S	12.1	20.5	14.4	-	-	-	-	15.2	1.5	2.7	18.9	4.5	22.7	1.5	-	-
03B	S	15.6	25.8	8.6	8.6	-	0.8	1.6	0.8	-	4.7	20.3	7.8	9.4	1.6	-	-
06A	S	18.8	22.7	13.3	12.5	-	4.7	3.1	-	3.1	-	2.3	7.0	6.2	1.6	4.7	-
06B	S	14.6	23.6	8.9	13.0	-	4.9	4.1	0.8	1.6	2.4	2.4	6.5	4.9	3.2	8.9	-
09A	N	12.1	23.5	8.3	6.1	3.8	6.8	6.8	1.5	2.3	7.6	0.8	9.1	10.6	0.8	-	-
09B	N	12.5	15.2	16.9	8.0	2.7	2.7	5.4	1.8	3.6	6.2	2.7	7.1	9.8	3.6	1.8	-
096	N	11.6	17.9	17.9	4.5	-	1.8	1.2	-	8.0	9.8	0.9	9.8	11.6	0.9	1.8	-
010A	N	16.5	15.7	17.4	4.9	-	4.9	2.5	0.8	9.1	5.8	-	9.1	9.9	3.3	-	-
010B	N	15.3	21.0	17.7	4.8	0.8	6.4	3.2	2.4	4.0	4.8	2.4	4.0	8.1	4.8	-	-
010C	N	10.4	23.2	19.2	7.2	1.6	2.4	1.6	3.2	4.8	1.6	-	18.4	6.4	-	-	-
011A	S	8.5	28.8	11.0	1.7	-	-	2.5	-	2.5	4.2	23.7	-	14.4	2.5	-	-
013A	S	14.8	20.0	12.2	6.9	2.6	2.6	2.6	1.7	-	9.6	8.7	2.6	4.3	1.7	8.7	0.8

TABLE 1 (Continued)

STATION	Province	vein quartz	black & garnet phyllite	granulitic phyllite	granite (undiff.)	biot. & musc. granite	granite gneiss	gneiss (undiff., felsic)	mica schist	siliceous schist	granulite	amphibolite	hornblende diorite & meta-diabase	meta-volcanics (felsic)	quartzite	pegmatite	feldspar
015A	S	11.3	30.4	13.9	11.3	-	-	2.6	0.9	-	3.5	4.3	7.8	-	2.6	6.1	5.2
018A	S	11.4	16.8	15.3	-	-	-	2.3	-	0.8	6.9	25.2	-	19.8	-	1.6	-
020A	S	11.2	20.9	14.9	6.0	0.7	2.2	5.2	4.5	0.7	8.7	11.2	6.0	-	1.6	11.2	-
022A	S	11.1	13.9	6.2	9.0	2.1	4.1	5.6	11.8	0.7	3.5	4.9	0.7	4.1	1.4	20.8	-
022B	S	10.7	17.4	14.9	10.7	1.6	8.3	3.3	5.8	9.1	4.1	6.6	1.6	4.1	0.8	9.1	0.8
023A	S	12.6	18.1	7.9	9.4	2.4	4.8	3.9	5.5	3.2	4.8	9.4	4.8	2.4	2.4	8.7	-
023B	S	13.7	20.6	8.4	12.2	1.5	3.1	3.8	2.3	2.3	4.6	6.9	4.6	4.6	1.5	9.9	-
024A	S	15.2	18.4	10.4	8.8	1.6	4.0	2.4	2.4	0.8	3.2	11.2	4.0	1.6	2.4	13.6	-
024B	S	13.6	18.9	10.6	7.6	5.3	3.8	-	3.8	-	5.3	13.6	4.5	-	0.8	11.4	0.8
025A	S	13.6	25.4	9.3	5.1	-	4.2	5.1	-	0.8	7.6	19.5	2.5	3.4	2.5	0.8	-
025B	S	7.4	28.7	7.4	24.3	-	1.5	2.9	0.8	0.8	5.1	11.8	5.1	2.9	0.8	0.8	-
027A	S	16.3	22.5	16.3	7.8	3.9	3.9	4.6	3.9	4.6	3.9	3.9	4.6	4.6	2.3	0.8	9.3
027B	S	11.5	16.4	7.4	11.5	2.5	3.3	4.1	9.8	4.9	7.4	5.7	1.6	25.0	0.9	10.6	-
027C	S	15.7	19.7	14.2	6.3	3.2	5.5	1.6	2.4	0.8	7.1	4.7	2.4	3.9	-	12.6	-

TABLE 1 (Continued)

STATION	Province	vein quartz	black & garnet phyllite	granulitic phyllite	granite (undiff.)	biot. & musc. granite	granite gneiss	gneiss (undiff., felsic)	mica schist	siliceous schist	granulite	amphibolite	hornblende diorite & meta-diabase	meta-volcanics (felsic)	quartzite	pegmatite	feldspar
029A	S	9.4	14.7	15.9	12.4	2.9	6.5	5.3	6.5	3.5	5.8	5.3	3.5	1.8	-	6.5	-
029B	S	9.9	19.1	11.3	9.9	2.8	7.1	3.5	2.8	2.8	7.1	5.6	5.0	2.1	0.7	9.9	-
029C	S	7.1	11.0	4.7	18.1	3.9	7.9	3.1	8.7	1.6	5.5	3.9	4.7	2.4	-	17.3	-
030A	S	8.4	11.3	12.7	9.2	2.8	10.6	4.9	4.9	4.2	8.4	2.8	-	1.4	0.7	17.2	-
030B	S	12.3	16.2	17.7	9.2	3.1	4.6	1.5	5.5	3.8	3.8	7.0	7.7	1.5	-	6.2	-
031A	S	11.7	18.0	10.9	11.7	1.6	7.0	2.3	1.6	3.1	6.2	3.9	1.6	2.3	-	18.0	-
031B	S	10.1	18.5	10.1	10.9	-	8.4	1.7	5.0	1.7	5.0	5.0	0.8	6.0	-	17.6	-
N1A	N	13.1	23.4	10.9	3.6	-	2.9	2.2	2.2	7.2	5.1	2.8	19.7	5.1	0.7	0.7	-
N2A	S	10.2	13.4	8.7	12.6	2.4	7.9	1.6	3.1	3.1	5.5	2.4	4.7	3.9	0.8	19.7	-
N3A	S	13.7	17.6	19.8	9.9	-	4.6	-	2.3	3.1	5.3	5.3	6.9	3.1	2.3	6.1	-
N3B	S	15.0	16.4	12.8	15.0	0.7	2.8	2.1	2.8	2.1	5.0	2.1	7.1	5.0	-	10.7	-
N5A	S	8.7	9.3	16.1	11.4	-	10.7	3.4	7.3	4.7	7.3	4.7	5.4	4.7	-	6.0	-
N5B	S	10.6	11.2	23.1	13.0	-	7.1	3.0	3.0	1.8	5.3	1.2	5.9	3.0	-	10.6	1.2
N5C	S	7.2	13.7	20.3	11.7	-	7.8	1.3	7.2	1.9	6.5	5.2	2.6	4.6	-	8.5	1.3

TABLE 1 (Continued)

STATION	Province	vein quartz	black & garnet phyllite	granulitic phyllite	granite (undiff.)	biot. & musc. granite	granite gneiss	gneiss (undiff., felsic)	mica schist	siliceous schist	granulite	amphibolite	hornblende diorite & meta-diabase	meta-volcanics (felsic)	quartzite	pegmatite	feldspar
N6A	S	13.1	18.5	15.4	12.3	-	3.8	2.3	2.3	4.6	5.4	2.3	8.5	3.1	2.3	6.2	-
N8A	N	15.9	29.2	25.6	1.7	-	-	1.7	0.9	1.7	4.4	2.6	8.0	8.0	-	-	-
N9A	S	9.0	17.3	13.8	15.9	-	6.9	2.1	6.9	1.4	3.6	3.6	2.8	2.1	-	14.5	-
N10A	S	17.4	16.7	19.7	11.4	1.5	5.3	1.5	0.8	2.3	3.8	-	4.5	3.0	-	12.1	-
N10B	S	9.4	13.8	23.2	18.1	-	5.1	0.7	1.4	-	8.0	-	8.7	2.8	-	8.7	-
N11A	S	12.5	16.7	9.2	16.7	-	5.8	3.3	4.2	1.7	5.8	-	7.5	1.7	-	15.0	-
N12A	S	12.3	17.4	28.3	7.2	2.9	4.3	2.2	3.6	2.2	2.2	1.4	5.1	1.4	-	9.4	-
N12B	S	14.5	15.1	26.4	7.6	0.6	2.5	2.5	3.8	1.8	6.3	0.6	5.7	0.6	1.2	10.7	-
N12C	S	12.4	17.8	24.8	11.6	0.8	3.9	2.3	4.6	-	4.6	1.6	9.3	0.8	-	5.4	-
N14A	S	11.4	13.7	22.1	16.8	-	5.3	1.5	3.8	2.3	0.8	-	10.6	1.6	-	9.9	-
N14B	S	8.2	18.7	14.9	13.4	-	4.5	2.2	5.2	3.1	5.2	2.2	8.2	1.5	0.8	11.9	-
N14C	S	13.6	22.4	16.8	14.4	-	3.2	1.6	4.8	3.2	2.4	3.2	5.6	3.2	-	6.4	-
N15A	S	11.2	22.4	20.3	2.8	0.7	5.6	0.7	4.9	1.4	2.8	0.7	6.2	2.1	0.7	9.8	0.7
N15B	S	10.6	13.8	18.7	13.8	-	4.1	2.4	0.9	3.2	11.4	0.8	3.2	1.6	0.8	8.9	1.6

TABLE 1 (Continued)

STATION	Province	vein quartz	black & garnet phyllite	granulitic phyllite	granite (undiff.)	biot. & musc. granite	granite gneiss	gneiss (undiff., felsic)	mica schist	siliceous schist	granulite	amphibolite	hornblende diorite & meta-diabase	meta-volcanics (felsic)	quartzite	pegmatite	feldspar
N17A	S	11.4	28.0	16.7	12.9	-	4.5	0.8	4.5	-	4.5	-	4.5	2.3	-	9.8	-
N17B	S	14.8	17.9	18.8	7.9	-	3.9	1.6	5.5	3.9	5.5	-	9.4	1.6	-	9.4	-
N18A	S	12.8	34.9	23.8	-	-	-	4.6	-	0.9	-	19.3	3.7	-	-	-	-
N19A	S	12.3	15.6	20.1	11.7	-	3.9	1.9	5.2	1.2	1.9	-	11.7	1.3	1.3	1.7	-
N19B	S	10.9	14.1	28.1	10.2	0.8	7.0	2.3	1.6	3.1	5.5	-	10.2	3.9	-	2.3	-
N19C	S	13.2	15.8	17.5	12.3	-	3.5	-	7.9	1.8	4.4	-	7.0	-	0.9	15.8	-
N21A	S	14.4	24.0	20.0	17.6	-	4.0	-	3.2	-	3.2	-	4.8	3.2	-	5.6	-
N29A	S	5.9	21.2	11.0	14.4	-	10.2	2.5	6.8	1.7	4.2	4.2	2.5	2.5	-	12.7	-
N30A	S	7.1	19.7	14.2	10.2	-	7.9	2.4	7.9	1.6	6.3	2.4	4.8	1.6	-	14.2	-
D1A	S	7.1	22.7	22.0	13.5	-	6.4	2.8	2.6	1.4	5.0	1.4	5.0	1.4	-	7.8	-
D1B	S	10.3	23.1	13.5	13.5	-	6.4	-	8.7	1.6	4.0	2.4	5.6	-	-	11.1	-
D3A	S	14.5	25.2	16.0	11.4	-	5.3	3.1	2.3	1.5	4.6	-	6.1	-	-	9.9	-
D3B	S	13.7	44.6	18.0	10.1	-	2.2	-	1.4	0.7	2.2	-	2.9	0.7	0.7	2.2	0.7
D3C	S	11.2	60.0	26.4	0.8	-	-	-	-	-	-	-	1.6	-	-	-	-

Figure 32. -- Moving average diagrams of the conglomerate clast compositions according to province location within the depositional basin. The Northfield Province was not contoured due to the poor field exposure. Composition of this province is presented in Table 1.

a.: Southern Province

b.: Northern Province

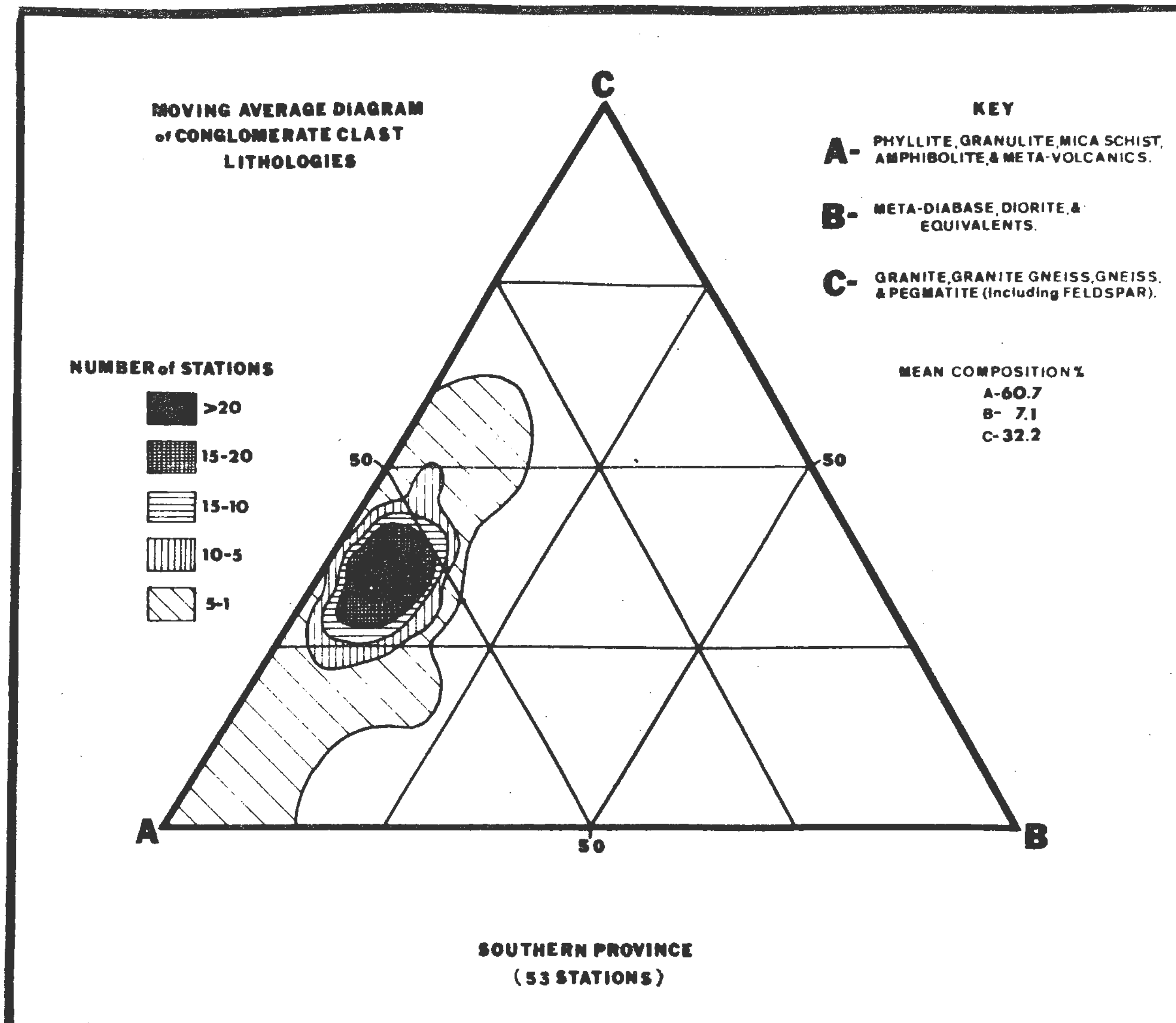

MOVING AVERAGE DIAGRAM
of CONGLOMERATE CLAST
LITHOLOGIES
C
KEY
A- PHYLLITE, GRANULITE, MICA SCHIST, AMPHIBOLITE, & META-VOLCANICS.
B- META-DIABASE, DIORITE, & EQUIVALENTS.
C- GRANITE, GRANITE GNEISS, GNEISS, & PEGMATITE (Including FELDSPAR).
NUMBER of STATIONS
>20
15-20
15-10
10-5
5-1
MEAN COMPOSITION %
A-60.7
B- 7.1
C-32.2
50
50
50
A
B
SOUTHERN PROVINCE
(53 STATIONS)

Figure 32a

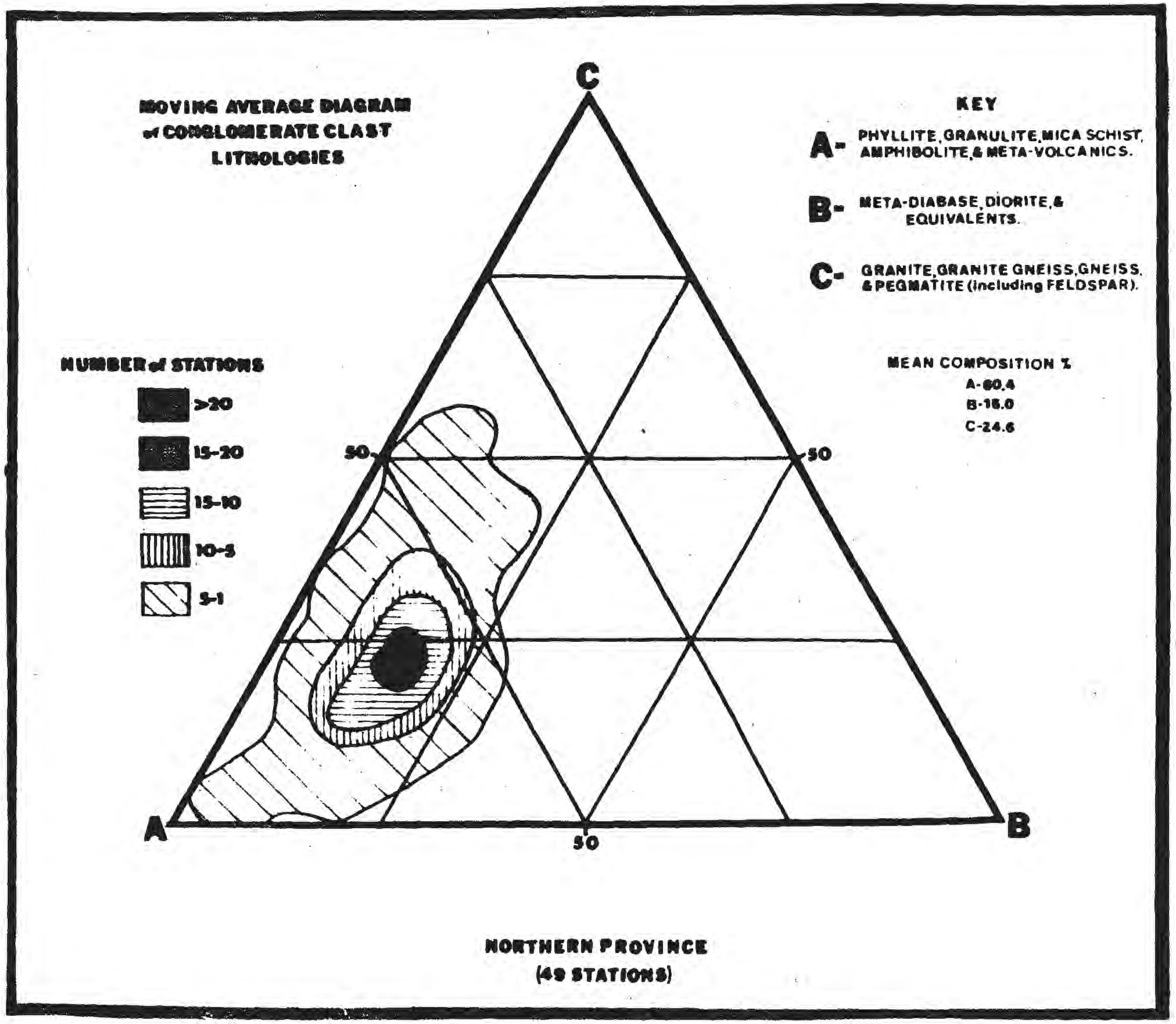

MOVING AVERAGE DIAGRAM of CONGLOMERATE CLAST LITHOLOGIES
C
KEY
A- PHYLLITE, GRANULITE, MICA SCHIST, AMPHIBOLITE, & META-VOLCANICS.
B- META-DIABASE, DIORITE, & EQUIVALENTS.
C- GRANITE, GRANITE GNEISS, GNEISS, & PEGMATITE (including FELDSPAR).
NUMBER of STATIONS
>20
15-20
15-10
10-5
5-1
MEAN COMPOSITION %
A-60.4
B-15.0
C-24.6
50
50
50
A
B
NORTHERN PROVINCE
(49 STATIONS)

Figure 32b

indicators in the northern part of the conglomerate facies with the pre-Triassic rocks east of the Northern Province is not as distinct as in the southern section (Table 2). However, several sawed sections of phyllite clasts from the Northern Province contain staurolite, which can be correlated with numerous staurolite-bearing horizons in the pre-Triassic rocks east of the Northern Province.

These data indicate that the conglomerate was derived from crystalline formations that are very similar to the pre-Triassic rocks that presently border the Triassic basin. The following is a discussion of the specific formations that contributed detritus during late Triassic sedimentation.

Quartzite and granulite clasts were derived from the Clough Quartzite (Silurian). A number of smaller quartzite and siliceous schist clasts resemble stretched quartz pebbles commonly found in the Clough. Quartzite, black garnetiferous phyllite, and granulite clasts are tentatively correlated with the Bernardston Formation (Balk, 1956). Parts of the Littleton Formation may have also contributed minor amounts of phyllite. The Leydon Argillite (Silurian) presently exposed west of the Triassic basin contains small grains of leucoxene in black phyllitic-slate layers that can be correlated with leucoxene-bearing phyllite clasts in the Northern Province. Although this correlation is difficult to prove, it appears that this formation was an important source of Triassic sediment. The large percentage of phyllite clasts in the Triassic conglomerates suggests that several phyllite-bearing formations were source rocks.

Mica schist clasts were derived primarily from the Partridge Formation (Middle Ordovician) and the Littleton Formation (Lower Devonian). Minor amounts of schistose rock may have been contributed by the Gile Mountain Formation (Lower Devonian).

Table 2. -- Metamorphic minerals present in mica schist clasts in the Mount Toby Conglomerate. N - Northern Province; S-Southern Province.

TABLE 2

SAMPLE	PROVINCE	METAMORPHIC MINERALS
126A-1	N	Chlorite, garnet.
T3A'-4	N	Chlorite, garnet.
07B-3	S	Fine sillimanite (?) in muscovite, chlorite rimmed on garnet.
022B-3	S	Sillimanite.
N10A-2	S	Sillimanite, garnet, and fractured muscovite.

Many of the above formations contain dikes and sills of mafic composition. These rocks were undoubtedly the source for the hornblende, diorite, gabbro, and diabase clasts. The majority of the amphibolite clasts are derived from the Erving member of the Littleton Formation (Lower Devonian) and the Ammonoosuc Volcanics (Middle Ordovician), although the latter formation may have served only as a minor source. Metavolcanics primarily composed of "light gray to white well-laminated, hard and splintery rock in which little dark spheres are present"(Balk, 1956) occur as lenses within the phyllite beds of the Bernardston Formation and identical clasts are present in most conglomerate sections.

Granitic rocks are important constituents in many of the conglomerate horizons. Precise source area correlation is a difficult problem for none of the granitic clasts are similar in composition to the gneiss dome rocks that are prominent features in the pre-Triassic crystalline terranes (P. Robinson, oral communication, 1966). Thus, the only other known source for the granitic detritus is from ubiquitous granitic dikes and sills in many horizons of the pre-Triassic rocks. Most of these rocks are gneissic and muscovite-biotite granites. Some of the granitic material can be correlated with known formations. Clasts with large crystals of microcline feldspar appear to be derived from the Kinsman Quartz Monzonite (Devonian) that presently crops out just north of the Massachusetts-Vermont border west of the Border Fault. Many clasts, especially in the central portion of the area, apparently are derived from the Williamsburg Granodiorite. This name is an all-inclusive term for several of the granitic rocks presently exposed on the west side of the Triassic basin.

Pegmatite and large feldspar clasts are derived from dikes, sills, and lenses that are extremely common in the crystalline rocks east of the border fault. Clasts of vein quartz have a similar derivation. Quartz veins are present in most outcrops of pre-Triassic rocks east of the basin. Siliceous schist clasts are distinguished from vein quartz by the presence of a weak foliation due to the alignment of the fine-grained mica or chlorite flakes (Fig. 33). These clasts are more brittle than vein quartz and probably are derived from metamorphosed quartz veins.

Pieces of conglomerate are fresh or weathered. The effects of weathering usually consist of hematite staining around the outer rim of the clast; the inner portion is fresh. Krynine (1950) felt that the presence of fresh and weathered detritus was indicative of humid weathering conditions. Fresh detritus is eroded from canyon walls by vigorously downcutting streams, and weathered detritus is eroded from a soil mantle on the interfluves. The final sediment contains both fresh and weathered detritus. However, an alternative process is proposed to account for the mixture of fresh and weathered detritus. Figure 34 shows a phyllite clast with a weathered rim (hematite staining) about a fresh core. Such clasts are abundant in the conglomerate facies. When a clast of this type is broken during transportation it produces both fresh and weathered detritus. Thus the ultimate production of fresh and weathered sediment is controlled not only by different types of detritus being eroded from the interfluves and canyon walls but also by breakdown during transportation of partially weathered boulders and gravels.

Sandstone

Approximately thirty-five percent of the section is composed of sandstone. Sandstones were analyzed for mineralogy and texture by detailed

Figure 33. --- Siliceous schist clast in the Mount Toby Conglomerate east of Gill. Note the blocky and rectangular appearance of the clast. These clasts display a weak foliation (F) and tend to be brittle.

Figure 33

Figure 34. -- Granulitic phyllite clast from the Mount Toby Conglomerate east of Mount Toby showing a weathered rim (w) and a fresh (f) core. This type of clast will produce both fresh and weathered detritus when broken during transportation.

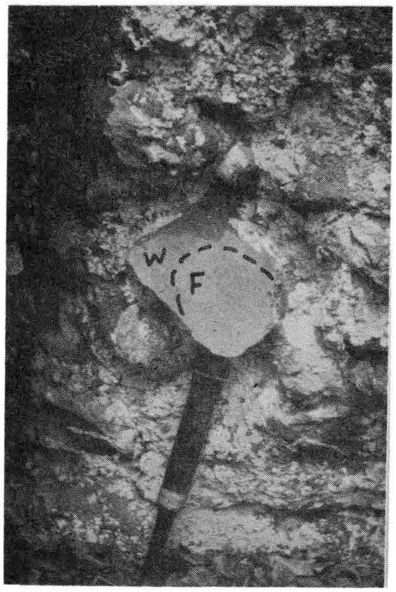


Figure 34

study of thirty-six thin sections. Mineralogy was determined from 200 point counts, grain size was calculated from 100 point counts, and roundness was evaluated using 50 points. In all cases, a ribbon count method was used. The data are summarized below.

Color. - Visual comparison of colors of sandstones with the Rock Color Chart(Goddard and others, 1951). All colors were evaluated on freshly broken dry surfaces. The following color ranges are present: 5R 4/2, grayish red, to R 4/2 dark yellowish brown; 5R 3/4 musky red; and 5R 4/1, brownish gray. Color in these sediments is influenced primarily by the color of the matrix. Red and brown refect abundant hematite and limonite in the matrix, whereas gray results from concentrations of metamorphic rock fragments and quartz. In gray rocks the matrix content is low.

Mineralogy. - The main constituents of the sandstones are quartz, feldspar, metamorphic rock fragments, plutonic rock fragments, and mica. Table 3 summarizes the percentage of minerals and indicates the location of the samples.

Quartz varies from 16.3 to 46.7 percent in the sandstone suite. Grain diameters of the quartz average 1.2 mm, and most of the grains are composite with marked or prominent undulose extinction (Folk, 1965, p. 74). Inclusions are very rare, but a few grains contain patches of vermicular chlorite. Hematite rims are present on 1 percent of the quartz grains that were counted, and quartz overgrowths are rare.

Feldspar makes up 5.6 to 42.4 percent of the sandstone suite and it occurs in several size classes ranging from 0.1 mm to 2.5 mm. Five types of feldspar were differentiated for study purposes: orthoclase,

Table 3. -- Composition of the sandstone suite. No is the Northfield Province; N is the Northern Province; and S is the Southern Province. F and W refer to fresh and weathered varieties of feldspar. [Heavy minerals point-counted include: garnet, apatite, indicolite, and beryl.]

TABLE 3

STATION	Province	Rk. Frags.		Feldspar						quartz	stretched meta.qzt.	detrital mica	detrital chlorite	secondary mica	secondary chlorite	heavy minerals	clay galls	carbonate	matrix
		plutonic	metamorphic	orthoclase & microcline		plagioclase		undiff.											
				f	w	f	w	f	w										
AIZ	S	-	30.0	tr.	1.4	-	tr.	tr.	1.4	34.6	2.3	7.4	2.3	-	-	-	-	II.I	6.5
AIY	S	tr.	24.2	tr.	2.2	2.3	-	1.8	3.6	38.2	2.7	7.2	2.3	-	-	1.4	6.7	-	8.6
AJH	S	3.7	15.2	3.2	13.8	tr.	4.6	1.4	2.8	36.6	2.8	4.6	tr.	-	-	-	tr.	-	6.9
AJG	S	3.4	13.3	tr.	13.3	1.7	1.7	-	2.6	41.7	tr.	7.7	1.3	-	-	-	tr.	4.3	14.1
AJI	S	4.7	20.8	1.9	8.1	tr.	3.8	2.4	tr.	38.4	3.8	5.2	2.4	-	-	-	-	1.9	5.2
AJX	S	5.1	15.2	2.3	8.8	tr.	2.3	1.8	6.0	38.7	1.8	6.5	1.4	-	tr.	tr.	tr.	-	7.4
AJW	S	11.4	10.0	3.8	6.6	tr.	5.2	3.3	5.5	34.8	1.9	8.1	3.3	-	-	tr.	-	-	4.8
AKF	S	6.3	34.6	2.7	1.3	1.8	tr.	-	4.9	24.0	3.1	7.5	2.7	-	-	-	tr.	-	9.3
AKG	S	7.2	10.1	3.8	3.8	tr.	4.6	tr.	7.2	40.5	5.1	5.9	2.1	-	-	-	2.1	-	10.5
AKL	S	8.1	14.9	4.3	2.6	-	2.6	2.6	3.8	33.6	3.8	10.6	1.7	-	-	-	5.9	-	5.5
AKN	S	5.1	19.1	1.4	2.3	1.4	2.3	tr.	8.8	35.0	5.6	5.6	1.4	-	-	1.4	tr.	2.8	6.1
AAB	S	6.1	30.8	tr.	1.4	tr.	tr.	-	6.5	30.8	3.3	1.9	1.9	-	-	-	-	8.4	6.1
AKA	S	4.7	17.7	4.7	10.6	tr.	3.3	tr.	3.3	37.8	4.2	2.3	2.3	-	-	-	1.9	-	6.5
AJK	S	5.6	40.2	1.4	tr.	1.4	tr.	-	5.6	19.2	1.9	4.7	2.3	-	tr.	tr.	tr.	8.4	6.1

TABLE 3 (Continued)

STATION	Province	Rk. Frags. plutonic	Rk. Frags. metamorphic	Feldspar orthoclase & microcline f	Feldspar orthoclase & microcline w	Feldspar plagioclase f	Feldspar plagioclase w	Feldspar undiff. f	Feldspar undiff. w	quartz	stretched meta.qzt.	detrital mica	detrital chlorite	secondary mica	secondary chlorite	heavy minerals	clay galls	carbonate	matrix
AEQ	N	tr.	2.3	tr.	11.3	2.7	2.7	-	14.4	40.0	tr.	6.8	1.4	-	-	1.8	tr.	3.1	9.9
AET	N	4.8	tr.	4.3	14.3	2.9	6.7	5.2	8.6	45.3	tr.	3.8	2.4	-	tr.	tr.	-	-	4.3
AIL	N	11.3	3.5	2.5	4.1	-	3.5	-	15.9	40.0	3.5	4.0	tr.	-	-	-	tr.	-	7.5
ACD	N	tr.	7.6	3.1	4.1	1.7	tr.	tr.	7.1	42.4	5.8	10.5	1.8	tr.	tr.	-	tr.	2.7	9.8
AFQ	N	1.7	7.9	1.7	8.3	tr.	tr.	tr.	11.4	34.0	-	11.4	7.9	-	-	tr.	tr.	-	12.2
AFP	N	6.7	41.4	-	2.7	-	tr.	-	10.4	19.3	3.1	3.1	4.5	-	tr.	-	tr.	-	10.0
AFR	N	3.6	33.6	4.9	3.5	-	-	tr.	2.7	29.2	tr.	4.9	2.2	-	tr.	-	-	-	11.1
AAG	N	7.1	10.6	-	5.3	2.2	tr.	tr.	9.7	30.3	tr.	12.8	4.0	-	tr.	-	2.2	tr.	10.6
ACA	N	6.6	12.8	tr.	3.1	-	3.1	-	17.7	35.4	-	6.2	2.1	-	-	-	-	-	11.5
AEZ	N	3.4	46.3	-	3.0	-	2.5	-	3.8	19.4	3.4	3.8	2.1	-	-	-	tr.	2.1	6.3
AFC	N	10.7	45.6	-	2.8	-	1.9	-	6.1	16.3	2.3	3.3	1.4	-	-	-	tr.	-	7.0
AAX	N	6.2	44.0	-	1.4	-	-	-	5.7	17.2	2.6	4.3	1.9	-	-	-	tr.	8.5	4.3
AFD	N	8.3	41.5	tr.	2.8	-	tr.	-	6.0	22.1	tr.	3.7	-	-	-	-	tr.	4.2	8.3
AAL	N	5.6	12.0	7.2	6.7	2.4	1.9	2.9	9.1	45.0	1.9	tr.	tr.	-	-	-	tr.	-	5.3

TABLE 3 (Continued)

STATION	Province	Rk. Frags. plutonic	Rk. Frags. metamorphic	Feldspar orthoclase & microcline f	Feldspar orthoclase & microcline w	Feldspar plagioclase f	Feldspar plagioclase w	Feldspar undiff. f	Feldspar undiff. w	quartz	stretched meta.qzt.	detrital mica	detrital chlorite	secondary mica	secondary chlorite	heavy minerals	clay galls	carbonate	matrix
AHR	N	3.3	49.7	-	2.3	-	tr.	-	8.0	21.1	tr.	7.0	2.3	-	-	-	-	-	4.2
AIR	N	5.1	39.6	tr.	3.7	-	tr.	-	9.2	25.4	tr.	2.3	3.7	-	-	-	-	6.0	6.0
AGI	N	7.0	38.4	-	3.2	-	-	-	10.5	24.0	tr.	3.2	3.2	-	-	-	-	1.4	7.9
ABU	N	6.9	29.0	tr.	3.7	-	tr.	8.3	-	38.2	1.8	2.3	tr.	-	-	-	1.4	-	6.5
ACE	N	11.6	9.2	4.2	5.1	tr.	2.8	tr.	7.9	46.7	tr.	1.9	1.9	-	-	-	2.8	-	3.2
AHD	No	9.7	7.8	3.7	2.8	-	2.3	1.4	10.2	39.1	4.2	8.3	2.3	-	-	-	tr.	-	8.3
AGV	No	7.7	13.0	tr.	3.6	-	40.0	tr.	9.9	42.6	2.7	4.0	-	-	tr.	-	tr.	-	9.9
AGO	No	22.0	10.5	4.1	4.6	-	tr.	tr.	10.0	35.0	tr.	5.0	1.8	-	-	-	-	-	6.8
AGQ	No	22.2	16.4	3.4	2.9	tr.	2.5	tr.	5.5	28.6	-	3.4	2.5	tr.	5.0	1.3	tr.	3.8	4.6

microline, albite, plagioclase, and undifferentiated feldspar. No feldspar type is restricted to a particular grain size. Fresh and altered feldspar are present in approximately equal proportions.

Alteration usually consists of vacuolization and sericitization in all feldspar types examined (Fig. 35). Orthoclase locally contains abundant kaolinite; microline is rarely altered.

Feldspar overgrowths (Fig. 35) are present in 1 to 2 percent of the feldspar. The overgrowths are generally unaltered, but a few display vacuolization. Overgrowth development shows no preference for a particular feldspar. Quartz and rock fragments are locally rimmed with secondary feldspar, but in these instances the source of secondary feldspar seems to be nearby primary feldspar.

The fact that a high percent of the feldspar was derived from pegmatite, granite, granite gneiss, and gneiss explains the abundant alteration by vacuolization. Alteration to sericite can be explained both by hydrothermal activity and by weathering in a semi-arid climate (Folk, 1965, p. 84). Kaolinite suggests that part of the source area was weathered under humid conditions.

Metamorphic rock fragments make up from a mere trace to 49.7 percent of the sandstones and are divided into two groups. The largest group is composed of fine-grained mica and chlorite, quartz, and feldspar. These fragments which were derived from a low-grade metamorphic terrance composed of slate or phyllite are distinctly foliated and may show crinkle lineations (Fig. 36). They are both fresh and weathered. Weathering is recognized by a hematite stain. Secondary chlorite occurs with mica in 50 percent of the counted grains. Sericite is also common in the fine-grained rock fragments.

Figure 35. -- Photomicrograph of an orthoclase feldspar grain showing alteration by both vacuolization and sericitization (brighter streaks). Note the unaltered feldspar overgrowth. (Nicols crossed).

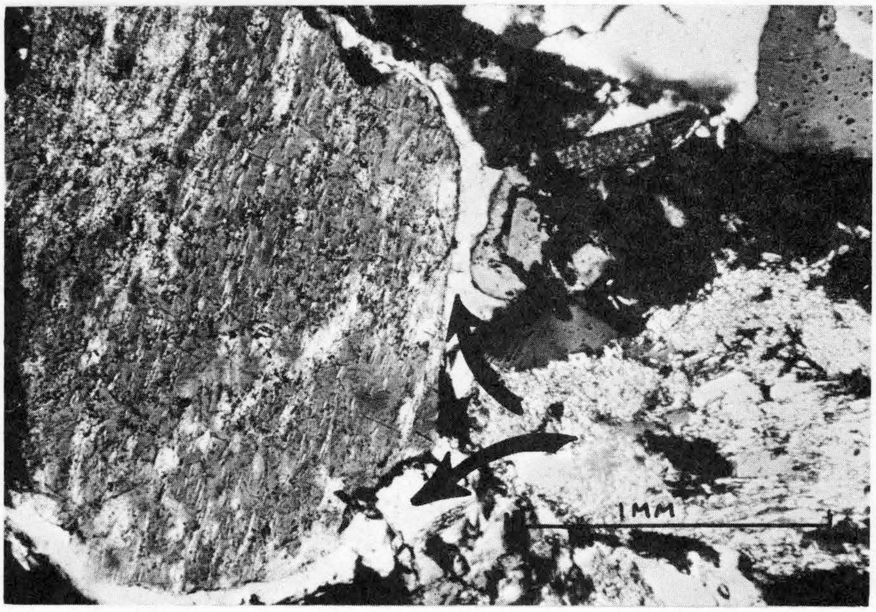


Figure 35

The second group includes coarse grained and distinctly schistose rock fragments (Fig. 37). The platy minerals are biotite and muscovite, and the granular minerals are quartz and feldspar.

Plutonic rock fragments have been distinguished in this study and are unique compared to other fragments. Plutonic rock fragments are important constituents in many sandstones (Table 3 and Fig. 38). They are composed of equigranular interlocking mosaics of medium-grained feldspar and quartz. These rock fragments range in size from 1.0 mm to 3.5 mm and individuals average 0.2 mm. Feldspar in this type of fragment may be fresh or altered; alteration consists of sericitization or vacuolization. No kaolinitization was found. This type of fragment was derived from granitic dike rocks.

Detrital mica has an average grain size of 0.5 mm and may form as much as 12.8 percent of the thin section. Muscovite is commonly more abundant than biotite, and both fresh and weathered micas were present; muscovite is less altered than biotite. Secondary biotite is developed in limited zones in the matrix, and chlorite is associated with biotite in a few places. Mica displays excellent alignment parallel to bedding surfaces in a large number of sections (Fig. 39).

Detrital chlorite may be absent or may comprise as much as 7.9 percent with an average content of 2.1 percent. The detrital chlorite averages 0.25 mm in diameter. Fresh and weathered types occur in approximately equal amounts. Two varieties are present: (1) an iron-rich variety recognized by deep-blue pleochroism, and (2) a magnesium-rich variety characterized by pale-green pleochroism. The magnesium-rich variety is much more abundant than the iron-rich variety. Secondary chlorite, abundant in a few zones, is present in fine-grained, weathered, low-grade

Figure 36. -- Photomicrograph of a fine-grained metamorphic rock fragment. Note the distinct foliation (F) and crinkles (C). (Nicols uncrossed).

Figure 37. -- Photomicrograph of medium-grained fragment (arrow). Note the foliation (F). (Nicols crossed).

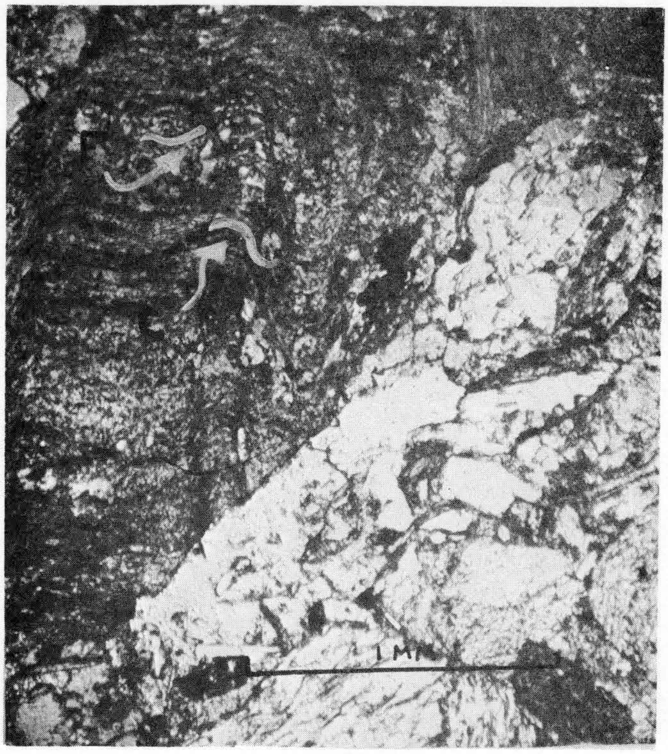


Figure 36

Figure 37

Figure 38. -- Photomicrograph of a plutonic rock fragment (outlined in white). Composed of an interlocking mosaic of quartz and feldspar grains. Note microcline fragment (M) in bottom of the picture. (Nicols crossed).

Figure 39. -- Photomicrograph of detrital mica (M) that is parallel to bedding (B). (Nicols uncrossed).

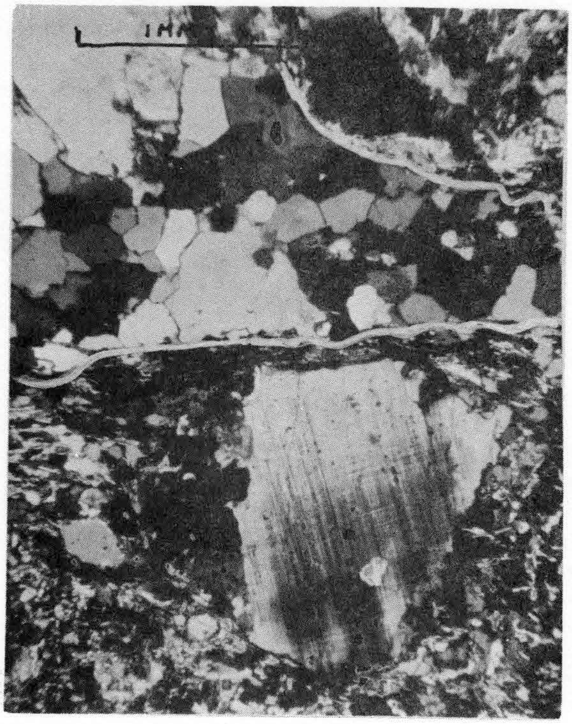


Figure 38

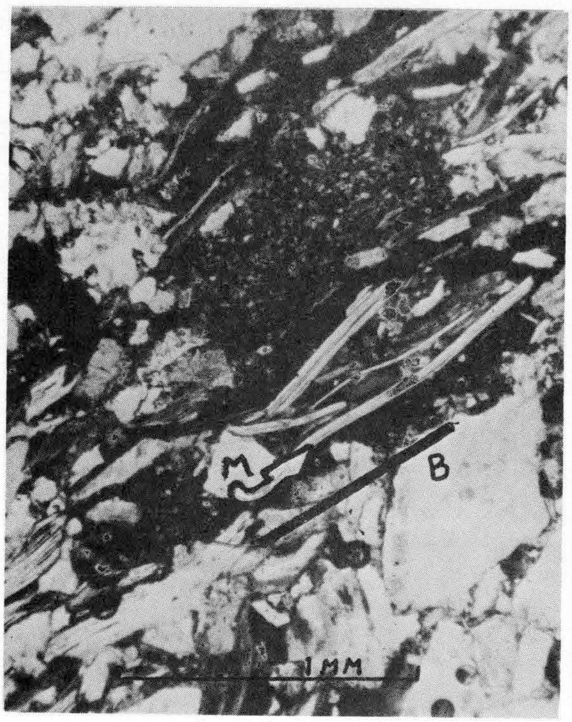


Figure 39

metamorphic rock fragments. Secondary chlorite was observed in the matrix of several samples.

Clay galls occur in restricted zones, commonly at the base of bedding or sedimentation units, which indicates that they were transported very short distances. In the zones where they are present they occur in abundance. They are from 1.75 mm to 6.0 mm long.

Several types of heavy minerals are present but not abundant. Varieties in the point counts include garnet, tourmaline, apatite, and beryl. Magnetite, illmenite, and epidote are present in trace amounts. A blue-green variety of tourmaline, indicolite, is abundant in two thin sections and is present as a trace constituent in a third. Pegmatities east of the fault commonly contain tourmaline but indicolite has not been identified in any of them (P. Robinson, oral communication, 1966); however, pre-Triassic pegmatites west of the fault contain small amounts of indicolite.

No primary carbonate is present in any part of the sandstone suite. However, up to 11.1 percent of secondary sparry calcite is present in several zones and is a cementing agent. It shows no mineralogic preference and may replace matrix, rock fragments, quartz, or feldspar; replacement may be restricted to definite horizons, however.

The matrix of the sandstones consists of a fine-grained mixture of quartz, feldspar, mica, chlorite, sericite, clay minerals, limonite, and hematite.

<u>Texture</u>. - Grain size and roundness were determined in 13 samples of representative parts of the sandstone section. Grain size was determined by measurement of the apparent long axis using a calibrated ocular, and the results are grouped into 0.50 ϕ classes. The grain-size distributions are

shown in Figure 40. Cumulative curves were constructed using arithmetic probability paper in order to estimate mean grain size, sorting, skewness, and kurtosis. Values were determined employing standard graphical formulas (Folk, 1965, pp. 45-49). The results are summarized in Table 4. All parameters are presented in terms of thin-section (number) distribution rather than weight distribution. Most of the samples are positively skewed and display only moderate sorting.

Roundness was determined by visual comparison with Powers' Roundness Scale (1953). Folk's (1965) log transformation (ρ value) was used for final presentation. Since the sandstones are composed of constituents of varying hardness, two different counts of 50 points each were made. Quartz and feldspar were counted in arkoses, and quartz and metamorphic rock fragments were counted in litharenites. Mean roundness (Mzp) and roundness sorting (Gp) were calculated for quartz, feldspar, and rock fragments by standard graphical formulas, using values estimated from cumulative curves constructed on arithmetic probability paper. The data are summarized in Table 5.

Compaction and Cementation. - Dominant cements are primarily hematite and limonite; however, the effects of compaction appear to be equally significant in the induration of the sandstones. Indentation of mica flakes and fine-grained metamorphic rock fragments by quartz and feldspar provides evidence of compaction (Fig. 41). This grain penetration is probably related to compactional loading. Pressure solution appears to be the chief process of compaction between feldspar or quartz grains.

Well-indurated sandstones display tighter grain packings than friable sandstones. This is substantiated by the fact that well-indurated sandstones contain higher percents of grain contacts than friable sandstones.

Figures 40 -- Cumulative curves of grain-size distribution of representative samples in the sandstone facies. Values refer to graphical formulas of Folk (1965, p. 45-49). Samples ahd and ago are from the Northfield Province; ajw, akn, ajg, akl, and aiy are from the Southern Province; and aax, aet, ail, abu, afq, and aal are from the Northern Province.

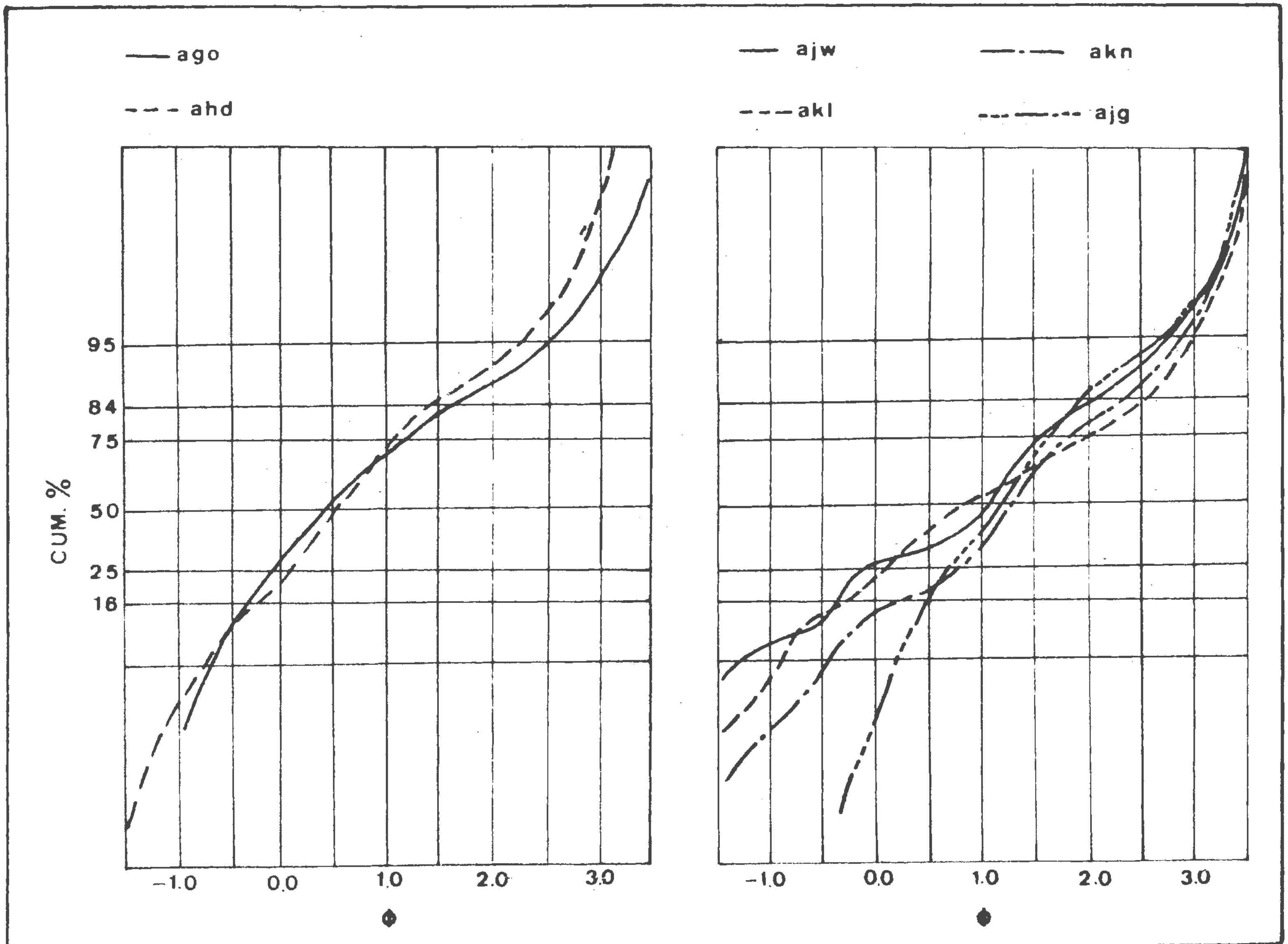


Figure 40a

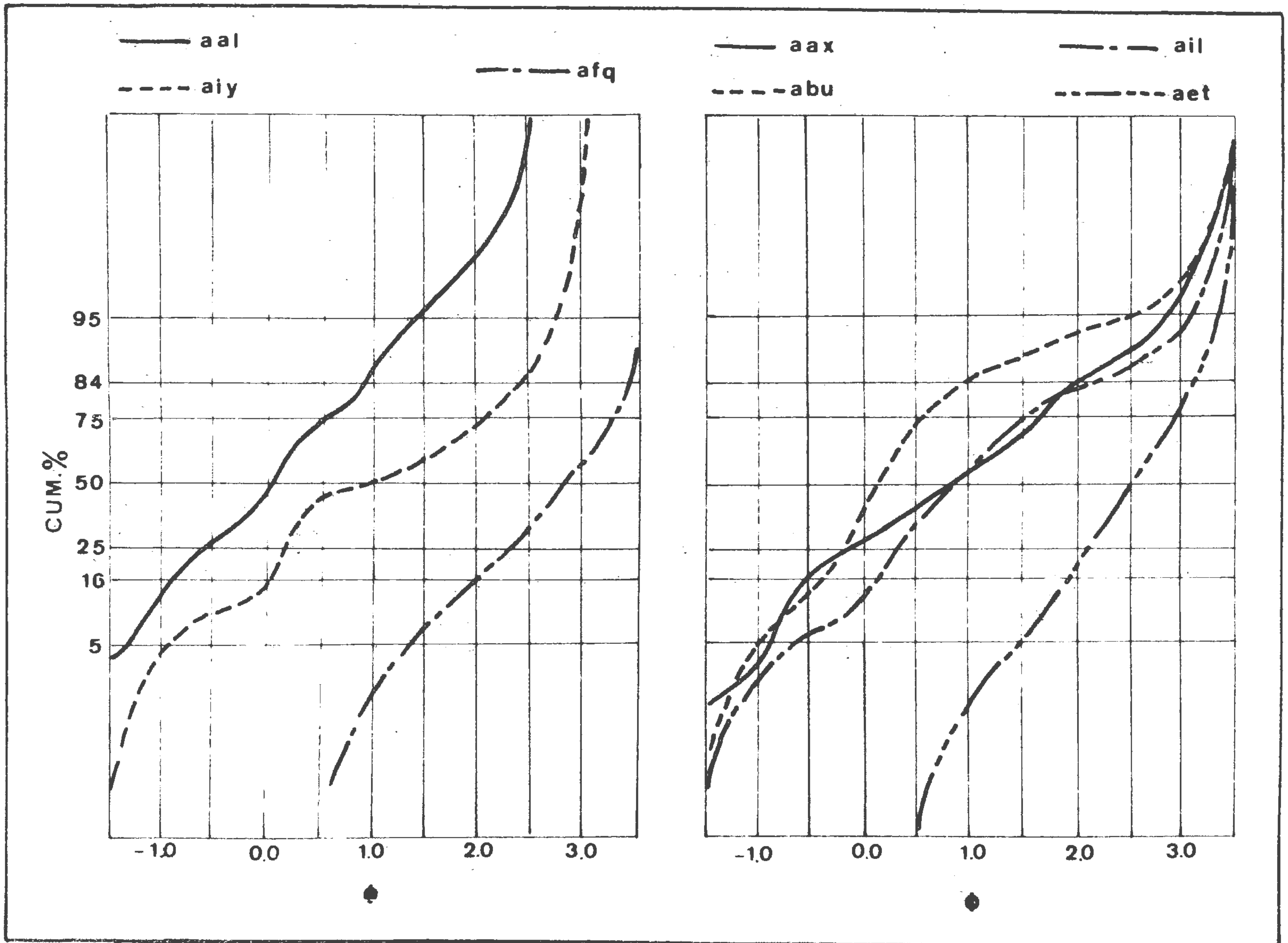


Figure 40b

TEXTURAL RELATIONSHIPS (sandstone facies)

No Northfield Province

N Northern Province

S Southern Province

Sample	**ahd**	**ago**	**ajw**	**akn**	**ajg**	**akl**	**aax**	**aet**	**ail**	**abu**	**afq**	**aal**	**aiy**
Province	No	No	S	S	S	S	N	N	N	N	N	N	S
Md_ϕ	.55	.45	1.05	1.30	1.25	.85	.85	2.50	.90	.10	2.80	.05	1.00
Mz_ϕ	.55	.53	.85	1.30	1.18	.98	.80	2.50	1.00	.20	2.74	.05	1.13
σ_I	.82	.91	1.18	1.00	.69	1.24	1.20	.58	1.09	.61	.70	.85	1.12
Sk_I	.07	.22	-.22	.74	.02	.12	.04	.07	.11	.26	-.39	.01	.09
K_G	1.24	1.02	.98	1.25	1.22	.84	1.03	.90	1.21	1.72	.97	.94	.77

Table 4

Roundness Data

	AHD (no)	AGO (no)	AJW (s)	AKN (s)	AJG (s)	AKL (s)	AAX (n)	AET (n)	AIL (n)	ABU (n)	AFQ (n)	AAL (n)	AIY (s)
qz. $M_z\rho$	3.4	2.9	2.8	3.3	2.7	3.3	2.7	3.7	3.0	3.3	3.6	2.9	2.8
rf. or f. $M_z\rho$	3.9 f	3.3 f	3.6 f	3.6 rf	3.9 rf	3.5 rf	3.7 rf	4.0 f	3.6 f	3.7 rf	3.8 f	3.2 f	3.1 rf
qz. $\sigma_I\rho$	1.01	.78	.76	.79	.75	.84	.62	1.03	.78	.81	.90	.79	.73
rf. or f. $\sigma_I\rho$	1.01 f	.93 f	.83 f	.77 rf	.87 rf	.72 rf	.87 rf	.92 f	.85 f	.88 rf	.95 f	.71 f	.95 rf

qz.-quartz
f.-feldspar
rf.-rock fragments

no — Northfield Province
n — Northern Province
s — Southern Province

Table 5

Figure 41. -- Compaction phenomena in the sandstone suite. Sketched from actual thin sections.

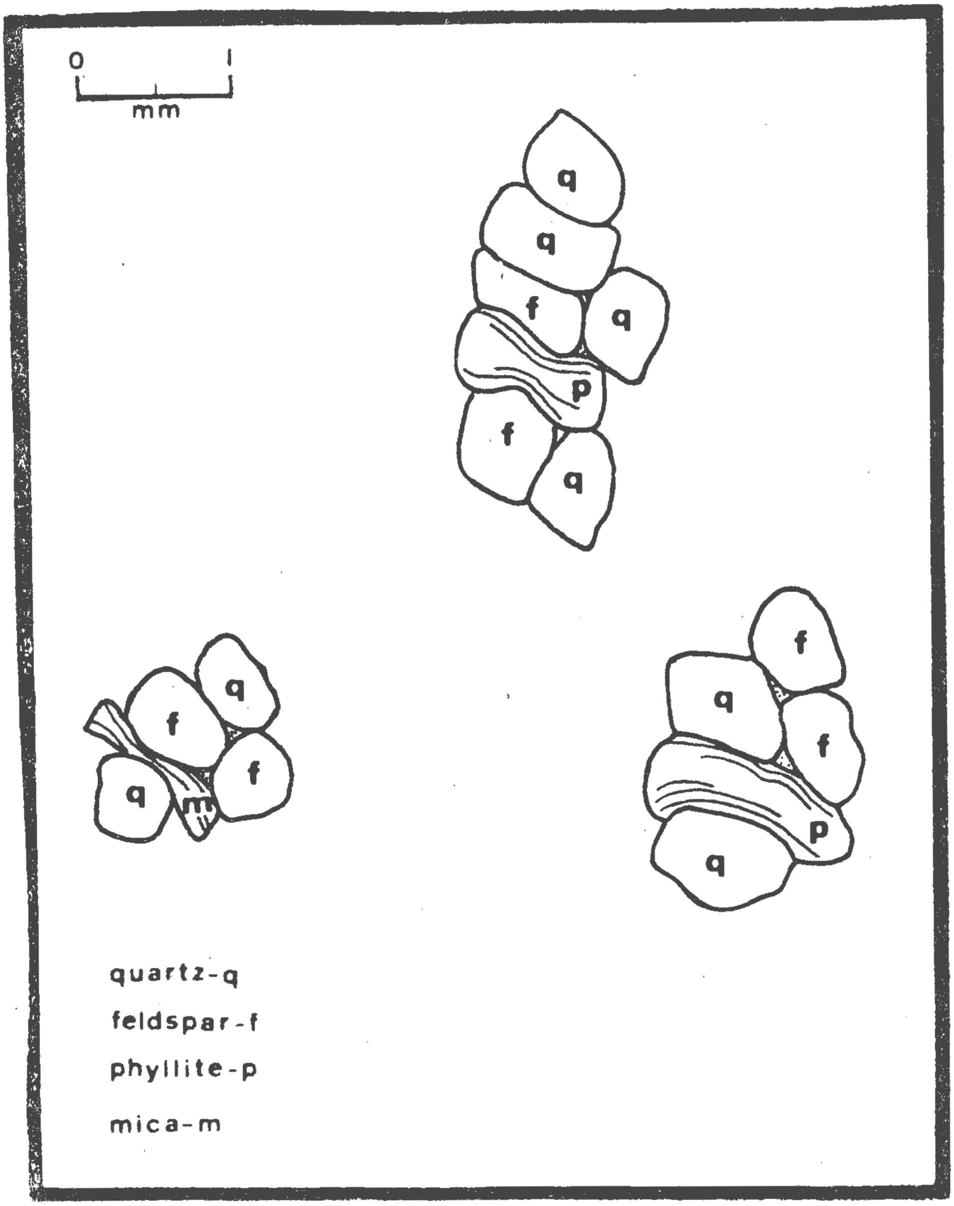

0
1
mm
q
q
f
q
p
f
q
q
f
q
f
m
f
q
f
p
q
quartz-q
feldspar-f
phyllite-p
mica-m

Figure 41

Allen (1962, p. 679) found a similar relationship in the Old Red Sandstone.

Classification. - The tripartite nomenclature proposed by Folk (1966) was used as the basis of classification of the sandstone suite. The rock name consists of three parts: grain size, textural maturity, and mineralogy. The classification is well-suited to these rocks because textural and mineralogic variability is very large.

The mineralogic classification of the sandstones facies is summarized in Figure 42. Samples are differentiated according to their geographic occurrence. Samples from Northern and Southern Provinces range from litharenites to arkoses (Fig. 42). Samples from the Northfield Province consist entirely of arkose and lithic arkoses (Fig. 42).

Arkoses in the Northern Province locally occur farther from the fault than do litharenites. This may be explained either by selective sorting or by mineralogic evolution of litharenites to arkoses during transportation. The deposition of rock fragments and feldspar in different parts of the basin due to selective sorting is ruled out because the arkoses and litharenites show a random distribution in the Southern Province and in some parts of the Northern Province. Thus it appears that during transportation a litharenite may evolve to an arkose by the release of granular minerals (quartz and feldspar) in schistose fragments by transportational breakdown. In proximal parts of the basin, rocks would be classified as litharenites, but as reworking and breakdown of rock fragments develop, arkoses would be deposited in more distal parts of the basin.

Two methods were undertaken to test this mineralogic evolution. First, the granular constituents of schist fragments were analyzed from the Northern Province and found to consist of 25 to 50 percent feldspar. Samples of mica schists from pre-Triassic rocks in the University of Massachusetts collection were also analyzed and found to contain 20 to 55 percent feldspar.

Figure 42. -- Classification of the sandstone suite (after Folk, 1966). Q - quartzose sandstone; SA - subarkose; SL - sublitharenite; A - arkose; LAk - lithic arkose; FL - feldspathic litharenite; and LA - litharenite. QZ? F? RF? Q includes all quartz types except chert, F includes feldspar and plutonic rock fragments, and RF includes all rock fragments (except plutonic rock fragments) and chert.

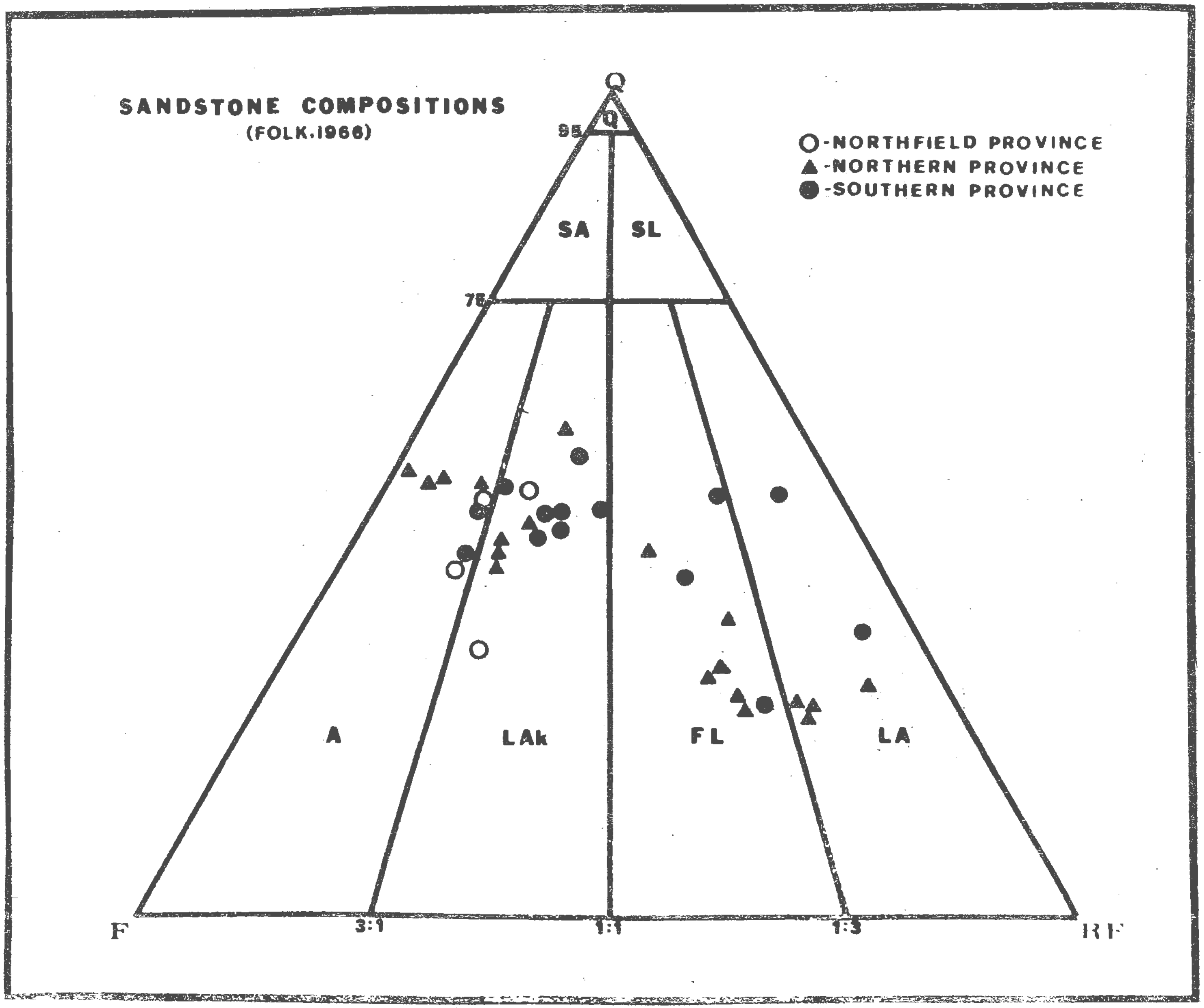

SANDSTONE COMPOSITIONS
(FOLK,1966)
Q
95
Q
SA
SL
75
A
LAk
FL
LA
F
3:1
1:1
1:3
RF
O-NORTHFIELD PROVINCE
▲-NORTHERN PROVINCE
●-SOUTHERN PROVINCE

Figure 42

Second, the size of granular minerals in pre-Triassic schists was compared to the size of granular minerals (quartz and feldspar) in arkoses in the Northern Province by plotting their respective grain sizes against sorting (Fig. 43). The results show that quartz and feldspar grains in arkoses and schists are about the same size, but that pre-Triassic schists are better sorted than the sandstones.

Thus it is possible for a schistose terrane in the source area to produce both litharenites and arkoses if transportational reworking of the litharenites occurs.

Mudrock

At least 20 percent of the section is mudrock, but its outcrop extent is not well known due to its low resistance to erosion. This is particularly true in the central portion of the area where Pleistocene and Holocene deposits have buried a large section of mudrocks. Calcareous units, commonly interbedded with mudrocks, are included in this facies.

Color is the most obvious feature of this part of the rock suite. The color values are: 5R 4/2, grayish red; 5R 6/2, pale; 5R 3/4, dusky red; 10R 4/2, dark yellowish brown; 5YR 2/2, dusky brown; N3, dark gray; and N1, black. The various shades of red indicate that hematite is very abundant in the mudrocks. Black and gray mudrocks occur in limited horizons. The black and gray coloring is due carbonaceous material deposited under reducing conditions - perhaps in small swamps or lakes. Some mudrocks show a black (N1) and dusky brown (5YR 2/2) alteration. This alteration reflects periodic changes in oxidizing and reducing conditions in parts of the basin.

The mineral composition of the siltstone portions of the mudrock facies was analyzed in 4 thin sections. These rocks consist primarily of quartz and feldspar with a hematitic clay matrix. Rock fragments are scarce. The siltstones are poorly sorted which is due in part to

Figure 43. -- Plot of grain size of quartz and feldspar in the sandstone facies and in pre-Triassic schists against sorting (Folk, 1965).

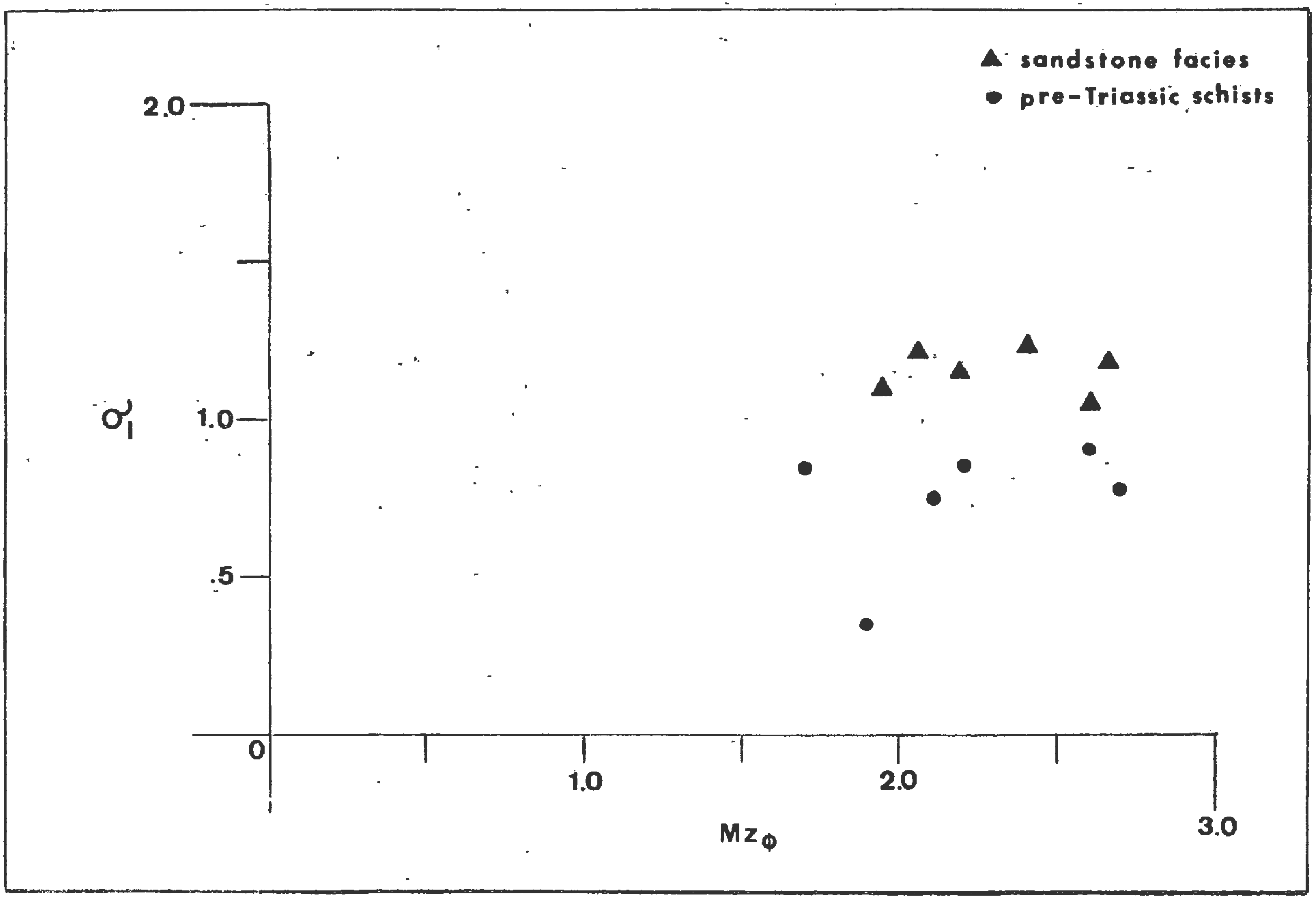

sandstone facies
pre-Triassic schists
2.0
1.0
.5
0
1.0
2.0
3.0
σ'1
Mzφ

Figure 43

the action of burrowing organisms. Large clay galls are smeared out in some horizons.

Calcareous shales and fine sandstones occur locally in the mudrock facies. Beds range from two inches to two feet in thickness. A lens two feet thick and nine feet long is exposed on the west side of Taylor Hill. This lens consist of elliptical pods of calcite approximately 15 mm along the long axis. Grain boundaries are outlined by irregular films of hematite (Fig. 44). Hematitic clay occurs in pores between the carbonate pods (Fig. 45). The carbonate is primarily micrite with minor amounts of hematite (Fig. 45); secondary dolomite is present in several of the individual pods (Fig. 46).

The structure of the carbonate pods suggests that they were deposited in ephemeral bodies of water as caliche or tufa limestone in arid or semi-arid climates. They are similar to specimens of caliche collected from Holocene playa-lake environments (University of Massachusetts collection).

Another part of the mudrock facies that has an important bearing on Triassic history is exposed in a zone traceable from Taylor Hill northward to Turners Falls. It is a mud-pebble breccia composed of laminated mudrock clasts set in a mud matrix (Fig. 47). The clasts average about 35 mm in mean size; they are commonly angular and some display chevron folds.

The formation of this mud-pebble breccia is probably best explained as a result of faulting in the underlying basement. A small fault initiated breakage of laminated lake beds and broke partially indurated mudrock into breccia pieces. The earthquake also initiated downslope slumping of the broken clasts into undisturbed mud units, ultimately forming a

Figure 44. -- Photograph of sawed section of a calcareous bed in the Turners Falls Sandstone east of Taylor Hill. Note the white eye-shaped pods of micrite surrounded with hematitic mud. This is interpreted as a primary caliche deposit.

Figure 45. -- Photomicrograph of one of the micrite pods. Minor hematitic mud occurs as impurities in the micrite pods. (Nicols crossed).

Figure 46. -- Photomicrograph of secondary development of dolomite (D) in the micrite pods. (Nicols uncrossed).

mud-pebble breccia. This interpretation is shown in Figure 48.

SEDIMENTARY HISTORY

The interpretation of the sedimentary history of the Turners Falls Sandstone and Mount Toby Conglomerate is based on the analysis of stratigraphic relationships, sedimentary structures, textural and mineralogic character of the sediments, and regional geologic setting.

The distribution and thickness of the entire section indicates a trough or wedge-shaped depositional basin with the long axis N-S parallel to the depositional strike. The initial filling of the basin was by alluvial fans growing from the region of a scarp developed along the Border Fault and extending about one to two miles westward into the basin. Three main loci of fan complexes are shown on a contour map of conglomerate clast size (Fig. 30). The majority of material was deposited from mudflows (Sheetflood and streamflood deposits, Blissenbach, 1954). Mudflows were probably triggered by violent storms in the source area. The presence of coarse conglomerate throughout the entire vertical section exposed along the fault indicates that techonism was proceeding during sedimentation.

The mudflow deposits were immediately reworked by fluvial processes. The stream regimens were maintained by the excess of water provided by the mudflows. These streams were intermittent with a high capacity and competence. These stream deposits can be recognized by the presence of coarse gravel channel fills interbedded with streamflood or sheetflood deposits (Figs. 49 and 50). The stream deposits are differentiated on the basis of overall sorting, erosional basal contacts, and excellent imbrication. These relationships agree with the data presented by Blissenbach (1954) and Denny (1965) in their investigations of alluvial fans.

Figure 48 -- Diagram, parallel to depositional strike, showing interpretation of the formation of the mud-pebble breccia.

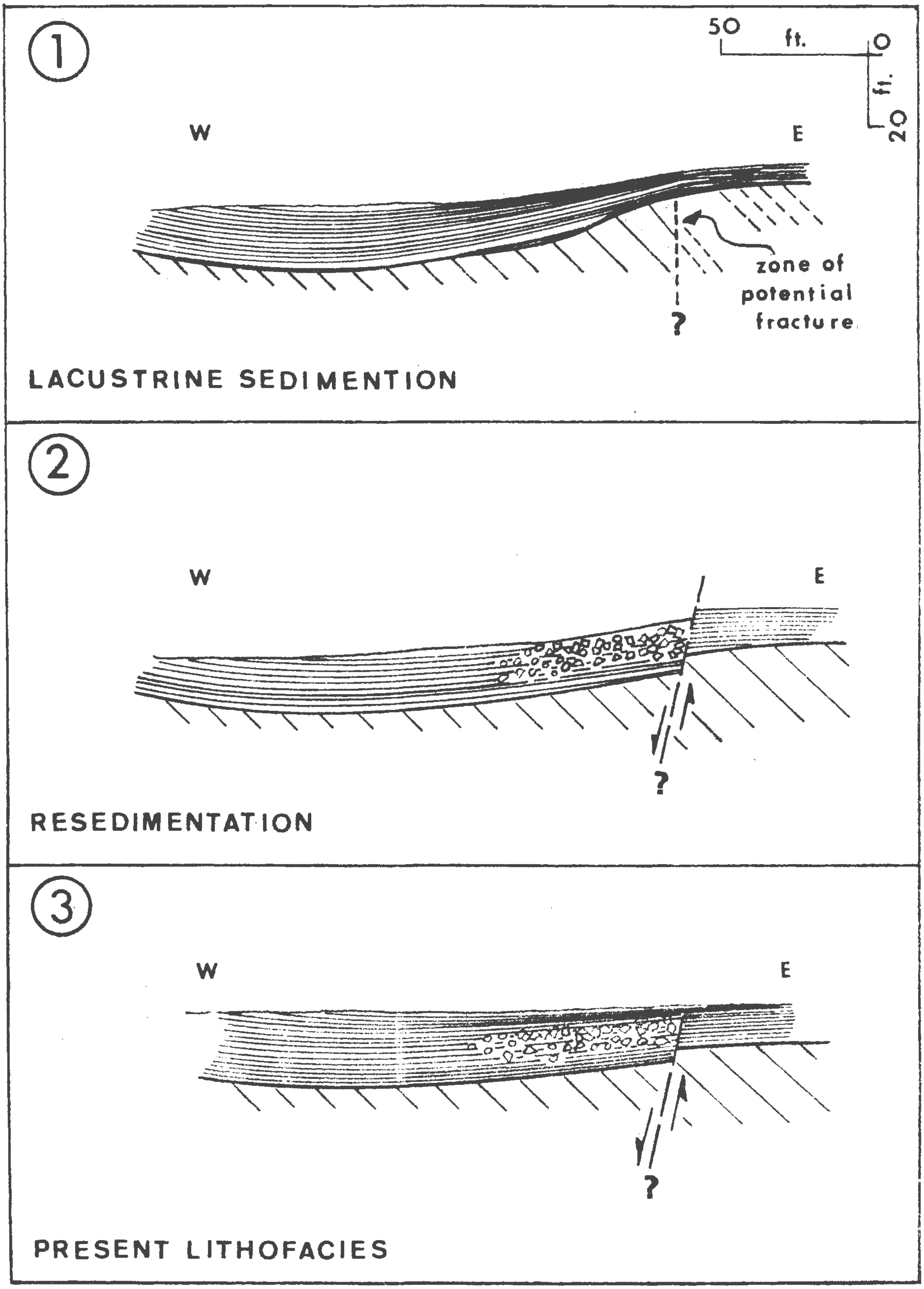

1
50
ft.
0
ft.
20
W
E
zone of
potential
fracture
?
LACUSTRINE SEDIMENTION
2
W
E
?
RESEDIMENTATION
3
W
E
?
PRESENT LITHOFACIES

Figure 48

Figure 49. -- Interbedded sheetflood (sf) and streamflood (sfl) deposits in the Mount Toby Conglomerate east of Turners Falls.

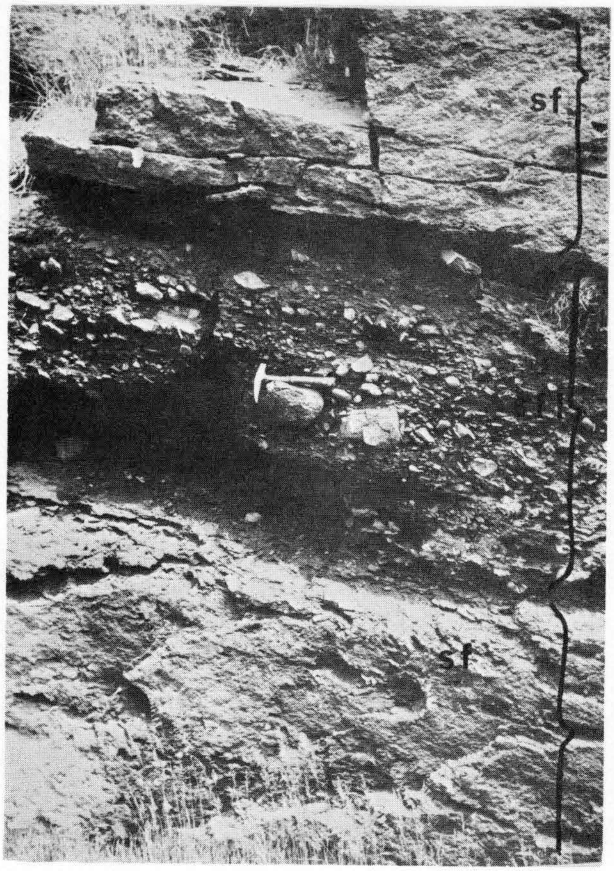


Figure 49

Additional sediment was brought into the basin by intermittent streams that originated in the vicinity of the fault scarp. These streams are important for they tend to maintain equilibrium between erosion in the source area and deposition in the basin and they are characterized by broad, flat-floored troughs with or without distinct banks. The sediment ranges in size from clay to boulders, but finer fractions constitute only a small part of the total bedload (Denny, 1965, p. 39). Deposits of this kind are characterized by the presence of gravel lenses and coarse sand lenses in a predominantly coarse conglomerate facies. They are present at several localities along the Border Fault. At Roaring Brook on the east side of the Mount Toby highland, coarse sandstone beds overlie a coarse conglomerate of mudflow or talus origin.

The fan complexes were the loci for fluvial sedimentation within the depositional basin. Blissenbach (1954)and Denny (1965 found that fan surfaces are traversed by numerous meandering and braiding streams that possess abundant cut-and-fill structure, current ripple marks, crossbedding, and good imbrication (Blissenbach, 1954). The streams are also subject to large variations in capacity and competence, and are reworking the large volume of mudflow sediment.

Criteria for recognizing this environment in the Turners Falls Sandstone and the Mount Toby Conglomerate are abundant. The profusion of cut-and-fill structures suggests that channel migration, channel piracy, and subsequent abandonment were active processes during the late Triassic. The polymodal nature of the paleocurrent indicators (Fig. 17) attests to the braiding and meandering habit of the streams. The size and distribution of the crossbeds imply that they were formed quickly in rapidly migrating channels. The current ripples, cuspate ripples, and irregular ripples are best explained as features indigenous to alluvial fans and their associated streams. The presence of antidunes and plane beds indicate that fan streams often flowed in the upper flow regime and were characterized by high velocities and shallow water depths (Wessel and others, 1967; Hand and others, 1968).

Many of the fine sand and mudrock deposits reflect flood plain sedimentation. Denny (1965, p. 11) pointed out that the fanstreams finally finger out on the peripheral edges of the fan, making it impossible to distinguish between fluvial and flood plain deposits. This zone between flood plain and fluvial deposits probably represents the area where caliche was deposited.

Finally, as the hydrologic competence of the streams decreased, the remaining detritus, almost exclusively mud, was deposited in a playa environment. Playas are common to Holocene fan complexes also. (Blissenbach, 1954; Denny, 1965). Evaporite deposits such as halite, anhydrite, and glauberite were formed in the playas. Local ponding produced more permanent lakes that were probably maintained by underground springs. These more permanent lake environments were capable of supporting a diverse flora and fauna. Fish are the most abundant fossils.

A summary of the criteria used to delineate the different environments in the Turners Falls Sandstone and the Mount Toby Conglomerate is shown in Figure 50.

The fan-complex deposits consist of three distinct facies (Fig. 50). A proximal-fan facies composed of mudflow (sheetflood and streamflood) deposits is recognized on the basis of poor sorting, random distribution of conglomerate clasts, lack of pebble imbrication, and pebbly sandstone

Figure 50. -- Measured stratigraphic sections showing the sedimentary features used in discriminating different aspects of the depositional setting.

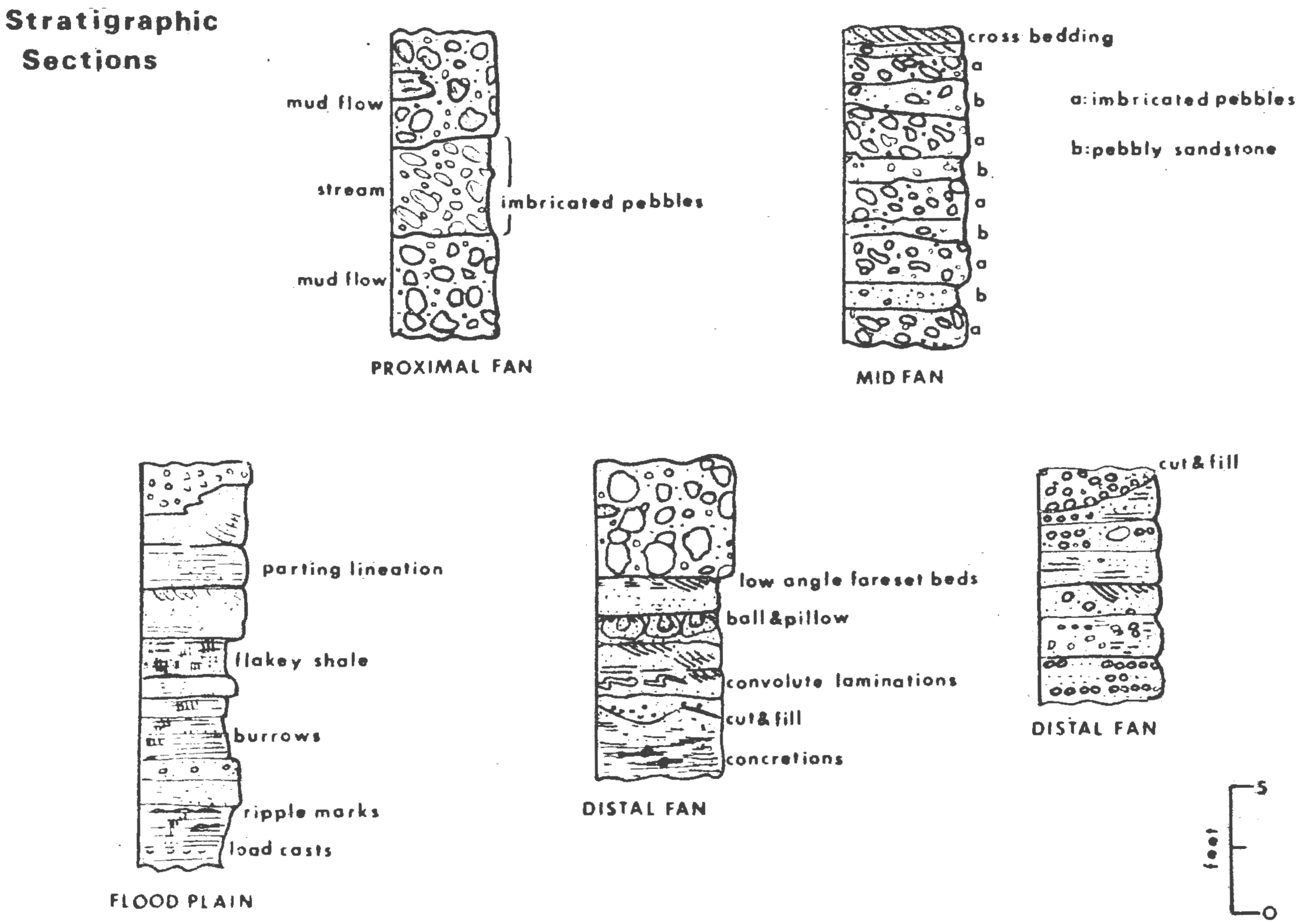

Stratigraphic Sections
mud flow
stream
mud flow
imbricated pebbles
PROXIMAL FAN
cross bedding
a: imbricated pebbles
b: pebbly sandstone
MID FAN
parting lineation
flakey shale
burrows
ripple marks
load casts
FLOOD PLAIN
low angle foreset beds
ball & pillow
convolute laminations
cut & fill
concretions
DISTAL FAN
cut & fill
DISTAL FAN
5
feet
0

Figure 50

occurring in irregular lenses. Stream deposits occasionally are interbedded with the proximal mudflow sediments (Figs. 49 and 50); stream deposits display pronounced imbrication, moderate sorting and contain no sandstone lenses (Fig. 50). The mid-fan facies is recognized by the presence of cyclic units of pebbly sandstone and pebbly conglomerate eight to twenty-seven inches thick. The pebbly sandstones display low-angle foreset bedding, plane beds, and isolate imbrication (Fig. 50). The pebbly conglomerates are moderately well sorted and contains contact imbrication (Laming, oral communication, 1967). The distal-fan facies (Fig. 50) is characterized by cut-and-fill structures, low-angle foreset bedding, isolate imbrication, plane beds, ball-and-pillow structures, backset bedding, and convolute laminations. These structures are usually developed in pebbly sandstone, coarse sandstone, and sandy, pebbly conglomerate. Distal fan deposits commonly have erosive basal contacts with underlying flood plain deposits (Fig. 50).

The fan-complex facies intertongue westward with flood plain deposits. Flood plain deposits are primarily composed of fine to coarse sandstones, siltstones, silty claystones, and minor lenses of fine conglomerate. Structures present include plane beds and associated parting lineation, load casts, ripple marks, burrows, flaky shale units, and crossbedded units with foreset inclination generally greater than fifteen degrees (Fig. 50).

Late Triassic Climate

Introduction. - The climate of the Newark Epoch has been a subject of debate for over one hundred years. Russell (1892, p. 46) concluded that the red rocks of the Newark system "were formed from debris of land that had been long exposed to the action of a warm, moist atmosphere."

Both Dana (1883) and Davis (1898) accepted the hypothesis as proposed by Russell, and Dana postulated a heavy rainfall with some temporary glaciation. Barrell (1908), however, proposed a semi-arid climate. He compared Triassic sedimentation and climate with the conditions prevailing in the Great Valley of California. He considered fanglomerates (as defined by Lawson, 1912) to be indigenous features of arid or semi-arid regions. Raymond (1927) believed that the Triassic climate was warm and humid. Krynine (1950, p. 182), the most recent investigator, felt that "a savanna climate of that type, with a uniformly high temperature around 80° F., a totally rainless dry season lasting at least three months and a heavy rainfall exceeding 50 inches in the valley proper and in excess of sixty or seventy inches in the erosion region of the scarp ..." was characteristic of the original ideas of Barrell (1908, 1915). The criteria for this conclusion are summarized below.

Climatic Criteria. - Floral evidence, as discussed by Lull (1953, p. 20), shows that the plants are mainly in the black shales "which apparently represent lakes or swamps due to damming up of the drainage." The present study supports Lull's conclusions, with the exception that fragmental plant detritus is locally present in some of the red and brown mudrocks. Coal is also present in minor amounts. Lull (1953, p. 24) described three main types of plants - ferns, cycads, and conifers--all of which are limited to the black shales.

Animal fossils reported from the Triassic include fresh-water shells, one insect, trails, fish, and terrestrial vertebrates. The shells include two fresh or brackish water forms which, according to Lull (1953, p. 39), point to a somewhat permanent body of water. The trails were reviewed by Hitchcock (1858) and Lull (1915, 1953). The fish are limited to the black shale horizons, and although their geographic range is from Turners Falls to New Haven, their occurrence in the black shales indicates only the presence of fresh or brackish water in small permanent lakes. Such lakes, according to Lull (1953, p. 20)"may well represent the recurrence of periodical climatic cycles of greater than average humidity and consequent expansion of the aquatic habitat; or a disturbance of the drainage, climatic conditions remaining constant." The terrestrial vertebrates are represented by scarce skeletal remains and by numerous footprints, but their overall habitat is not well known. In conclusion, the organic assemblage is not a definitive indicator of Triassic climatic conditions.

Paleoclimatic data as deduced from sedimentological evidence includes types and abundance of structures, authigenic minerals, clay minerals, terrigenous particles, and sediment texture.

Raindrop impressions, mudcracks, and footprints are not necessarily representative of a particular climate. All that is required is a period of dryness (Krynine, 1950, p. 163). However, the preservation of dessication marks in large numbers, such as in the Turners Falls Sandstone and the Mount Toby Conglomerate, would seem to favor an arid or semi-arid climate. Lack of vegetation also enhances the development of these structures, and even a seasonal humid climate (Krynine, 1950) would support some sort of vegetation. The red hematitic soils in the basin would not favor fossil preservation of the vegetation, but in the present study no evidence of rootlets or associated structures was found. This suggests a scarcity of vegetation is characteristic of arid or semi-arid climates (Blissenbach, 1954).

The directional sedimentary structures are suggestive of certain climatic processes in the depositional basin. The small lateral extent of the crossbedded units indicates deposition by short-lived braiding or meandering streams. Irregular ripple marks (Fig. 12) also have been described from braided channels (Doeglas, 1962, p. 176). Doeglas (1962, p. 169) notes that braided streams are best developed under semi-arid or arid conditions. The abundance of scour-and-fill structures indicates large variations in stream competence, a condition favored by intermittent drainage subject to periodic and torrential flooding. The upper flow regime structures (plane beds and antidunes) and the low-angle foresets have been described from alluvial fan environments in arid and semi-arid climates (McKee and others, 1967; Power, 1961: Rahn, 1967).

The texture of the conglomerates has climatic significance also, for large boulders are not present in fans developed under humid conditions (Krynine, 1950, pp. 184-187) John Rodgers (oral communication, 1966) found that under humid conditions sorting and roundness in alluvial fans are the same as in fans forming under arid or semi-arid conditions with the exception that large boulders are not produced under humid conditions. Figure 51 shows a boulder seventy-two inches long in the Mount Toby Conglomerate at the western edge of the present basin. Similar boulders three to four feet long abound in the conglomerate. This is suggestive of arid or semi-arid conditions in which mudflows constitute the primary depositional medium (Blissenbach, 1954).

The matrix of the conglomerates contains very little mud. This phenomenon has been noted by Walker (1967, p. 358) in fanglomerates developed in an arid climate in southern California. He attributes the lack of mud to a very poorly developed soil zone in the source area due to a lack of chemical weathering. The same reasoning can be applied to the present study area, suggesting that semi-arid or arid conditions prevailed in the depositional basin.

Figure 51. -- Large granitic boulders in the Mount Toby Conglomerate deposited near the western edge of the present basin west of Sunderland. The largest boulder is 72 inches long.

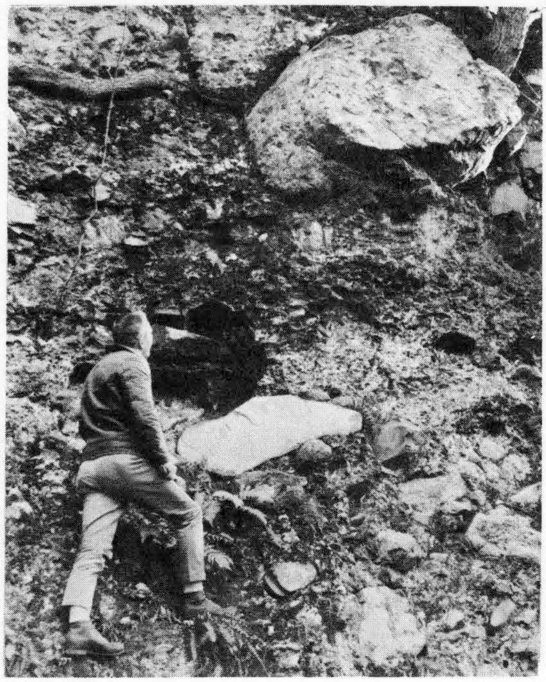


Figure 51

The chemical state of the terrestrial fragments is directly related to climate. A rugged topography weathered under humid conditions produces fresh and weathered material as the streams cut through a deeply weathered mantle to fresh bedrock (Krynine, 1950). Krynine (1950, pp. 186-192) showed that vertical erosion favors both weathered fragments formed in the interfluves and fresh fragments formed in the canyons. The weathered fragments from the soil zone dislodge by impact fresh particles from the canyon walls. The final agglomeration of sediment will consist of fresh and weathered constituents, provided deposition is rapid. An alternative to this hypothesis has been suggested to produce the same phenomena (see p. 89).

The detrital fragments in the Turners Falls Sandstone and the Mount Toby Conglomerate display evidence of being exposed to humid conditions. The mudrocks contain hematitic clay. The sandstone and conglomerate matrices contain minor amounts of hematite and hematitic rims on particles of all sizes. Labile constituents (phyllite, biotite, chlorite, and feldspar) are fresh or weathered, and the feldspar is locally kaolinitic. All of these factors point to intense weathering under humid conditions.

Walker (1967, p. 359) has shown that red coloration can be produced diagenetically under arid or semi-arid conditions by oxidation of ferromagnesium minerals. This type of post-depositional alteration can be recognized by: (a) hematitic halos around iron-bearing detrital grains (especially biotite); (b) replacement of a chlorite-biotite matrix by hematite; and (c) irregular outline of hematitic coatings on quartz and feldspar grains (1967, pp. 365-366). Both biotite and chlorite in the sandstone facies show chemical alteration to hematite (Figs. 52a and 52b) and a biotite-chlorite matrix commonly shows alteration to hematite (Fig. 52c). These data suggest that a portion of the hematite originated in

Figure 52a. -- Photomicrograph of primary chlorite (C) showing post-depositional alteration to hematite (H). Sample is from the Turners Falls Sandstone in the Northern Province.

Figure 52b. -- Photomicrograph showing post-depositional alteration of a biotite grain (B) to hematite (H). Sample is from the Turners Falls Sandstone in the Southern Province. The arrows point to relict portions of the biotite grain.

Figure 52c. -- Photomicrograph of biotite-chlorite matrix (M) being altered to hematite (H) in the Turners Falls Sandstone. Sample is from the Northern Province.

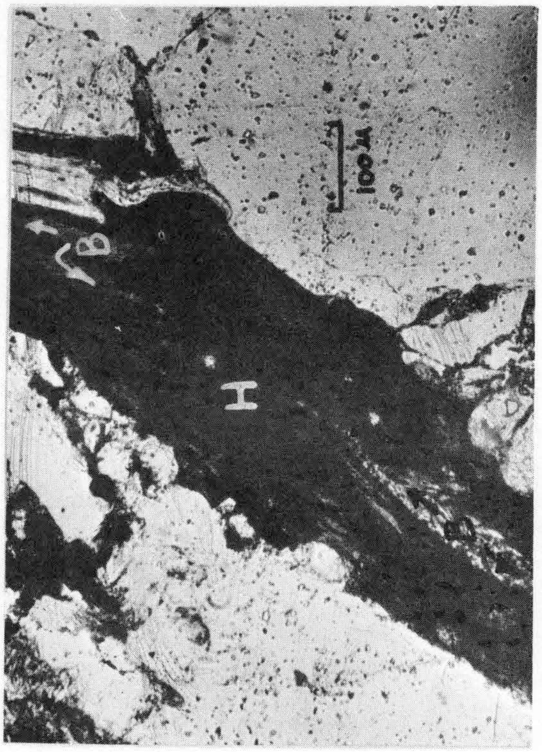


Figure 52a

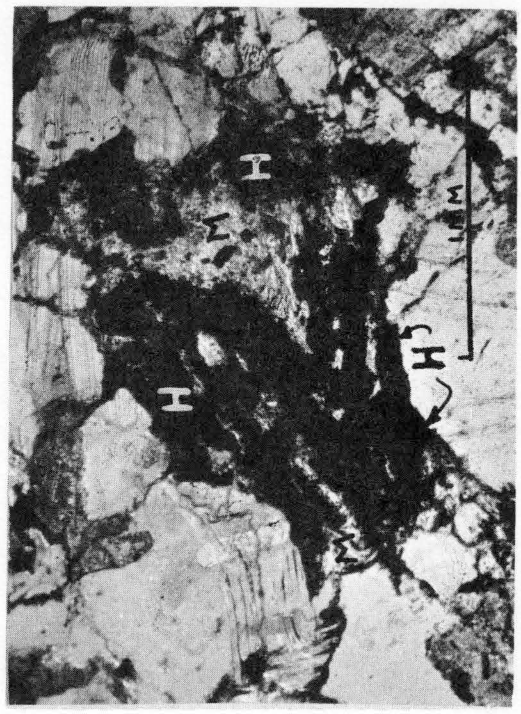


Figure 52c

basin and that detrital constituents were weathered under both humid and arid to semi-arid conditions.

The pre-Triassic rocks exposed at the inselberg at Taylor Hill are fresh and lack evidence of being subjected to chemical weathering. Physical weathering is best developed in arid or semi-arid climates (Blissenbach, 1954), and the chemically unaltered state of these crystalline rocks implies that semi-arid conditions prevailed in the depositional basin.

The authigenic minerals preserved in the present basin are directly related to the Triassic climate. Soluble salts such as halite and gypsum are produced by the complete evaporation of extensive bodies of water in desert regions. Playa deposits contain abundant concentrations of halite, gypsum, and glauberite. Emerson (1895) reports cavities representing halite crystals from West Springfield, Holyoke and Wilbraham, and Abel (1926) reported gypsum casts in the Connecticut part of the Connecticut Valley Triassic. Casts similar to those described by Emerson are also present east of Turners Falls at Barton Cove. The ground water in the sandstone and shale facies contains calcium and sulfate concentrations in small percentages. These Triassic rocks form a separate ground-water basin (Saines and Motts, oral communication, 1967). John Sanders (oral communication, 1966) describes Triassic lake beds in Connecticut that have as much as twenty percent calcium carbonate. Undoubtedly much of this carbonate and sulfate is secondary, but a large portion must be leached from primary evaporite deposits. These and the presence of limestone (caliche) in sample AOB (Figs. 44, 45, and 46) are certainly evidence of a semi-arid climate in the basin.

Proposed Late Triassic Climate.- Data presented above strongly suggest that the Turners Falls Sandstone and the Mount Toby Conglomerate were deposited in a basin charactericaed by semi-arid climatic conditions. The basin was bordered by a moderately high, rugged source area that was subjected to humid weathering. The transition from humid to semi-arid conditions probably took place along the fault scarp. Chemically weathered detritus was produced in the humid source area and moved westward down the scarp where it became mixed with the physically weathered detritus formed on the scarp. Many of the large boulders were weathered from the semi arid portion of the scarp.

The short but heavy sporadic cloudbursts reaching the scarp, produced the water necessary to initiate mud flows. The abrupt break in slope between the scarp and the basin floor provided the geometrical conditions necessary for the formation of alluvial fans. Excess water from the mudflows produced braiding intermittant streams that reworked mudflow deposits and moved the finer material to deeper parts of the basin. Figure 53 summarizes the proposed Triassic paleogeography.

Figure 53. -- A paleogeographic summary of Late Triassic depositional conditions in the northern part of the Connecticut Valley. Semi-arid conditions prevailed in the depositional basin and part of the scarp; the highland source area was weathered under humid conditions.

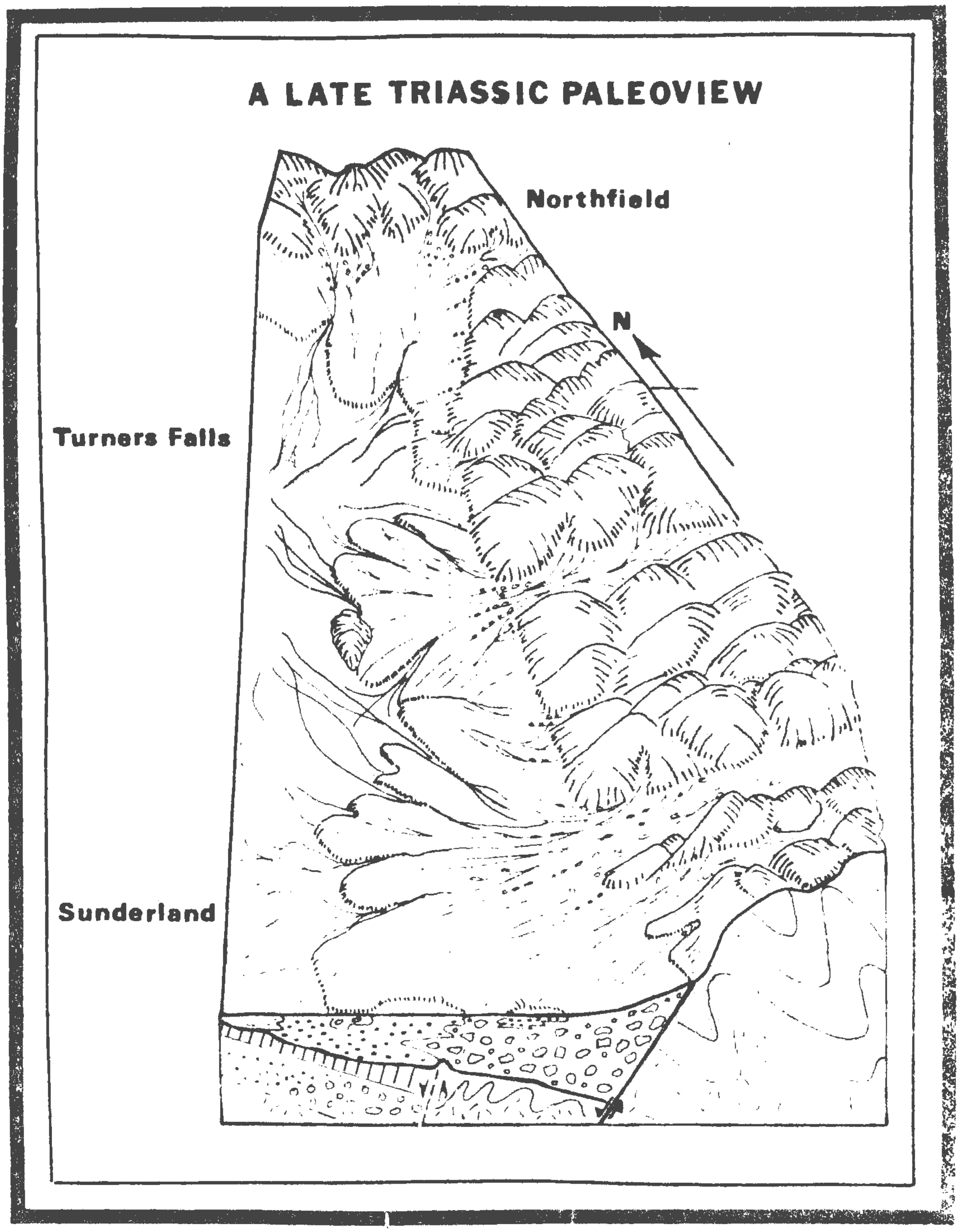

A LATE TRIASSIC PALEOVIEW
Northfield
N
Turners Falls
Sunderland

Figure 53

SUMMARY AND CONCLUSIONS

Summary

The depositional history of the Turners Falls Sandstone and the Mount Toby Conglomerate began with basin filling, primarily by alluvial fans. Fan complexes were built up by successive accumulations of sheetflood, streamflood, and stream deposits. Stream regimens were maintained by recurring tectonism along the Border Fault. Between periods of mudflow sedimentation, streams originating on the fan complexes reworked much of the fan detritus. The mudrock facies reflects deposition associated with flood plain and playa environments. Authigenic minerals such as calcite and gypsum were formed in these environments.

Textural data from all rock facies, nature of the primary sedimentary structures, and authigenic mineralogy indicate that the late Triassic deposits accumulated under a semi-arid climate. The presence of abundant hematitic clay reflects humid weathering in the source area. More or less permanent lakes characterized by black shales are a result of local damming. These lakes were probably fed by springs.

Stratigraphic relationships show that deposition occurred in a wedge-shaped trough. Paleocurrent data suggest that this Late Triassic basin was characterized by interior drainage.

Conclusions

Sedimentary Structures (Directional). - Low-angle crossbeds (5° - 7°) characteristic of many of the foreset beds formed in the upper part of the lower flow regime, and the small horizontal distribution of 40 crossbeds indicates that deposition occurred in rapidly shifting channels. The association of parting lineation with antidunes supports Allen's (1964) conclusion that it is developed in the upper flow regime. A tripartite division of upper flow regime deposits is proposed and consists of plane beds, antidunes, and conglomerate. Antidune structures of this sequence are preserved by rapid burial of conglomerate. The rare occurrence of oscillation ripple marks suggests a lack of permanent water bodies. The amplitude of cuspate ripples represents a response at the sedimentary interface to fast moving streams of short duration.

Sedimentary Structures (Non-directional). - Deformational structures including loading phenomena, slump structures, load casts, ball-and-pillow structures, and convolute laminations indicate that preconsolidated Triassic sediments contained varying amounts of water prior to final burial and consolidation. Deformation was influenced primarily by the amount of overburden and the speed of accumulation of overburden. Scour-and-fill structures attest to the fact that channel migration and stream braiding were common features of Triassic sedimentation. Abundant dessication features and raindrop impressions suggest that prolonged dry periods were common. The fossil record serves only to date the age of the deposits and confirm their continental origin.

Conglomerate Fabric and Dispersal Trends. - Gravel fabric is a valid means of examining dispersal trends of conglomeratic rocks. Fabric and imbrication may aid in the interpretation of environments within a conglomerate facies. Sheetflood deposits rarely display imbrication but streamflood and stream deposits are usually imbricated. Analysis of a moving average diagram of maximum pebble size shows that three major alluvial fan complexes are present. Roundness varies little throughout the depositional basin. Exfoliation probably influences the rounding of particles.

Petrography. - Analysis of the conglomerate fragments indicates that the Northern and Southern Provinces were bordered by lithologically different source areas. The Southern Province received more granitic detritus and the northern area received more rock types. Phyllite and vein quartz are distributed in equal proportions throughout the source area and depositional basin. Correlation between conglomerate clasts and metamorphic isograd indicators in the clasts shows that the Triassic source rocks were similar to crystalline rocks presently surrounding the depositional basin.

The sandstones are predominately arkose, lithic arkoses, feldspathic litharenites, and litharenites. They contain less than 10 percent matrix and less than 50 percent quartz. Transportational breakdown of metamorphic rock fragments can result in the production of quartz and feldspar. This suggests that litharenites may evolve to arkoses if the source area contributes schistose material to the depositional basin. Textural parameters (sorting, skewness, and kurtosis) show no significant trends in the sandstone facies.

The mudrock facies is composed primarily of red siltstones and shales with interbeds of calcareous and carbonaceous material.

Paleogeography. - Basin filling was accomplished primarily by alluvial fans deposited along the eastern margin of the basin. Depositional environments include alluvial fan, fluvial, flood plain, and playa lake. These different environments can be recognized by their lithologic characteristics, sedimentary structures, and textural relationships. Sedimentary structures, texture, and authigenic mineralogy indicate that semi-arid conditions prevailed in the depositional basin.

Reference's Cited

Abel, Otto, 1926, Die Lebensspuren in der oberen Trias des Connecticut und Massachusetts: Zool. Bot. Gesell., Wien, Verh. Jg. 1924-5, p. 74-75, 145-150.

Allen, J.R.L., 1962, Petrology, origin and deposition of the highest Lower Old Red sandstone of Shropshire, England: Jour. Sed. Petrology, v. 32, p. 657-697.

____________, 1964, Primary current lineation in the lower Old Red Sandstone (Devonian), Anglo-Welsh Basin: Sedimentology, v. 13, p. 89-108.

____________, 1965, A review of the origin and characteristics of Recent alluvial sediments: Sedimentology, v. 5, p. 89-191.

Bain, G.W., 1932, Northern area of the Connecticut Valley Triassic: Am. Jour. Sci., v. 23, p. 57-77.

Balk, Robert, 1956, Bedrock geology of the Bernardston quadrangle, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ-90.

____________, 1956, Bedrock geology of the Millers Falls quadrangle, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ-93.

____________, 1956, Bedrock geology of the Northfield quadrangle, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ-92.

Barrell, Joseph, 1908, Relations between climate and terrestrial deposits: Jour. Geology, v. 16, p. 159-190, 363-384.

____________, 1915, Central Connecticut in the geologic past: Conn. Geol. Nat. History Survey Bull. 23, 44 p.

Blackwelder, Eliot, 1929, Mudflow as a geologic agent in semi-arid mountains: Geol. Soc. America Bull., v. 39, p. 465-484.

Blissenbach, E., 1954, Geology of alluvial fans in semi-arid regions: Geol. Soc. America Bull., v. 65, p. 175-190.

Bluck, B.J., 1964, Sedimentation of an alluvial fan in southern Nevada: Jour. Sed. Petrology, v. 34, p. 395-400.

____________, 1965, The sedimentary history of some Triassic conglomerate in the Vale of Glamorgan, South Wales: Sedimentology v. 4, p. 225-245.

Bucher, W.H., 1919, On ripples and related sedimentary surface forms and their paleogeographic interpretations: Am. Jour. Sci. (4), v. 47, p. 149-210, 241-269.

Coleman, J.M., and Gagliano, S.M., 1965, Sedimentary structures in Mississippi River deltaic plains: in Middleton, G.V. (ed.), Primary sedimentary structures and their hydrodynamic interpretation, Soc. Econ. Paleontologists and Mineralogists Special Pub. No. 12, p. 133-148.

______________, Gagliano, S.M., and Webb, J.E., 1964, Minor sedimentary structures in a prograding distributary: Marine Geology, v. 1, p. 240-258.

Curray, J.R., 1956, The analysis of two-dimensional orientation data: Jour. Geology, v. 64, p. 117-131.

Dana, J.D., 1883, Origin of the Jura-Trias of eastern North America: Am. Jour. Sci., v. 25, p. 383-386.

Davis, W.M., 1898, The Triassic Formation of Connecticut: U.S. Geol. Survey, 18th Ann. Rept., part 2, p. 1-192.

Denny, C.S., 1965, Alluvial fans in the Death Valley region, California and Nevada: U.S. Geol. Survey Prof. Paper 466, 61 p.

Doeglas, D.J., 1962, The structure of sedimentary deposits of braided rivers: Sedimentology, v. 1, p. 167-190.

Emerson, B.K., 1895, A mineralogical lexicon of Franklin, Hampshire, and Hampden Counties, Massachusetts: U.S. Geol. Survey Bull. 126, 144 p.

______________, 1898, Geology of Old Hampshire County, Massachusetts; comprising Franklin, Hampshire, and Hampden Counties: U.S. Geol. Survey Mon. 29, 790 p.

______________, 1917, Geology of Massachusetts and Rhode Island: U.S. Geol. Survey Bull. 597, 289 p.

Folk, R.L., 1965, Petrology of sedimentary rocks: Austin, Texas, Hemphill's Bookstore, 159 p.

______________, 1966, Descriptive sandstone classification: Sedimentation class syllabus, The University of Texas, 3 p.

Frazier, D.E., and Osanik, A., 1961 Point bar deposits, Old River Locksite, Louisiana: Gulf Coast Assoc. Geol. Soc. Trans., v. 11, p. 121-137.

Goddard, E.N., chm., and others, 1948, Rock-color chart: Washington, Natl. Research Council (repub. by Geol. Soc. America, 1951), 6 p.

Gilbert, G.K., 1914, The transportation of debris by running water: U.S. Geol. Survey Prof. Paper 86, 263 p.

Hand, B., Wessel, J.M., and Hayes, M.O., 1968, Antidunes in the Mount Toby Formation (Triassic), Massachusetts (Abs.): Annual meeting, Northeastern Section, Geol. Soc. America, p. 31.

Harms, J.C., MacKenzie, D.B., and McCubbin, D.G., 1963, Stratification in modern sands of the Red River, Louisiana: Jour. Geology, v. 71, p. 560-580.

____________, and Fahnestock, R.K., 1965, Stratification, bed forms and flow phenomena (with an example from the Rio Grande): in Middleton, G.V., (ed.), Primary sedimentary structures and their hydrodynamic interpretation; Soc. Econ. Paleontologists and Mineralogists Special Pub. 12, p. 84-115.

Hitchcock, E., 1858, Ichnology of New England: A report on the sandstone of the Connecticut Valley, especially its fossil footprints: Boston.

Kennedy, J.F., 1961, Stationary waves and antidunes in alluvial channels: Calif. Inst. Technology, W.M. Keck Lab. of Hydraulics and Water Resources, Rept. KH-R-3, 36 p.

Klein, G. deV., 1965, Dynamic significance of primary structures in the Middle Jurassic Great Oolite Series, Southern England: in Middleton, G.V., (ed.), Primary sedimentary structures and their hydrodynamic interpretation; Soc. Econ. Paleontologists and Mineralogists Special Pub. 12, p. 173-191.

Krumbein, W.C., 1939, Preferred orientation of pebbles in sedimentary deposits: Jour. Geology, v. 47, p. 673-706.

____________, 1941, Measurement and geological significance of shape and roundness of sedimentary particles: Jour. Sed. Petrology, v. 11, p. 64-72.

Krynine, P.D., 1950, Petrology, stratigraphy, and origin of the Triassic sedimentary rocks of Connecticut: Connecticut Geol. Nat. History Survey Bull. 73, 243 p.

Lane, E.W., and Carlson, E.J., 1954, Some observations of the effect of particle shape on movement of coarse sediments: Am. Geophys. Union Trans., v. 35, p. 453-462.

Lawson, A.C., 1912, The petrographic designation of alluvial fan formations, Calif. Univ. Pubs. Geol. Sci., Berkeley, Calif., v. 7, p. 325-334.

Longwell, C.R., 1922, Notes on the structure of the Triassic rocks in southern Connecticut: Am. Jour. Sci., v. 4, p. 223-236.

____________, 1923, The Triassic of Connecticut: Am. Jour. Sci., v. 16, p. 259-263.

Lull, R.S., 1915, Triassic life of the Connecticut Valley: Connecticut Geol. Nat. History Survey Bull. 24, 285 p.

_____________, 1953, Triassic life of the Connecticut Valley: Connecticut Geol. Nat. History Survey Bull. 81, 336 p.

Middleton, G.V., 1965, Antidune crossbedding in a large fume: Jour. Sed. Petrology, v. 35, p. 922-927.

McBride, E.F., and Yeakel, L.S., 1963, Relationship between parting lineation and rock fabric: Jour. Sed. Petrology, v. 33, p. 779-782.

McGee, W.J., 1897, Sheetflood erosion: Geol. Soc. America Bull., v. 8, p. 87-112.

McKee, E.D., 1957, Flume experiments on the production of stratification and cross-stratification: Jour. Sed. Petrology, v. 27, p. 129-134.

_____________, 1965, Experiments on ripple lamination: in Middleton, G.V. (ed.), Primary sedimentary structures and their hydrodynamic interpretation; Soc. Econ. Paleontologists and Mineralogists Special Pub. 12, p. 66-83.

_____________, Crosby, E.J., and Berryhill, M.L., 1967, Flood deposits, Bijou Creek, Colorado, June, 1965: Jour. Sed. Petrology, v. 27, p. 829-851.

Newberry, J.S., 1898, Fossil fishes and fossil plants of the Triassic rocks of New Jersey and the Connecticut Valley: U.S. Geol. Survey Mon. 14, 152 p.

Pelletier, R.R., 1958, Pocono paleocurrents in Pennsylvania and Maryland: Geol. Soc. America Bull., v. 69, p. 1033-1064.

Pettijohn, F.J., 1957, Sedimentary rocks: New York, Harper and Bros., 718 p.

_____________, Potter, P.E., Siever, R., 1965, Geology of sand and sandstone: Bloomington, Indiana, Indiana University Press, 208 p.

Potter, P.E., and Pettijohn F.J., 1963, Paleocurrents and Basin Analysis: Berlin, Springer Verlag, 296 p.

Power, W.R., 1961, Backset beds in the Coso Formation, Inyo County, California: Jour. Sed. Petrology, v. 31, p. 603-607.

Powers, M.C., 1953, A new roundness scale for sedimentary particles: Jour. Sed. Petrology, v. 23, p. 117-119.

Rahn, P.H., 1967, Sheetflood, streamfloods, and the formation of pediments: Assoc. of Am. Geographers Annals, v. 57, p. 593-604.

Rapp, Anders, 1959, Avalanche boulder tongues in Lappland: Geog. Annaler, v. 41, p. 34-48.

_____________, 1960, Talus slopes and mountain walls at Tempelfjorden, Spitzbergen: Norsk Polarinst., Skr. 119, 96 p.

Raymond, P.E., 1927, The significance of red color in sediments: Am. Jour. Sci., v. 240, p. 658-668.

Reynolds, D.D., and Leavitt, D.H., 1927, A scree of Triassic age: Am. Jour. Sc. (5), v. 13, p. 167-171.

Rubey, W.W., 1930, Lithologic studies of fine grained Upper Cretaceous sedimentary rocks of the Black Hills region: U.S. Geol. Survey Prof. Paper 165A, 54 p.

Russel, I.C., 1892, The Newark System: U.S. Geol. Survey Bull. 85, 344 p.

Sanders, J.E., 1960, Origin of convoluted laminae: Geol. Mag., v. 97, p. 409-421.

Schlee, John, 1957, Fluvial gravel fabric: Jour. Sed. Petrology, v. 27, p. 162-176.

Schwarzacher, Walther, 1953, Crossbedding and grain size in the lower Cretaceous sands of East Anglia: Geol. Mag., v. 90, p. 322-330.

Simons, D.B., Richardson, E.V., and Nordin, C.F., 1965, Sedimentary structures generated by flow in alluvial channels: in Middleton, G.V. (ed.), Primary sedimentary structures and their hydrodynamic interpretation; Soc. Econ. Paleontologists and Mineralogists Special Pub. No. 12, p. 34-52.

Sorby, H.C., 1859, On the structure produced by the currents present during the deposition of stratified rocks: The Geologist, v. 2, p. 137-147.

_____________, 1908, On the application of quantitative methods to the study of rocks: Geol. Soc. London Quart. Jour., v. 64, p. 173-233.

Stokes, W.L., 1947, Primary current lineation in fluvial sandstones: Jour. Geology, v. 55, p. 52-54.

Ten Haaf, E., 1956, Significance of convolute lamination: Geologie en Mijnbouw, v. 18, p. 188-194.

Thornbury, W.D., 1965, Regional geomorphology of the United States: New York, John Wiley and Sons, 609 p.

Twenhofel, W.H., 1950, Principles of Sedimentation: New York, McGraw-Hill, 673 p.

Walker, R.G., 1963, Distinctive types of ripple drift cross-lamination: Sedimentology, v. 2, p. 173-188.

Walker, T.R., 1967, Formation of red beds in modern and ancient deserts; Geol. Soc. America. Bull., v. 78, p. 353-368.

Wessel, J.M., Hand, B.M., and Hayes, M.O., 1967, Sedimentary features of Triassic rocks in northern Massachusetts, N.E.I.G.C. Guidebook, 59th Annual Meeting, 194 p.

___________, 1968, Sedimentary history of Upper Triassic alluvial fan complexes in north-central Massachusetts (Abs.): Annual Meeting, Northeastern section, Geol. Soc. America, p. 62.

Willard, M.E., 1951, Bedrock geology of the Mount Toby quadrangle, Massachusetts; U.S. Geol. Survey Geol. Quad. Map GQ-8.

___________, 1952, Bedrock geology of the Greenfield quadrangle, Massachusetts: U.S. Geol. Survey Geol. Quad. Map. GQ-20.