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Depositional Environments of the Upper Devonian Oneonta Formation of South-Central New York

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DEPOSITIONAL ENVIRONMENTS OF THE

UPPER DEVONIAN ONEONTA FORMATION OF SOUTH-CENTRAL NEW YORK

BY

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ABSTRACT

The Oneonta Formation is a fluvial, nonmarine component of the Upper Devonian Catskill molasse sequence exposed in south-central New York. Stratigraphic sections, primary sedimentary structures, and lithological characteristics were examined with the intent of determining the depositional environments and type of fluvial system represented by the formation.

Detailed analysis resulted in identification of nine lithofacies. Lithofacies interpreted to be channel and bar deposits include: crude, large-scale trough cross-stratified pebbly intraclast sandstone; large-scale trough cross-stratified medium- and fine-grained sandstone; large accretionary troughs or lenses of cross-stratified pebbly or medium-grained sandstone, generally trough cross-stratified; solitary sets of large-scale planar - tabular cross-stratified medium-grained sandstone; wide, shallow troughs filled with large-scale inclined planar stratified fine-grained sandstone; horizontally bedded and very low-angle stratified fine-grained sandstone; and gray colored small-scale cross-stratified and ripple-drift cross-laminated sandstones and siltstones. Lithofacies interpreted as alluvial flood basin deposits include: red colored massive, small-scale cross-stratified, and ripple-drift cross-laminated very fine-grained sandstones and siltstones; blocky fracturing siltstone; and disrupted small-scale cross-stratified and irregularly stratified fine-grained

sandstones and siltstones.

The large-scale trough cross-stratified lithofacies are interpreted to result from in-channel megaripple deposition. The large accretionary units, planar cross-strata, and inclined planar stratification reflect bar deposition. The large accretionary units of large-scale cross-stratification represent bars formed at high-stage flow with subsequent modification during falling stages. Solitary sets of planar - tabular cross-strata and inclined planar stratification respectively were formed by the migration of solitary and multilobate high-stage linguoid bars which were largely unmodified. Horizontally bedded and low-angle stratified sandstones reflect plane bed or antidune deposition on bar surfaces. The gray colored small-scale stratified and ripple-drift cross-laminated sandstones and siltstone lithofacies results from bar-top deposition during waning and low-stages. The red colored member of the fine-grained sandstone and siltstone lithofacies is interpreted as levee deposits and the blocky lithofacies to be overbank deposits which have been intensely bioturbated. The disrupted small-scale cross-stratified and irregularly stratified sandstones and siltstones reflect crevasse splay deposition.

Paleocurrent data indicate a northwest paleoflow direction. The grand vector mean azimuth determined from the orientation of cross-strata is 293°. Flow was unimodal with low dispersion. Similar paleoflow patterns have been attributed to braided systems.

The Oneonta Formation sandstones are immature phyllarenites (Q_{39} - F_1 - L_{60}). They were derived from the collision orogen tectonic provenance of the contemporaneous Acadian Mountains.

Sedimentation was rapid with little detrital reworking. Substantial and rapid discharge fluctuations of a flashy nature are suggested. The fluvial system responsible for deposition of the Oneonta Formation is proposed to have been a sandy, braided system which was operative in a distal alluvial fan delta environment.

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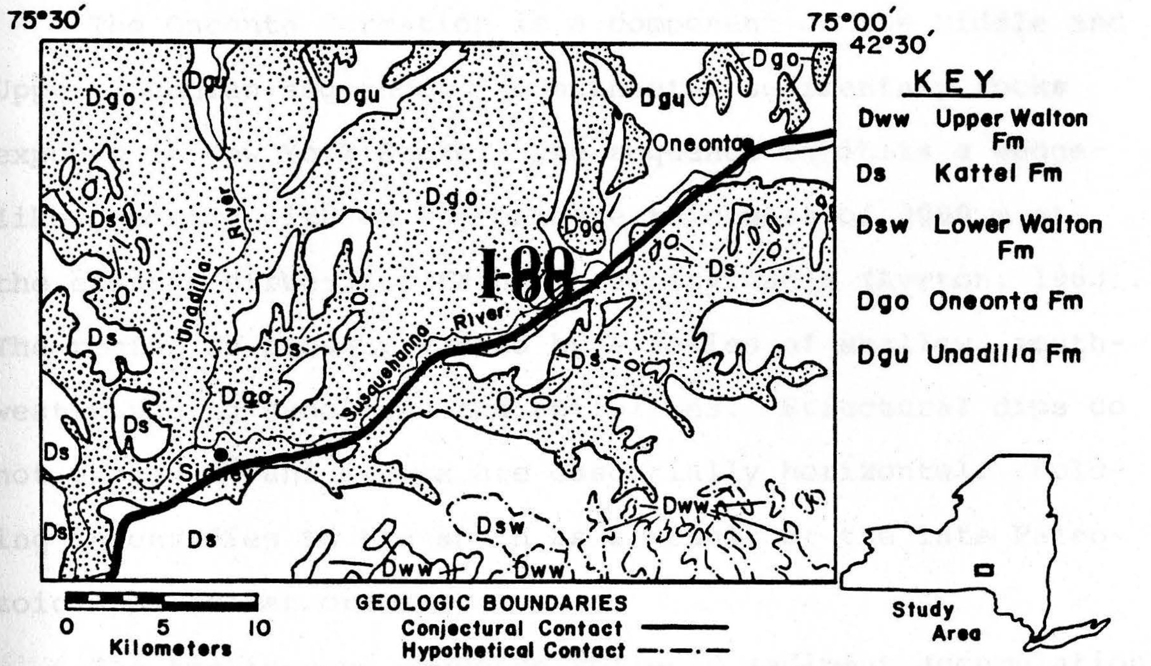
INTRODUCTION

A strict interpretation regarding the fluvial style and depositional environment of the Upper Devonian Oneonta Formation of New York State has never been formulated. The intent of this paper is to identify and describe the major lithofacies and associated paleoflow and petrologic characteristics, interpret processes of deposition, and propose a depositional environmental setting for the Oneonta Formation.

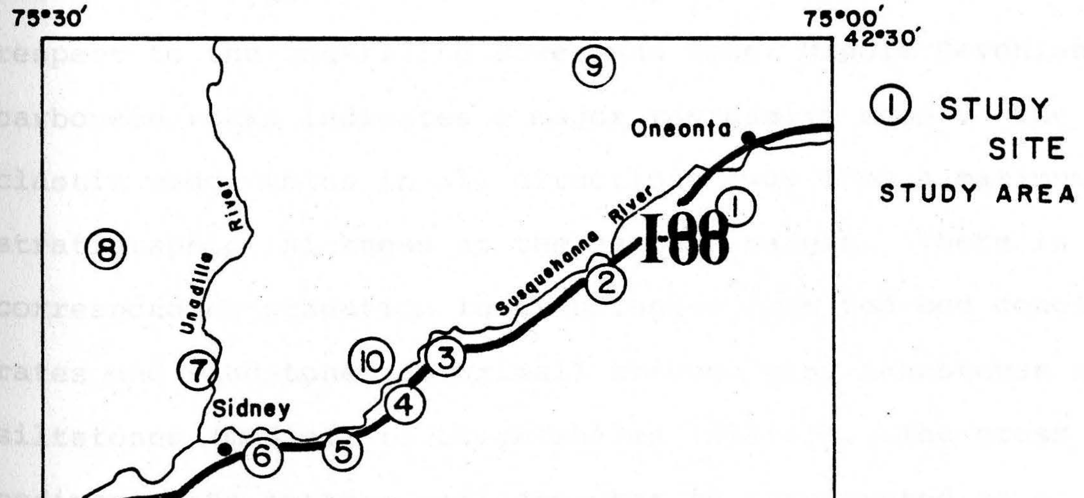
The formation is exposed in south-central New York State (Fig. 1). Approximately twenty localities were examined in the summer and fall of 1979. Specific location sites of detailed investigation and measured sections are shown in Figure 2.

Figure 1. Location map of the Oneonta Formation in south-central New York State. The Oneonta Formation is shown by the stippled pattern.

Figure 2. Locations of the Oneonta Formation investigated in detail. Scale is the same as in Figure 1.



75°30′
75°00′
42°30′
KEY
Dww Upper Walton Fm
Ds Kattel Fm
Dsw Lower Walton Fm
Dgo Oneonta Fm
Dgu Unadilla Fm
Dgo
Dgu
Ds
Dsw
Dww
Oneonta
Sidney
I-88
Unadilla River
Susquehanna River
0 5 10
Kilometers
GEOLOGIC BOUNDARIES
Conjectural Contact
Hypothetical Contact
Study Area



75°30′
75°00′
42°30′
42°15′
1 STUDY SITE
STUDY AREA
Oneonta
Sidney
I-88
Unadilla River
Susquehanna River
1
2
3
4
5
6
7
8
9
10

GEOLOGIC SETTING

The Oneonta Formation is a component of the Middle and Upper Devonian sequence of continental sedimentary rocks exposed in New York State. The sequence exhibits a wedge-like geometry with an approximate thickness of 3000 m at the eastern structural front in Pennsylvania (Ayrton, 1963). The region is broadly warped by a series of shallow, southwest plunging synclines and anticlines. Structural dips do not exceed 5^{o} and strata are essentially horizontal. Folding intensifies to the south as a result of the late Paleozoic Appalachian orogeny.

The terrigenous sequence reflects sediment accumulation in a subsiding cratonic basin. The development and filling of this foreland molasse basin was in response to the terminal suturing of the northern Appalachians during the Acadian Orogeny (Dewey and Bird, 1970; Graham et al., 1975). The western progradation of the Upper Devonian clastics with respect to the underlying Lower and lower Middle Devonian carbonate rocks indicates a major regressive event. The clastic wedge thins in all directions away from a maximum stratigraphic thickness at the eastern margin. There is a corresponding gradation in lithologies from red-bed conglomerates and sandstones (proximal) through gray sandstones and siltstones (medial) to black shales (distal). The gross sedimentation pattern reflects what is interpreted as a westward facies transition from fluvial (Catskill) to shallow (Chemung) and deep water (Portage) marine shelf deposits

(Sutton, 1963; Allen and Friend, 1968; Johnson and Friedman, 1969; Rickard, 1975). Integral facies relationships and paleocurrent evidence indicate the source lay to the east of the present Catskill structural front (McIver, 1960; Burtner, 1963; Fletcher, 1963; Leeper, 1963; Allen and Friend, 1968; Meckel, 1970; Glaeser, 1974). Based on petrologic studies, the source area is conjectured to have been a low-grade metamorphic terrain with associated sedimentary rocks (Mencher, 1939; Meyer, 1963; Allen and Friend, 1968; Ethridge, 1977).

The Oneonta Formation was first defined by Vanuxem (1842). It constitutes the western nonmarine portion of the Upper Devonian Genesee Group. The primary lithologies are characterized as intercalated gray, green, and red crossbedded sandstones; and red and green shales and siltstones. Minor amounts of intraclast pebble sandstone is present. Fossil flora predominates the relatively unfossiliferous strata. Distinguishing features include calcareous nodules, desiccation marks, biogenic structures, limonitized plant fragments, and rare lensoidal coal stringers. The geometry of the Oneonta Formation is that of a wedge which progessively thickens to the southeast. A maximum thickness of approximately 300 m is attained near Kaaterskill, New York. The formation is traceable in outcrop from the Catskill Mountains northwest to the vicinity of Chenango County, New York.

The Twilight Park Conglomerate is at an approximate stratigraphic position to be considered the eastern equivalent of the Oneonta Formation. Definitive correlation has been impossible as there are no traceable stratigraphic marker beds and considerable distance between the two formations (Rickard, personal communication). The lithology is a rounded quartz pebble conglomerate with a coarse-grained sandstone matrix. Clast imbrication is well-developed although stratification is crude and indistinct. Neither fossil fauna nor flora are present. The Twilight Park Conglomerate exhibits a wedge-like geometry. Its thickness decreases westward from over 600 m to less than 100 m. This thinning occurs over a lateral distance of less than 25 km from the Catskill front.

The Oneonta Formation interfingers laterally to the west with its marine equivalent, the Ithaca Formation. The lithologies of the Ithaca Formation are fine sandstones, siltstones, silty shales, and silty mudstones with basal black and brown shales. There is a high diversity of marine fauna with <u>Manticoceras</u> <u>styliophillum</u> providing ammonoid faunal control. The stratigraphic thickness (200 m - 300 m) is relatively constant laterally as the formation grades westward into the Genundewa Limestone and West River Shale.

The Unadilla Formation underlies and interfingers with the Oneonta Formation. The Unadilla Formation consists of dark arenaceous shales, shaly sandstones, and bluish-gray fine sandstones. It contains mixed pelagic and benthic marine fauna including the brachiopod, Leiorhynhus quadracostatum. Many beds are interpreted to be turbidite units. The formation interfingers to the west with the Geneseo Shale. The average thickness of the Unadilla Formation is less than 150 m.

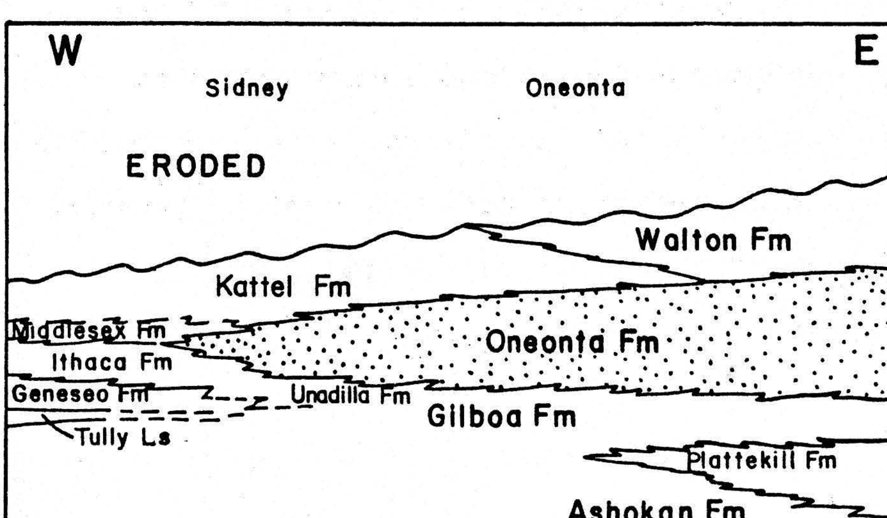
The Kattel Formation of the Sonyea Group overlies and interfingers with the Oneonta Formation. Its distinguishing lithologies include marine gray shales and siltstones with black or dark gray shales (Montour Shale). It is highly fossiliferous and dominated by brachiopod (Leiorhynchus globuliformis), bryozoan, and crinoid assemblages. The Kattel Formation thins eastward from approximately 200 m to less than 20 m over a distance of 25 km. It grades laterally into the Johns Creek and Middlesex Shales to the west.

The general stratigraphy and relationship of the Oneonta Formation to the adjacent formations is indicated in Figures 3 and 4. McCave (1969) proposes the marine - nonmarine facies relationships suggest a series of transgressive - regressive episodes comprising a major Late Devonian marine regression. He attributes this regression to the basin's inability to accomodate a large sediment influx. Sutton and others (1970) feel sedimentation was episodic with periods of rapid influx followed by periods of low input. This sediment influx is thought to have been in response to a discrete, localized tectonic pulse. There are no isolated wedges analogous to the Oneonta present

Figure 3. General stratigraphic section of upper Middle Devonian and Upper Devonian rocks of south-central New York State.

Figure 4. Stratigraphic relationship of the Oneonta Formation to adjacent formations in south-central New York State. Note the distinct wedge structure of the Oneonta Formation (stippled pattern) and the prominent intertongueing of nonmarine and marine facies. The continental source area lay to the east.

WEST FALLS GROUP (460-640 m)	UPPER WALTON FM	UPPER DEVONIAN
SONYEA GROUP (210-340 m)	KATTEL FM; LOWER WALTON FM	
GENESEE GROUP (370-460 m)	ONEONTA FM; UNADILLA FM; GILBOA FM	
HAMILTON GROUP (520-850 m)	MOSCOW FM; PANTHER MOUNTAIN FM; MARCELLUS FM; ASHOKAN FM; PLATTEKILL FM	MIDDLE DEVONIAN



in the Upper Devonian clastics along the rest of the Appalachian trend. This suggests a tectonic, rather than eustatic control of wedge development.

The nature of the marine - nonmarine transition appears to have been similar to that proposed by Glaeser (1974) and Walker (1972) for the Upper Devonian of northeastern Pennsylvania. Sand was effectively trapped in the alluvial basin. This resulted in a muddy, low-energy shoreline; comprised of small coalescing fan deltas, contiguous to the prograding alluvial plain.

METHODOLOGY

Methodology incorporated detailed measurement and description of stratigraphic sections, primary sedimentary structures and their orientation, and megascopic and microscopic lithologic characteristics.

Approximately 90 m of stratigraphic section was measured. Basal elevations for roadcut exposures were determined from information provided by the New York State Department of Transportation. Section measurement procedure follows that of Compton (1962). Black and white photomosaics were constructed to aid in mapping lateral and vertical changes in sedimentary structures and lithologies.

Sedimentary structures measured included large- and small-scale trough, planar, and tangential cross-stratification and parting lineation. As many measurements as obtainable were recorded where exposure permitted. One measurement was taken for each distinct sedimentary structural unit. Azimuths were measured as follows: (1) in the direction of maximum foreset inclination in the case of large- and small-scale planar and tangential cross-stratification; (2) parallel to trough axis in trough cross-stratified units; (3) parallel to the trend of parting step and grain lineation. Bed and set thickness, as well as the angle of foreset inclination of the cross-stratified units, were measured. Dubious measurements, where exposure was poor or maximum foreset inclination was indeterminate, were disregarded. Analysis of paleocurrent data follows the procedures of Curray (1956) and Miall (1974).

Representative rock samples of the distinct lithologies were collected for petrographic analysis. Forty-six thin sections were prepared using standard thin-section techniques. Impregnation of the samples with Petro-epoxy facilitated sectioning of the friable rocks. Thin-sections were evaluated using the Glegolev - Chayes method. Modal analysis was based on counts of 200 or 600 points with traverses perpendicular to bedding and covering the entire section. Percentages of monocrystalline quartz, polycrystalline quartz, feldspar, lithic fragments, accessory minerals, and cement were determined for the fifteen least altered sandstones. Percentages of lithic constituents were determined with counts of 100 and 300 fragments following the procedure of Graham and others (1976). Mean grain size was determined by measurement of the apparent long axis of twenty-five grains per thin-section. Sorting was visually estimated using sorting images (Pettijohn et al., 1972). Color was determined in hand speciman utilizing the Rock - Color Chart (Rock - Color Chart Committee, 1975). The remaining thirty-one sections were evaluated by the same techniques but were not analysed for modal percentages due to extensive alteration.

LITHOFACIES

Introduction

Lithofacies reflect unique assemblages of lithology, sedimentary structures, and biogenic structures. As such, lithofacies are interpreted to represent distinctive depositional environments. Lithofacies classification is similar to that used by Miall (1977). Nine majór lithofacies have been identified in the Oneonta Formation. The lithofacies include:

(1) Massive and crude large-scale trough cross-stratified pebbly intraclast medium-grained sandstone (Smt).

(2) Large-scale trough cross-stratified medium- and fine-grained sandstone (St_m and St_f).

(3) Large accretionary units of large-scale cross-stratified pebbly intraclast or medium-grained sandstone, often complexly interbedded (Stp).

(4) Solitary sets of large-scale planar - tabular cross-stratified medium-grained sandstone (Sps).

(5) Wide, shallow troughs filled with multiple sets of large-scale inclined planar stratified fine-grained sandstone (Spm).

(6) Horizontally bedded and very low-angle stratified fine- and very fine-grained sandstone (Sh and Sl).

(7) Small-scale cross-stratified and ripple-drift cross-laminated fine-grained sandstone to fine-grained siltstone including;

Gray member (Fl-G) and

Red member (Fl-R).

(8) Blocky fracturing coarse- to fine-grained siltstone (Fb).

(9) Disrupted small-scale cross-stratified and irregularly stratified fine-grained sandstone to fine-grained siltstone (Fd).

A representative stratigraphic sequence has been constructed based on actual measured sections (Figs. 5 - 7; Fig. 7 in back pocket).

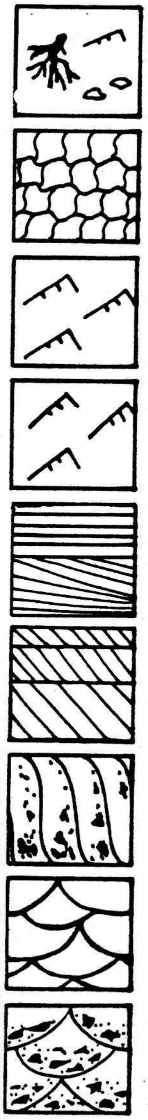
Detailed description and interpretation of the lithofacies follows. Descriptive bedding and cross-stratification terminology corresponds to that of Ingram (1954), Jopling and Walker (1968), and Harms and others (1975). Grain size is classified according to the Wentworth scale (Wentworth, 1922). Sorting parameters follow those of Pettijohn and others (1972). Degree of grain rounding was determined after Powers (1953). Interpretations are based on the lithologies, vertical and horizontal relationships of the sedimentary structures, degree and type of biogenic activity, and information from Recent fluvial environments.

Massive and Crude Large-Scale Trough Cross-Stratified Pebbly Intraclast Sandstone Lithofacies (Smt)

Description: The lithofacies is characterized by an erosional scour surface overlying small-scale cross-stratified

Figure 5. Key to representative and actual measured stratigraphic sections presented in the paper.

KEY TO STRATIGRAPHIC SECTIONS



Fd — Disrupted small-scale cross-stratified and irregularly stratified fine-grained sandstone to fine-grained siltstone.

Fb — Blocky fracturing coarse- to fine-grained siltstone.

Fl-R — Red member

Fl-G — Gray member

(Fl-R and Fl-G) — Small-scale cross-stratified and ripple-drift cross-laminated fine-grained sandstone to fine-grained siltstone.

Sh — Horizontally bedded fine- and very fine-grained sandstone.

Sl — Very low-angle stratified fine- and very fine-grained sandstone.

Spm — Multiple sets of large-scale inclined planar stratified fine-grained sandstone.

Sps — Solitary sets of large-scale planar cross-stratified medium-grained sandstone.

Stp — Large accretionary troughs or lenses of cross-stratified pebbly intraclast medium-grained sandstone.

St_f — Large-scale trough cross-stratified fine-grained sandstone.

St_m — Large-scale trough cross-stratified medium-grained sandstone.

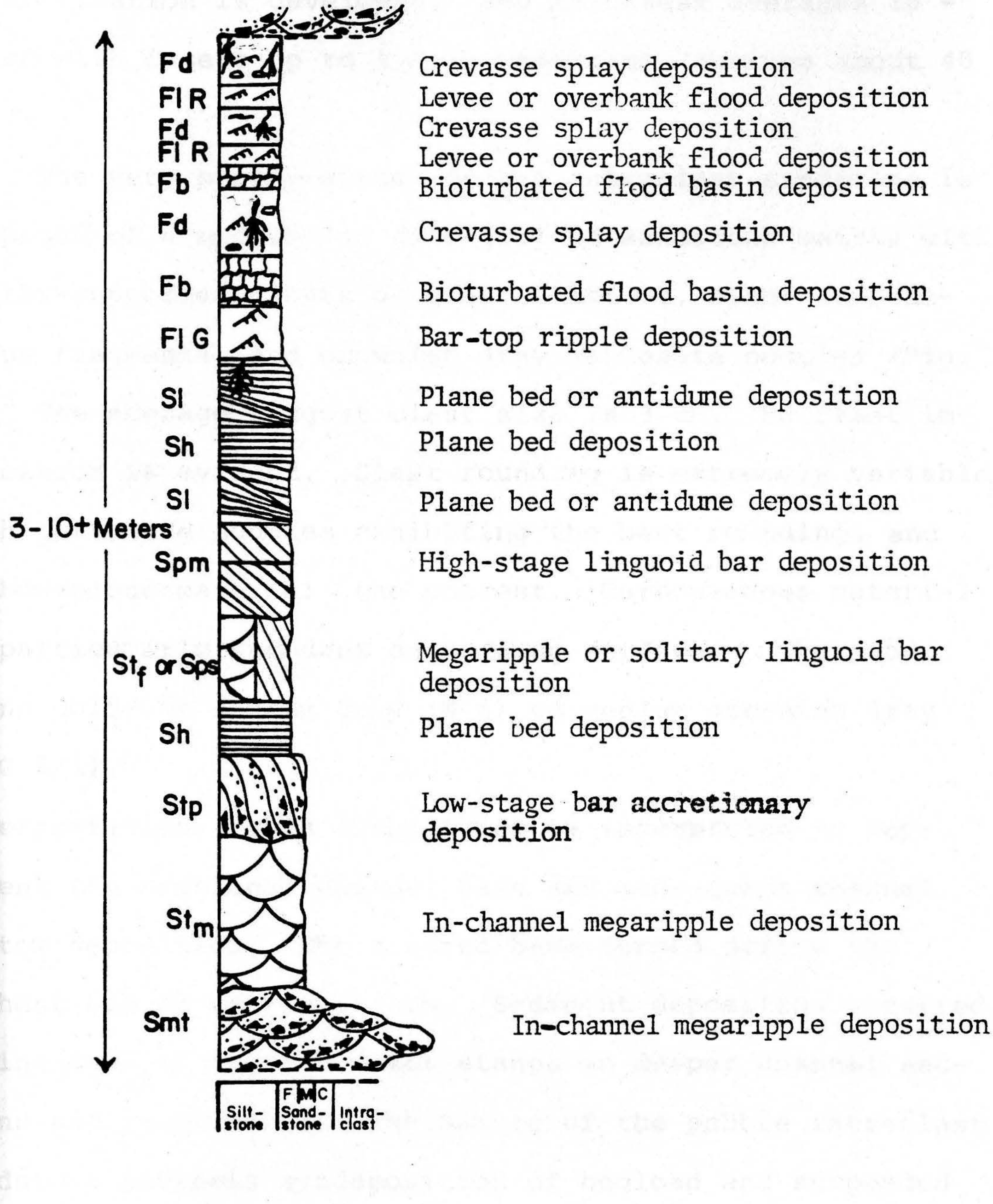
Smt — Massive and crude large-scale trough cross-stratified pebbly intraclast medium-grained sandstone.

Root Structures

Carbonate nodules

Figure 6. Representative stratigraphic section based on actual measured sections of the Oneonta Formation. Generalized interpretation of lithofacies with respect to depositional processes is also presented.

REPRESENTATIVE STRATIGRAPHIC SECTION



siltstones. Maximum depth of erosion of the scour surface is several meters. The pebbly intraclast sandstone occurs as discontinuous lenses or thin sheets above the scoured base. Massive or very crude large-scale trough cross-stratification is developed. Bed thickness averages 10 - 20 cm with cosets up to 1 m in thickness (average about 40 cm).

The very poorly-sorted pebbly intraclast sandstone is composed of a medium- to fine-grained sandstone matrix with matrix-supported clasts of gray siltstone, black carbonaceous fragments, and brownish gray carbonate nodules (Fig. 8). The average largest clast size is 3 cm. No clast imbrication is evident. Clast rounding is extremely variable with carbonate nodules exhibiting the best rounding, and carbonaceous material the poorest. Carbonaceous material is particularly abundant on bedding surfaces. The sandstone color is medium gray (N 5) to medium greenish gray (5 G 5/1).

Interpretation: This lithofacies is interpreted to represent the erosional channel base and subsequent channel bottom deposition. The scoured base formed during the highest stages of flood flow. Sediment deposition occurred during initial falling water stages in deeper channel sections and scour pools. The nature of the pebble intraclast sandstone reflects syndeposition of bedload and suspended material entrained by grain flow with flat bed deposition on previously scoured surfaces. This type of deposit, often

Figure 8. Crude large-scale trough cross-stratified pebbly intraclast sandstone lithofacies. Note the basal scour surface above the scale. Intraclasts include carbonate nodules, siltstone clasts, and carbonaceous fragments. Scale is 15 cm in length.

Figure 9. Large-scale trough cross-stratified medium-grained sandstone lithofacies. Inferred flow is out of the outcrop at 30° to the left (A). Scale is 30 cm in length. Area enclosed by the box is shown in detail in Figure 10.


15cm


A

referred to as pebble lag conglomerate in the literature, has been observed in both meandering and braided channel deposits (McGowen and Garner, 1970; Bluck, 1971; Cant, 1978a; Levey, 1978; Miall, 1978).

Large-Scale Trough Cross-Stratified Medium-Grained and Fine-Grained Sandstone Lithofacies (St_m and St_f).

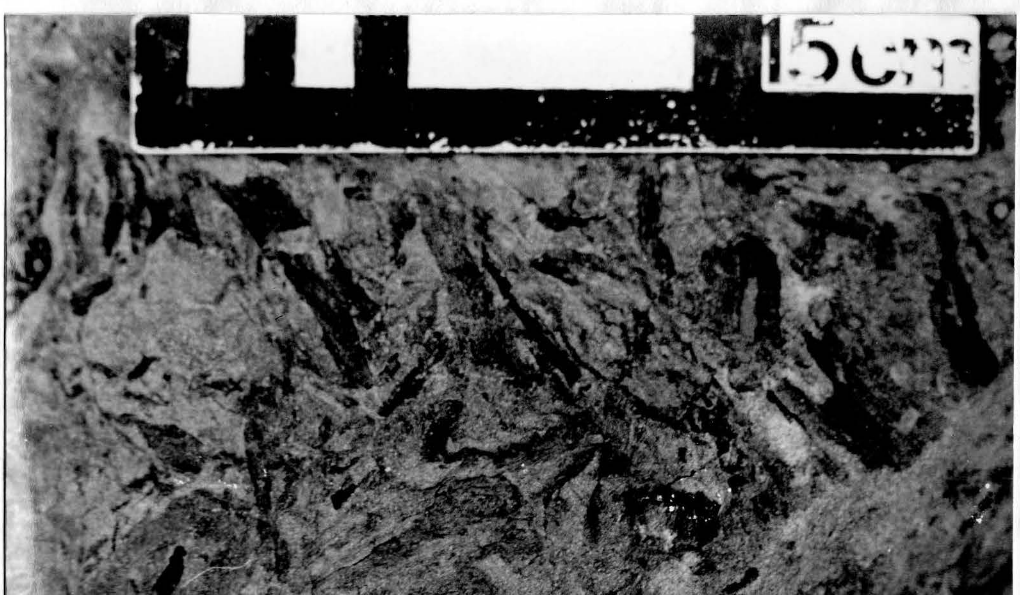
Description: The lithofacies overlies the massive and crude large-scale trough cross-stratified pebbly intraclast sandstone lithofacies. A gently undulating scour surface contact is present between the two lithofacies. The medium- to fine-grained sandstone displays crude to very well-developed large-scale trough cross-stratification (Figs. 9 and 10). Cross-stratification becomes better defined higher in the stratigraphic section. Trough depths range from 15 - 40 cm with an average thickness of 25 cm. Trough widths are variable, 30 cm to less than 100 cm, and sets truncate one another. Coset thickness varies between 40 cm and 100 cm.

The sandstone is moderately sorted with both normal and inverse graded beds. Scattered carbonaceous fragments and carbonate nodules are exposed on bedding surfaces (Fig. 11). The lithofacies is medium light gray (N 6.5) to light brownish gray (5 YR 5/1).

Interpretation: Investigators attribute large-scale trough cross-stratification to downcurrent migration of megaripples (Allen, 1963; Boothroyd and Ashley, 1975; Harms et al., 1975).

Figure 10. Detail of apparent dip of large-scale trough cross-stratification shown in Figure 9. Scale is 30 cm in length.

Figure 11. Comminuted carbonaceous debris on the bedding surface of large-scale trough cross-stratified medium-grained sandstone. Fragments show no preferred orientation with respect to inferred flow direction which is from the upper right to lower left. Scale is 15 cm in length.


5cm

Megaripples are lower flow regime bed forms synonymous to the dunes of Simons and others (1965). Megaripples are generated during high-stage and falling flows and commonly floor the channels. The nature of the well-developed cross-stratification implies rapid bedload transport resulting in moderate sorting of medium- and fine-grained sand and concommitant scour reattachment common to cuspate mega-ripples (Harms et al., 1975). Decrease in cross-stratification is thought to be one of the most accurate indicators of channel and bar-top paleoflow direction (Harms et al., 1963; Williams, 1971; High and Picard, 1974).

Large Accretionary Troughs or Lenses of Large-Scale Cross-Stratified Pebbly Intraclast or Medium-Grained Sandstone Lithofacies (Stp)

Description: The large accretionary units of large-scale cross-stratified pebble intraclast or medium-grained sandstone lithofacies lies above an irregular, sharply defined scour surface. The accretionary units are trough or lense shaped with accretionary bedding being well-developed. Cross-stratification within the accretionary units is complex, but generally is large-scale trough cross-stratification (Fig. 12). There are often several laterally co-existing units. Pebble-sized clasts are concentrated creating distinct accretionary bedding.

The dark brownish gray (5 YR 3/1) colored pebbly intra-clast sandstone is very poorly sorted with a medium-grained

Figure 12. Large accretionary lense of large-scale trough cross-stratified medium-grained sandstone. Note the accretionary bedding within the lense. The accretionary lense is under- and overlain by small-scale cross-stratified siltstones as indicated by the arrows. This lithofacies is interpreted as in-channel bar forms which formed during high-stage flows and were subsequently modified during falling stages. The associated siltstones represent bar-top and/or overbank ripple-drifted silts deposited during the falling stages of flow. Distance between drill holes is approximately 1 m.

Figure 13. Solitary set of large-scale planar cross-stratified medium-grained sandstone. Large-scale trough cross-stratified medium-grained sandstone underlies the lithofacies. Horizontally bedded medium-grained to fine-grained sandstone overlies the set. Inferred flow direction is from left to right. Scale is 1 m in length.

matrix. Grain size decreases horizontally along the depositional dip of the unit as well as vertically. The nature of the matrix-supported clasts is identical and clast/matrix ratio is less than in the previously described pebbly intraclast lithofacies. The average largest clast size is 2 cm. The medium-grained sandstone of the accretionary units is moderately to poorly sorted.

Interpretation: The large accretionary troughs or lenses of large-scale cross-stratification are interpreted as in-channel bar forms. The large accretionary units of pebbly intraclast large-scale cross-stratification are thought to represent bars which formed under high-stage flow conditions and were subsequently modified during falling stages. These bars formed by the migration of megaripple groups which transported bedload material as a discrete unit or package. The nature of the bottom contact indicates that the scour was produced by the migration of the bar in response to fluctuations in flow strength. The complex changes in cross-stratification within individual units indicates changes or pulses in flow velocity as the bar migrated downcurrent and was dissected by low flows. These bars are thought to have occupied the deepest sections of the channel and were modified due to changes in flow velocity and depth.

Solitary Sets of Large-Scale Planar - Tabular Cross-Stratified Medium-Grained Sandstone Lithofacies (Sps)

Description: Distinctive solitary sets of large-scale planar - tabular cross-stratified medium-grained sandstone generally lie above large-scale trough cross-stratified sandstones and interbedded with horizontal and very low-angle stratified sandstones (Fig. 13). Cross-stratification is well defined. Some sets have cross-stratification which is planar in upcurrent sections and flattens downcurrent to become tangential. Cross-bed thickness is 10 to 15 cm. Solitary sets are 50 to 90 cm thick and 10 to 15 m in length. Individual foresets are normally graded and tend to exhibit alternating coarser and finer grain size. The medium light gray (N 6.5) to medium gray (N 5.5) sandstones are moderately sorted. Granular intraclasts and scattered carbonaceous fragments are exposed on bedding surfaces.

Interpretation: This internal cross-stratification has been extensively documented in Recent fluvial systems (Harms et al., 1963; Ore, 1964; Collinson, 1970; McGowen and Garner, 1970; Smith, 1971; Williams, 1971; Smith, 1972; Boothroyd and Ashley, 1975; Levey, 1978). Stratification is produced by migration of bar forms called sandwaves (Harms et al, 1963; Harms et al., 1975; Jones, 1977), transverse bars (Ore, 1964; Smith, 1971; Williams, 1971; Smith, 1972; Jackson, 1976; Levey, 1978), or linguoid bars (Collinson, 1970; Bluck, 1971; Williams, 1971; Nummedal et al., 1974; Boothroyd and Ashley, 1975; Boothroyd and Nummedal, 1978; Blodgett and Stanley, 1980). The term linguoid bar will be used in the following discussion because it is thought that the dispersion in cross-strata azimuths is indicative of slightly sinuous to lobate-crested bar forms.

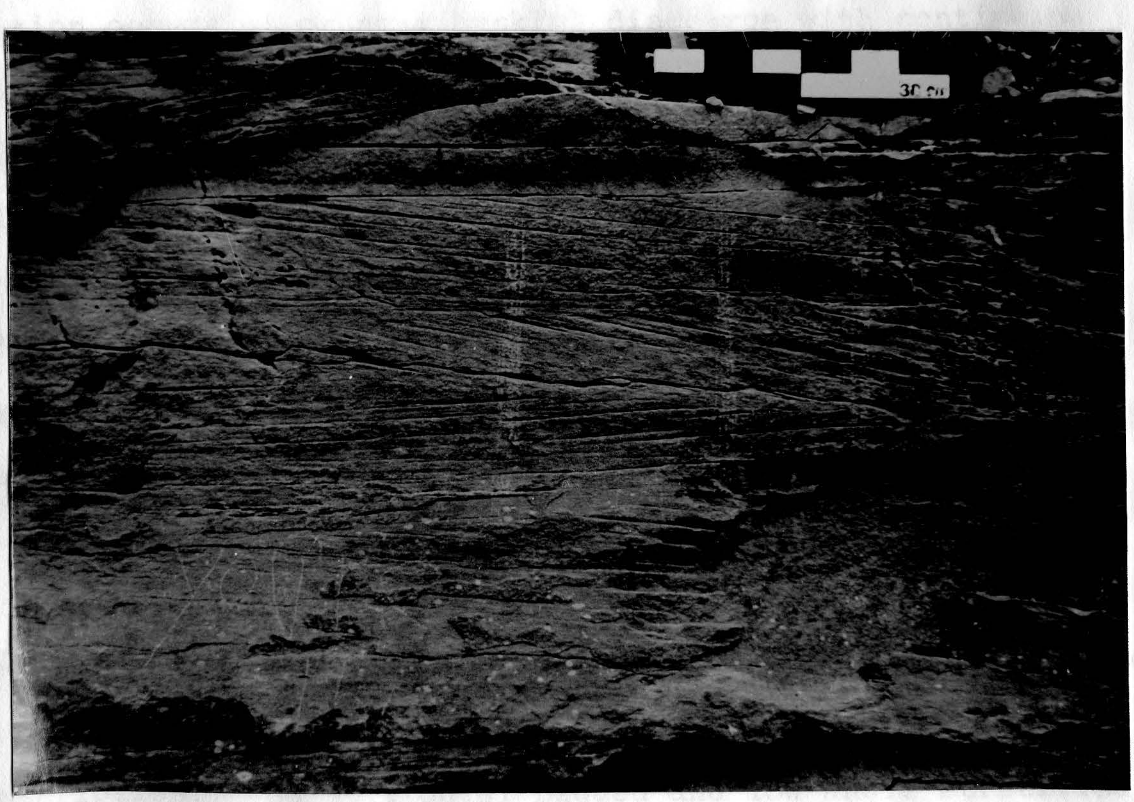
The solitary sets of large-scale planar - tabular cross-stratified sandstone are thought to be formed by linguoid bars during high-stage flow with slight modification during falling stages. The solitary sets of planar - tabular cross-strata reflect deposition of singular linguoid bars, similar to cross-channel bars of Cant and Walker (1978) or the transverse bars of Smith (1971; 1972). These bars are straight-crested with large length-to-width ratios. They occupied intermediate channel depths and were little modified by rapidly falling stages.

Wide, Shallow Troughs Filled With Multiple Sets of Inclined Planar Stratified Fine-Grained Sandstone (Spm)

Description: Wide, shallow troughs on the order of tens of meters in width are filled with multiple sets of inclined planar stratification. These stratified fine-grained sandstones are often intercalated with horizontal and low-angle stratified sandstones. The inclined planar stratification is well-developed (Figs. 14 and 15). Sets have inclined (wedge) basal contacts. Set thickness is variable (10 - 60 cm). Coset thickness is 1 to 1.5 m. There are many truncation and reactivation surfaces. Sets often exhibit stratification azimuths that deviate from the orientations of adjacent sets. The medium light gray (N 5.5)

Figure 14. Wide, shallow troughs filled with multiple sets of large-scale inclined planar stratified fine-grained sandstone. Trough widths are up to tens of meters. Inferred flow direction is out of the photograph at 30° to the right. Scale is 30 cm in length. Detail of the stratification is shown in Figure 15.

Figure. 15. Detail of the inclined planar stratification filling wide troughs shown in Figure 14. Note the truncation surfaces formed by the inclined wedge bases of the sets. The dip directions of apparent inclination of the beds are very divergent as a result of the multilobate nature of linguoid bar deposition. Scale is 30 cm in length.


30 cm

fine-grained sandstone is well sorted. There is no evidence of carbonaceous material or carbonate nodules on exposed bedding surfaces. Biogenic structures are numerous.

Interpretation: The wide, shallow troughs filled with inclined planar stratification are interpreted as being developed from semi-repetitive, multilobate linguoid bar deposition. These bar forms have crestlines which are markedly convex in a downstream direction (Collinson, 1970; Boothroyd and Ashley, 1975; Boothroyd and Nummedal, 1978). The multilobate nature of the bars gives rise to highly dispersive foreset azimuths (Fig. 14). Multilobate, high-stage linquoid bars form in response to non-uniform expanding, shallow flow. Nonuniformity of flow is supported by the presence of reactivation surfaces. Initial bar formation occurs at or near bankful discharge with continuing bar activity during all but the lowest stages of flow (Boothroyd, 1972). Schwartz (1978) documents the formation of linguoid bars with rapidly subsiding flood discharge in the Red River during high flow conditions. Modification of these high-stage linguoid bars is thought to be minimal because of the preserved well-developed cross-stratification. Bar surfaces were exposed during falling stages and were subsequently vegetated.

Horizontally Bedded and Very Low-Angle Stratified Fine-Grained and Very Fine-Grained Sandstone Lithofacies (Sh and Sl)

Description: The horizontal bedded and low-angle stratified fine- to very fine-grained sandstone lithofacies is intercalated with the large-scale inclined planar fine-grained lithofacies. Many sets are horizontally bedded although some are inclined at very low angles (less than 10^{o}) creating wedge-like sets (Fig. 16). Parting lineation is present on bedding surfaces (Fig. 17). Low-angle stratified sandstone may be transitional to horizontally bedded sandstone downdip along the paleoslope (Fig. 18). Beds exhibit both normal and inverse grading. Bed thickness ranges from 1 to 10 cm and decreased in thickness upwards in each set. Set thickness is variable but does not generally exceed 80 cm. Sets are laterally extensive and can be traced for tens of meters. Many sets, particularly the very low-angle stratified variety, truncate one another vertically and laterally. The lithofacies is moderately sorted although medium-grained sandstone and siltstone in some fine- to very fine-grained beds give rise to poor sorting. Mica, scattered carbonaceous fragments, and carbonate nodules are found on bedding surfaces. Biogenic structures are also present. There is a transitional vertical color gradation from medium gray (N 5.5) to pale grayish red (5 R 5/2).

Interpretation: The lithofacies is interpreted to result from sand deposition in elevated channel areas, shallow scours, and on bar tops. It has been observed in meandering and braided channel environments (McKee et al., 1967; Collinson, 1970; Bluck, 1971; Boothroyd and Ashley, 1975; Miall, 1977; Cant, 1978a; Levey, 1978; Rust, 1978). Al-

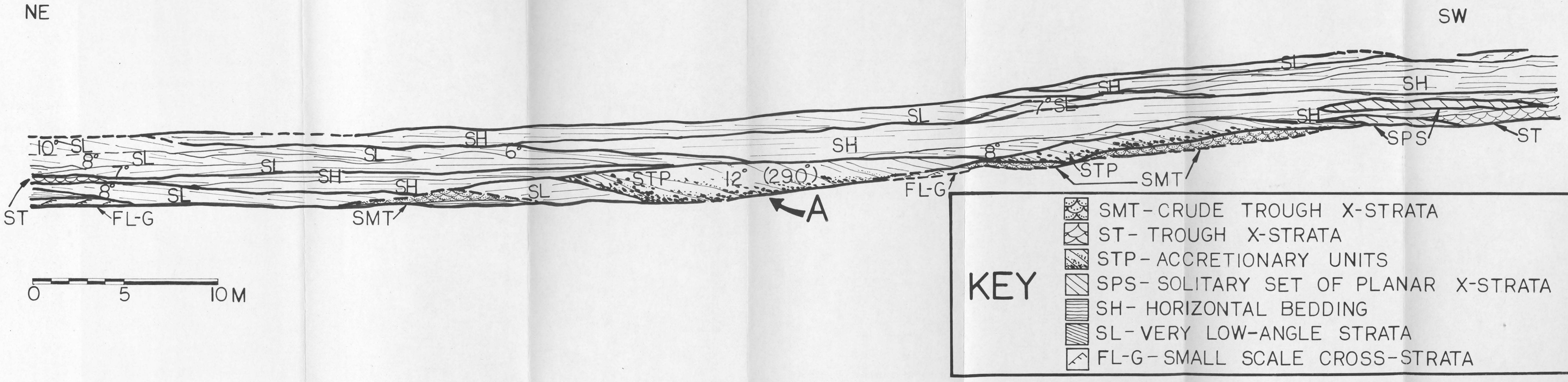
Figure 16. Horizontally bedded very fine-grained sandstone lithofacies. Scale is 1 m in length.

Figure 17. Parting grain and step lineation on the bedding plane of the horizontally bedded very fine-grained sandstone lithofacies. Inferred paleoflow parallels the lineation structure. Scale is 30 cm in length.


I M


30 cm

Figure 18. Nature of the relationship of horizontally bedded and very low-angle stratified sandstones. Note the transitional nature from one type of stratification into another. The inferred paleoflow is left to right. A is an accretionary lense deposited by bar migration and accretion. The average stratification angles for distinct sets are given in degrees.


NE
SW
10° SL
8°
SL
7°
8°
SL
SL
SH
SH
SH
6°
SL
SH
SMT
SL
STP
12° (290°)
A
SH
SL
8°
FL-G
SH
7° SL
SH
SL
SH
STP
SMT
SPS
ST
ST
FL-G
0
5
10 M
KEY
SMT-CRUDE TROUGH X-STRATA
ST- TROUGH X-STRATA
STP- ACCRETIONARY UNITS
SPS- SOLITARY SET OF PLANAR X-STRATA
SH- HORIZONTAL BEDDING
SL- VERY LOW-ANGLE STRATA
FL-G- SMALL SCALE CROSS-STRATA

though horizontal and low-angle stratification may form under lower or upper flow regime conditions, the association of parting lineation on bedding surface implies upper flow regime conditions (Allen, 1964a; Harms et al., 1975). Upper flow regime plane bed conditions were established when flow velocity increased. Increases in flow velocity may result as flow depth is decreased due to flow over bar tops or channeling between bars. Decreasing flow depth when velocity is constant may also result in upper flow regime conditions as the bed phase moves from the megaripple (dune) and/or bar (sandwave) fields into the upper plane bed field (Middleton and Southard, 1977). Low-angle stratification particularly reflects sand deposition under shallow high-velocity flow conditions into low relief scours (Rust, 1978). Scours develop between bars and on bar-tops in response to topographic irregularities. Rust (1978) suggests the low-angle stratification associated with large-scale trough cross-stratification and scour implies deeper, less ephemeral flow than observed in deposits of Bijou Creek (McKee et al., 1967). Low-angle stratification may also be developed by antidune deposition on bar tops during upper flow regime conditions (Waechter, 1970). The presence of the biogenic structures which are identical to those in both the multiple sets of inclined planar stratified and disrupted small-scale cross-stratified sandstone lithofacies (Lithofacies Spm and Fd, respectively) (Figs. 22 and 23), suggest vegetation of bar tops.

Small-Scale Cross-Stratified and Ripple-Drift Cross-Laminated Fine-Grained Sandstone to Fine-Grained Siltstone Lithofacies (Fl-G and Fl-R)

There are two distinct members of this lithofacies. One is gray in color (Fl-G) and is associated with the large-scale cross-stratified channel and bar deposits. The other member is red (Fl-R) and is interbedded with the small-scale cross-stratified alluvial flood basin deposits.

Gray Member (Fl-G)

Description: The gray colored member of this lithofacies is medium blueish gray (5 B 6/1) to medium dark gray (N 4.5) in color. It vertically succeeds the horizontally bedded and very low-angle stratified fine- to very fine-grained lithofacies and is interbedded with the coarser-grained sandstone lithofacies. It often occurs as thin discontinuous lenses which are truncated by coarser-grained lithofacies. Small-scale cross-strata and ripple-drift (A and B) is present in the fine-grained sandstones and coarse- to medium-grained siltstones. The medium- to fine-grained siltstones commonly exhibit draped lamination. Irregular stratification is absent. Deformation of the lithofacies, when it underlies the coarser-grained lithofacies, is prevalent. Sets of cross-stratification are thinly to thickly laminated and extremely fissile. Coset thickness varies from several to tens of centimeters. The coarser-grained siltstones and sandstone are well sorted. The finer-grained siltstones are very well sorted.

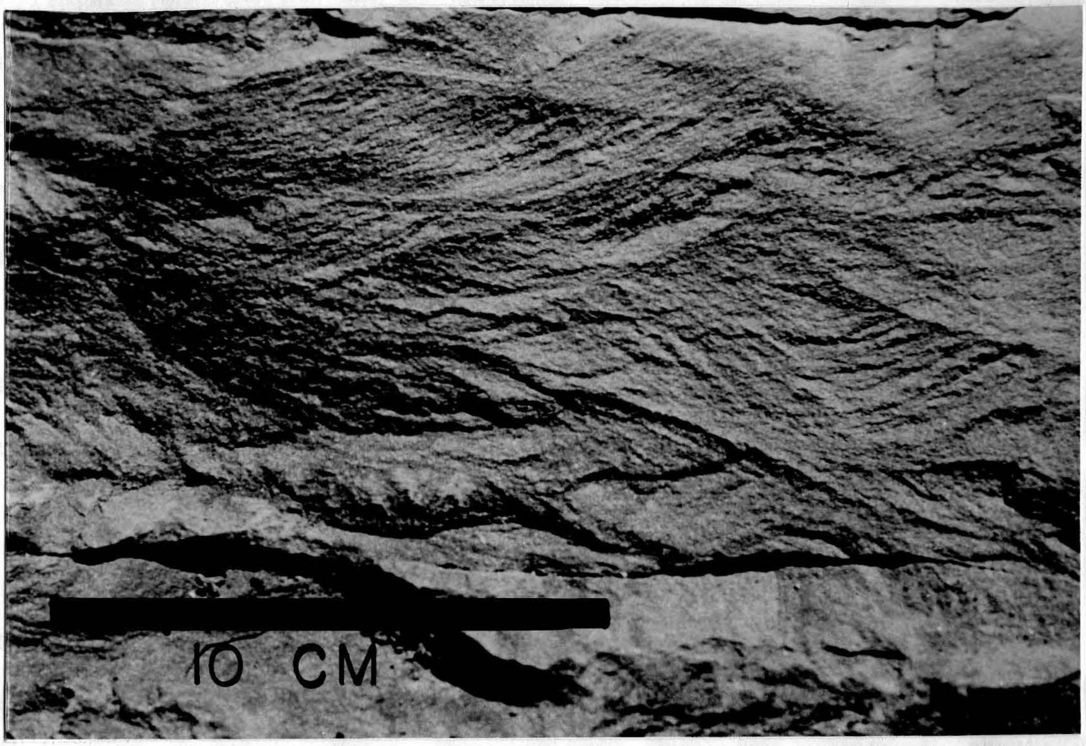
Interpretation: The fine-grained, small-scale cross-stratified and ripple-drifted nature of the gray member, in conjunction with its stratigraphic relationship to the other sandstone lithofacies, suggests bar-top deposition resulting during waning flow and low-stage conditions. Smith (1972) reports the replacement of plane bed configuration by small-scale cross-stratification when grain size is less than 0.5 to 0.6 mm. Small-scale ripples superimposed on larger scale bed forms, bars, and flat bed have been extensively documented (Williams, 1971; Smith, 1972; Bluck, 1974; Boothroyd and Ashley, 1975; Harms et al., 1975).

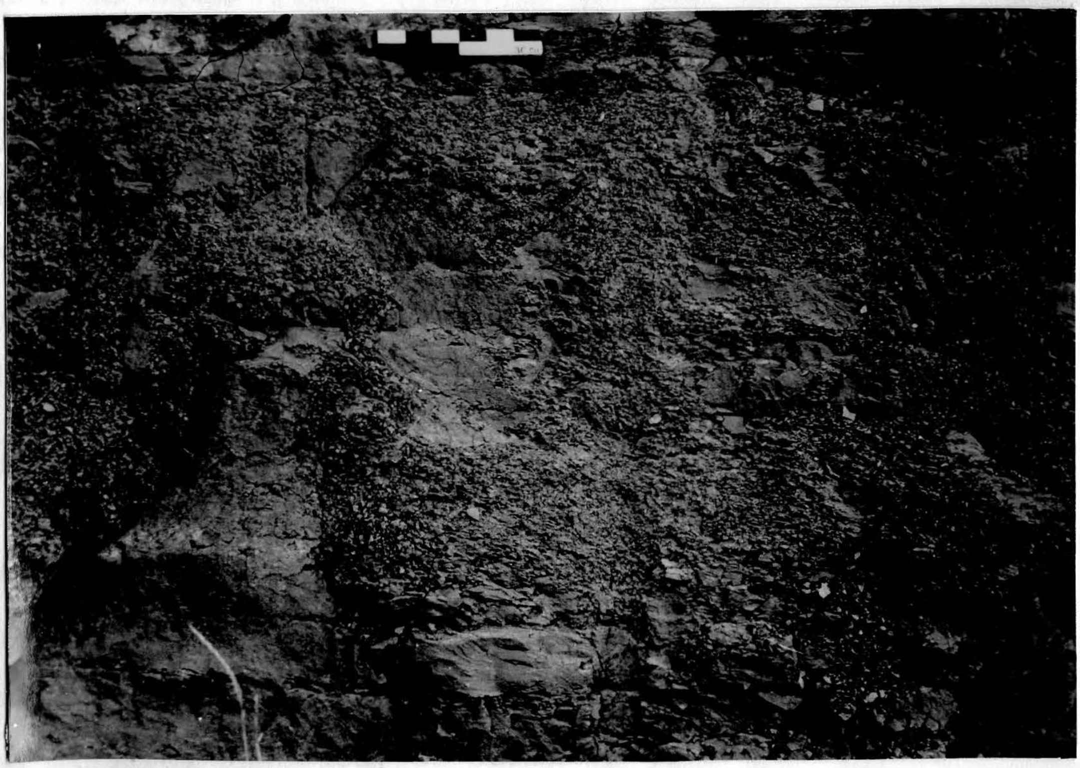
Red Member (Fl-R)

Description: The color of the red member ranges from medium brownish gray (5 YR 5/1) to dark grayish red (5 R 3/2). This member is intercalated with the blocky fracturing siltstone lithofacies and has a sharp erosive base. Some beds are massive and may be ungraded or normally graded. The massive beds are coarser-grained (very fine-grained sandstone to medium-grained siltstone). Bed thickness averages 10 to 15 cm. The small-scale cross-stratified beds exhibit fining-upward sequences with respect to grain size. There is a corresponding transition above the scoured base from small-scale cross-strata, through ripple-drift (A and B), to draped lamination; which caps the sequence (Fig. 19). The total sequence seldom exceeds 25 cm

Figure 19. Small-scale cross-stratified and ripple-drift cross-laminated very fine-grained sandstone and coarse-grained siltstone. Inferred flow from right to left. Scale is 10 cm in length.

Figure 20. Blocky fracturing coarse-grained to fine-grained siltstone lithofacies overlying massive very fine-grained sandstone. Siltstone has churned, structureless appearance. Scale is 30 cm in length.


10 CM



(averaging about 15 cm). Linear and cuspate ripple marks are ubiquitous on bedding plane surfaces. Siltstone intraclasts and scattered carbonate nodules are dipersed through the beds, particularly the massive ones. Nodules are transported and do not represent pedogenic horizon development in this particular lithofacies. Massive beds are poorly sorted in contrast to the well-sorted small-scale cross-stratified beds.

The two-dimensional geometry of the red colored member is that of a wedge which dips and thins away from the coarser-grained sandstone lithofacies. There is a corresponding transitional grain size decrease within individual beds of the wedge. The wedge interfingers and is interbedded with other fine-grained (very fine-grained sandstone and finer) lithofacies. The lateral extent of the wedge is continuous for hundreds of meters.

Interpretation: The red member of the small-scale cross-stratified fine-grained lithofacies is interpreted as levee and associated overbank flood deposits. Evidence supportative of this includes the coarseness of the lithofacies in respect to the other flood basin deposits (field observation); alternating coarse- and fine-grained beds; transitional grain size decrease in distal sections of the beds; geometry, proximity, and stratigraphic relationships of the lithofacies to the coarser sandstone channel and bar lithofacies; and associated sedimentary structures. The massive, ungraded, or normally graded beds suggest debris-laden flat bed deposition resulting from intense overbank flooding. Poor sorting suggests simultaneous deposition of bedload and suspended material. Siltstone clasts and cross-stratification around carbonate nodules assumes rip-up and redeposition of previously deposited material. The ripple-drift implies a rapid transition from lower flow regime bedload transport to fallout suspension deposition as flow velocity decreases (Walker, 1963; McKee, 1966; Jopling and Walker, 1968; Allen, 1970). This would occur as flow escapes channel confines and spills out onto the alluvial plain. McKee and others (1967) attribute the development of ripple-drift to waning flood flow in overbank areas. Interbedded massive and ripple-drifted beds may indicate pulses in flood flow.

Blocky Fracturing (Structureless) Coarse-Grained to Fine-Grained Siltstone Lithofacies (Fb)

Description: The blocky fracturing siltstone lithofacies displays no primary sedimentary structure other than isolated patches of small-scale cross-stratification. It has a knobbly, fractured appearance (Fig. 20). It is bounded by sharp scour surfaces and bed thickness, where apparent, is 2 - 10 cm with coset thickness up to 1 m. The siltstones are well sorted and pale grayish red (5 R 5/2) to grayish red purple (5 RP 4/2) in color. Thick, fibrous, dendritic structures are preserved. Carbonate nodules and mottled patches of greenish gray (5 G 5/1) fine-grained siltstones are dispersed throughout the lithofacies.

The blocky fracturing siltstone is laterally extensive and traceable for hundreds of meters. It is associated laterally and vertically with the undisrupted fine-grained lithofacies previously discussed.

Interpretation: The lithofacies is thought to represent the distal deposition of silts resulting from overbank flooding events. The intimate lateral and vertical relationship of the undisrupted fine-grained lithofacies to the blocky fracturing lithofacies, as well as the corresponding gradation in grain size, supports this interpretation. The absence of primary (physical) sedimentary structures is attributed to intense bioturbation which obliterated any original structure. Bluck (1971) documents botanical disruption of bedding in overbank areas. The knobbly surface represents fracture along breakage surfaces which developed between adjacent root systems. It is impossible to determine if the carbonate nodules developed in-situ or were transported. The greenish-gray mottling is thought to be related to pedogenic processes operative under reducing groundwater conditions (Hubert, 1978). Extreme bioturbation, mottling, and lack of subaerial exposure features implies an alluvial plain environment with a shallow water table which was extensively vegetated.

Disrupted Small-Scale Cross-Stratified and Irregular Stratified Fine-Grained Sandstone to Fine-Grained Siltstone Lithofacies (Fd)

Description: The disrupted small-scale cross-stratified fine-grained sandstone to fine-grained siltstone is interbedded with the previously described small-scale cross-stratified and blocky fracturing fine-grained lithofacies (Fig. 21). The lithofacies has a scoured, erosional base and slightly coarsening upward grain size transition. Disruption of bedding is caused by irregular stratification including biogenic features, polygonal cracks, raindrop impressions, and carbonate nodule development (Figs 22 - 25). The coarser siltstones are moderately sorted with finer siltstones being well sorted. Color varies from light grayish red (5 R 5/2) to grayish red (5 R 4/2).

The thick, fibrous, dendritic structures complexly infilled with siltstone or very fine-grained sandstone invasively crosscut, parallel, and branch downward at steep angles to the bedding (Fig. 22). These structures tend to occur in distinct horizons. The structures are often lined with a lusterous fine-grained siltstone layer when complete infilling has not occurred. In plan view, these structures are circular with diameters of the order of several millimeters to several centimeters. When these structures are traced along structure they become thinner and less fibrous with diameters less than 5 mm (Fig. 23). The structures have been interpreted as infilled root systems (Barrell, 1913; Walker, 1979 - photograph on p. 25).

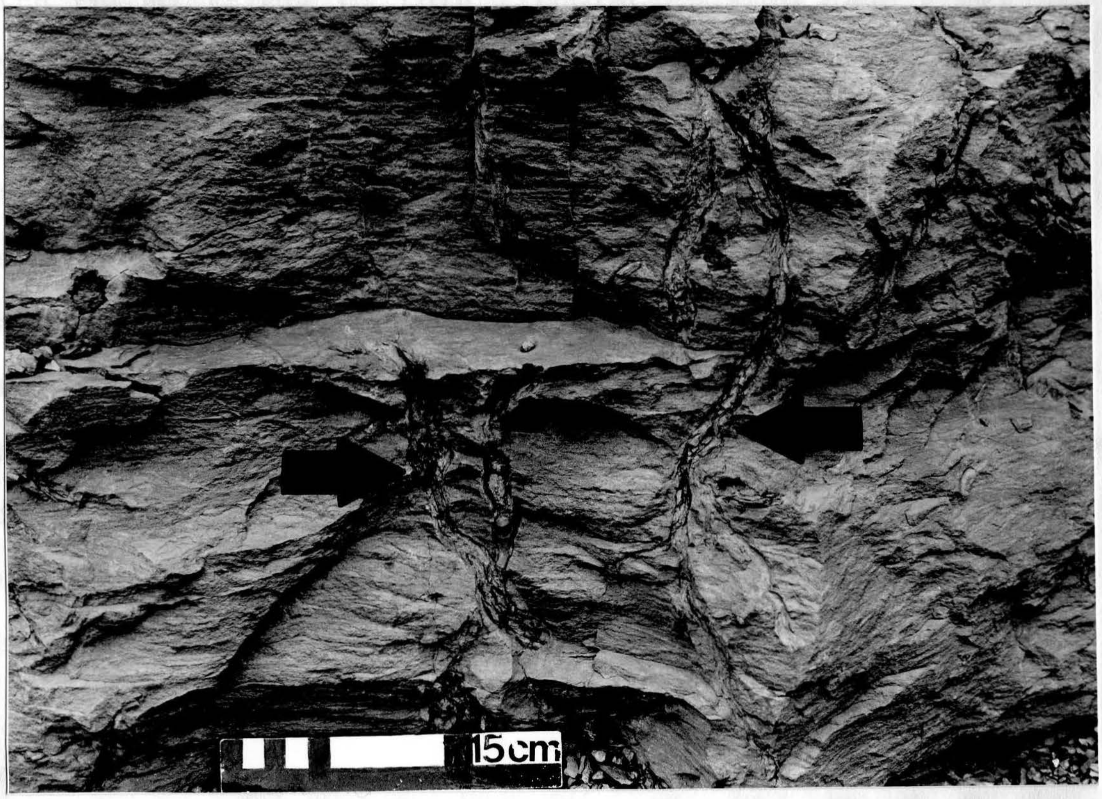
Well-developed, infilled polygonal cracks are associated

Figure 21. Intercalated small-scale cross-stratified and ripple-drift cross-laminated sandstones and siltstone (A); blocky fracturing siltstone (B); and disrupted small-scale cross-stratified and irregularly stratified sandstone (C) lithofacies. All the lithofacies are red in color. Note the interbedded nature and erosive bases of the beds. Scale is 1 m in length.


C
A
C
A
B
A

Figure 22. Thick, fibrous, dendritic structures infilled with fine-grained siltstone. They invasively cross-cut beds of disrupted small-scale cross-stratified very fine-grained sandstone. These trace fossil structures are interpreted as primary root structures due to their branching nature and fine-grained fill and lining. Scale is 15 cm in length.

Figure 23. Thin, fibrous, dendritic structures infilled with very fine-grained sandstone. The features are thought to be secondary root traces and often branch off from the primary root systems shown in Figure 22. Scale is 30 cm in length.


15cm

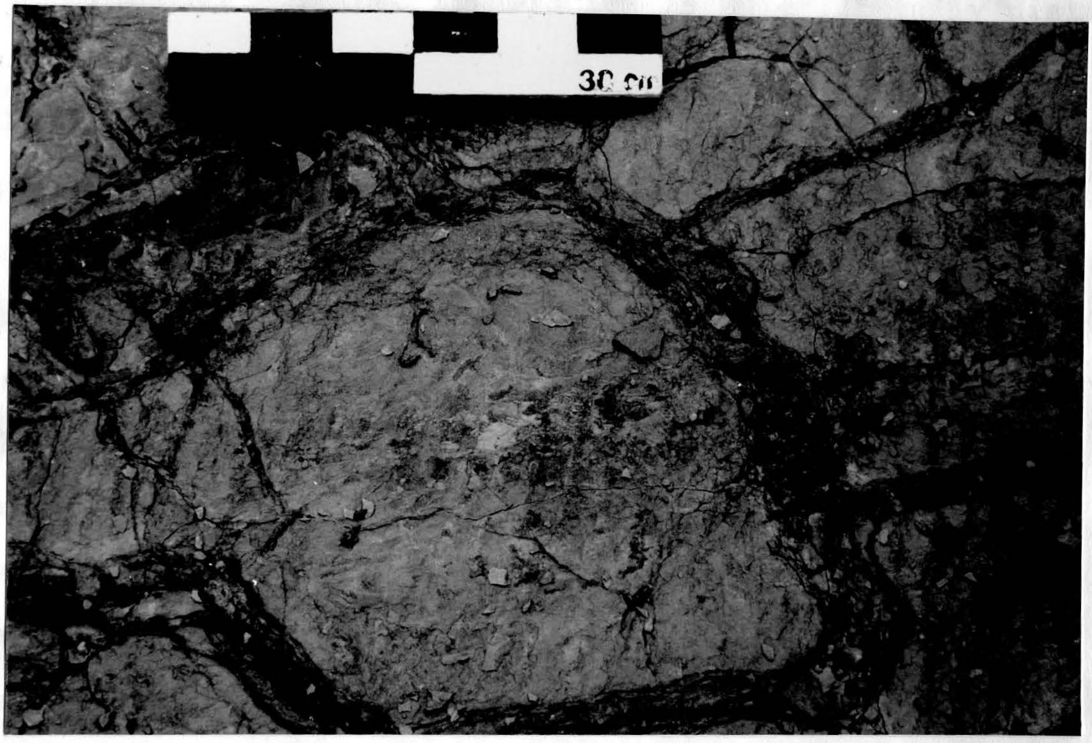

30 cm

with the siltstone of this lithofacies. In plan view, the polygons are several tens of centimeters across and bedding surfaces evidence linear ripple trains and the previously discussed biogenic structures. The wide (several centimeters), shallow (less than 1 cm), open sheet cracks expose and are infilled with the coarser-grained material of the beds below (Fig. 24). Carbonate nodules are common in the crack fill. There is no evidence of extensive deformation or flowage of crack fill. This suggests crack formation resulted from desiccation; rather than compaction, dewatering, or syneresis processes.

Carbonate nodules (calcareous concretions, cornstone, race) are best developed in this lithofacies although they are found dispersed throughout the other lithologies. The nodules are subrounded to subangular with low sphericity. The diameters range from several millimeters to less than 5 cm. The nodules appear to displace the adjacent bedding suggestive of in-situ development. Occasionally, vertical elongate nodules form distinct horizons less than 15 to 20 cm in thickness. Greenish-gray patches of siltstone outlining the general structure of root traces are present. Vertical cylindroids are rare. These horizons are seldom laterally continuous for more than several meters. The nature of the carbonate nodules may reflect young to early - mature development of a pedogenic profile (caliche) as defined by Reeves (1970). Gile and others (1966) would designate this carbonate profile development as stage 1 or 2.

Figure 24. Open sheet cracks, infilled with very fine-grained sandstone, in coarse-grained siltstone. Note the linear ripple train on the surface of the desiccation polygon. Scale is 30 cm in length.

Figure 25. Carbonate nodules that developed in-situ in coarse-grained siltstone. Nodules indicated by arrows. Root structures are also present. Scale is 30 cm in length.


30 cm


30 cm

This fine-grained lithofacies is more laterally distal with respect to the coarser-grained channel sandstones than the small-scale cross-stratified fine-grained sandstone and siltstone lithofacies. The gross geometry is often lense-like and laterally extensive. Load structures are sometimes present in basal beds. Small depressions infilled with fine-grained sandstone are associated with the lithofacies. The depressions are several tens of centimeters to less than 1 m deep and less than several meters wide.

Interpretation: The disrupted fine-grained lithofacies is interpreted as the result of crevasse splay deposition. Supporting evidence includes the geometry, stratigraphic relationship, and continuity of the beds; coarsening upward grain size sequences; development of in-situ carbonate nodules (caliche) and desiccation features; and distinct feeder and distributary channels (depressions). As flow breaches active channel banks or levees, discrete channels transport the coarsest sediment of the flood flow out onto the alluvial plain floor (Allen, 1964a, 1965; Coleman, 1969). Crevasse splay deposition results when flow can no longer entrain sediment due to lateral dispersion of flow or decrease in flow velocity. Sediment deposited is coarser than the previously deposited flood basin alluvium and a coarsening up sequence results. Crevasse splay deposits tend to be elevated above the alluval plain floor and thus enhance the development of subaerial exposure and biogenic features.

PALEOCURRENTS

Introduction

Paleocurrent measurements are utilized to facilitate interpretation of sedimentary facies regarding paleoflow and paleoenvironmental parameters. The most widely accepted method for analysing the orientation of two-dimensional sedimentary structures is the vector method (Reiche, 1938; Curray, 1956; Potter et al., 1977). The central tendency (vector azimuth), dispersion (vector magnitude), and probability that the observed orientation is real can be evaluated by this method.

A realistic appraisal of paleoflow conditions involves consideration of relative structure type and size to the flow-vector field. This is accomplished by use of a weighting factor based on the concept of sedimentary structure hierarchy as defined by Allen (1966). Miall (1974) uses set thickness cubed as the weighted measure in vector mean azimuth calculations. This parameter is thought to produce the most accurate estimate of sediment volume transported in the direction of discharge. An important consideration concerns cross-stratification azimuth divergence as documented by Smith (1972). Divergence in cross-stratification azimuths may influence directional variance, particularly in vertical successions, but is not thought to significantly affect the vector mean (Miall, 1974).

In this study, ungrouped and both weighted and unweighted data are analysed by the vector method as presented by Curray (1956) and Miall (1974). The calculations used and results are given in Tables 1, 2 and 3, respectively. Weighted vector mean calculations are not applicable to parting lineation due to the nature of the structure (no set thickness) and are considered separately as unweighted data. Calculations and results of parting lineation information are presented in Tables 1 and 3.

Description

Two-hundred and fourteen measurements of cross-stratification were obtained from the Oneonta Formation. Paleocurrent data and current rose constructions were analysed with respect to both local and regional paleoflow patterns. Current rose diagrams, constructed with 15° intervals, are shown in Figures 26 - 30. The diagrams tend to be unimodal and the following trends are observed when data from all locations are examined.

The large-scale trough cross-stratification has a resultant vector azimuth of 298° and very low dispersion values (92% - 99%). Cross-stratification within the large accretionary units also exhibits very low dispersion (90% - 99%) with a resultant vector azimuth of 313°. Large-scale planar - tabular cross-strata and inclined planar stratification have a higher degree of dispersion (66% - 84%) and resultant vector azimuth (239°) which deviated substantially from those of other cross-stratified structures. Small-scale cross-stratification dispersion is very low

TABLE 1

CALCULATIONS USED IN WEIGHTED AND UNWEIGHTED VECTOR ANALYSIS OF PALEOCURRENT DATA FROM THE ONEONTA FORMATION

FOR WEIGHTED DATA:

(1) $\tan \bar{\theta} = \dfrac{\Sigma n_w \sin \theta}{\Sigma n_w \cos \theta}$,

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

(3) $L = \dfrac{r}{n_w}(100)$,

(4) $p = e^{(-L^2 N)(10^{-4})}$;

FOR UNWEIGHTED DATA:

(1) $\tan \bar{\theta} = \dfrac{\Sigma n_u \sin \theta}{\Sigma n_u \cos \theta}$,

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

(3) $L = \dfrac{r}{N}(100)$,

(4) $p = e^{(-L^2 N)(10^{-4})}$;

WHERE:

N = number of observations.

θ = azimuth from 0^o - 360^o of each observation.

$\bar{\theta}$ = azimuth of the resultant vector.

n_w = weighted vector magnitude, in this case the cube of set thickness.

n_u = unweighted (observational) vector magnitude.

r = magnitude of the resultant vector.

L = magnitude of the resultant vector in terms of percent.

P = probability of obtaining a greater distribution by pure chance combination of random measurements (Rayleigh significance test).

TABLE 2

RESULTS OF WEIGHTED VECTOR ANALYSIS OF PALEOCURRENT DATA

LARGE-SCALE TROUGH CROSS-STRATIFICATION:

	Site 2	Site 3	Site 5	Site 7	Site 9	Study Area
N	36	11	16	27	No Data	90
$\bar{\theta}$	318°	309°	305°	219°	No Data	298°
r	3.9×10^{-2}	1.7×10^{-2}	1.1×10^{-2}	1.8×10^{-2}	No Data	6.8×10^{-2}
L	97%	99%	97%	92%	No Data	76%
p	$<10^{-4}$	$<10^{-4}$	$<10^{-6}$	$<10^{-9}$	No Data	$<10^{-22}$

LARGE ACCRETIONARY TROUGH OR LENSE UNITS:

	Site 2	Site 3	Site 5	Site 7	Site 9	Study Area
N	4	No Data	8	3	No Data	15
$\bar{\theta}$	294°	No Data	060°	281°	No Data	313°
r	2.9	No Data	1.2	1.9×10^{-1}	No Data	2.6
L	99%	No Data	99%	90%	No Data	59%
p	$<10^{-1}$	No Data	$<10^{-3}$	$<10^{-1}$	No Data	$<10^{-2}$

LARGE-SCALE PLANAR CROSS-STRATIFICATION AND INCLINED PLANAR STRATIFICATION:

	Site 2	Site 3	Site 5	Site 7	Site 9	Study Area
N	6	1	4	No Data	1	12
$\bar{\theta}$	249°	286°	190°	No Data	290°	239°
r	8.4×10^{-1}	—	3.9×10^{-1}	No Data	—	1.2
L	66%	—	84%	No Data	—	62%
p	$<10^{-1}$	—	$<10^{-1}$	No Data	—	$<10^{-2}$

SMALL-SCALE PLANAR, TANGENTAL, AND TROUGH CROSS-STRATIFICATION:

	Site 2	Site 3	Site 5	Site 7	Site 9	Study Area
N	19	No Data	14	No Data	No Data	33
$\bar{\theta}$	312°	No Data	276°	No Data	No Data	278°
r	1.6×10^{-6}	No Data	2.5×10^{-5}	No Data	No Data	2.6×10^{-5}
L	94%	No Data	99%	No Data	No Data	98%
p	$<10^{-6}$	No Data	$<10^{-5}$	No Data	No Data	$<10^{-13}$

TABLE 3

RESULTS OF UNWEIGHTED VECTOR ANALYSIS OF PALEOCURRENT DATA

PARTING LINEATION:

	Site 2	Site 3	Site 5	Site 7	Site 9	Study Area
N	28	4	20	12	No Data	64
$\bar{\theta}$	132°-312°	146°-326°	020°-200°	092°-272°	No Data	145°-325°
r	2.5×10^1	3.9	1.7×10^1	1.1×10^1	No Data	4.4×10^1
L	88%	97%	86%	89%	No Data	69%
p	$<10^{-9}$	$<10^{-1}$	$<10^{-6}$	$<10^{-4}$	No Data	$<10^{-13}$

Figures 26 - 30. Rose diagrams constructed with 15^{o} intervals showing the results of paleocurrent data from the Oneonta Formation. N, $\bar{\theta}$, and L values are given and $\bar{\theta}$ is indicated by an arrow.

Figure 26. Large-scale trough cross-stratification.

Figure 27. Large accretionary unit stratification.

Figure 28. Large-scale planar - tabular cross-stratification and inclined planar stratification.

Figure 29. Small-scale cross-stratification.

Figure 30. Parting lineation.

Figure 26

LARGE-SCALE TROUGH CROSS-STRATIFICATION

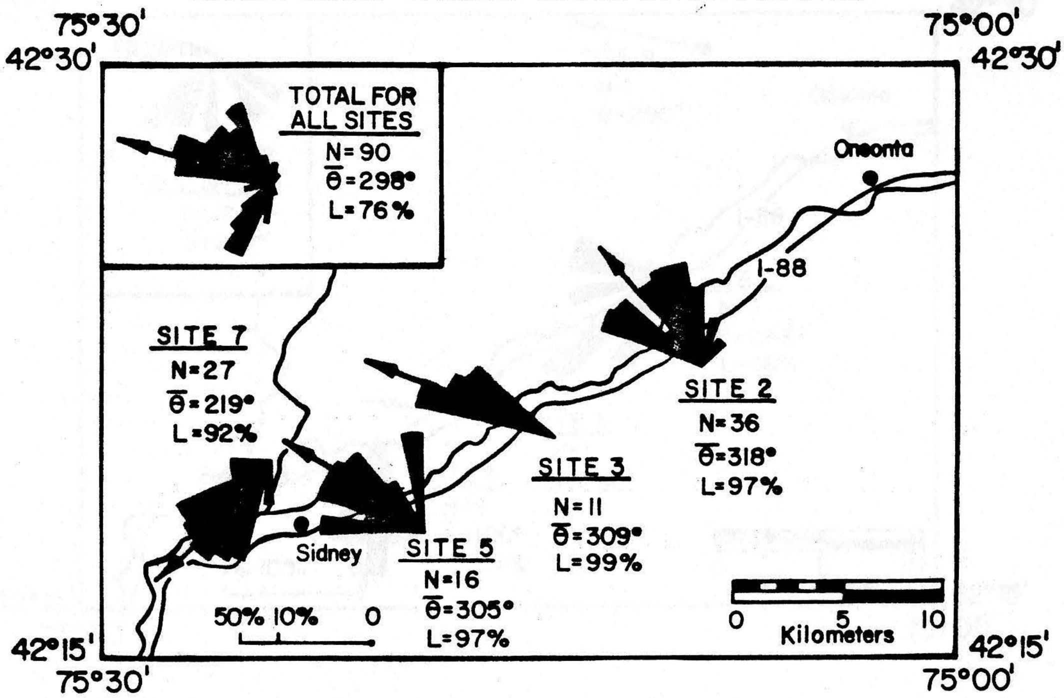


Figure 27

LARGE ACCRETIONARY TROUGH OR LENSE CROSS-STRATIFICATION

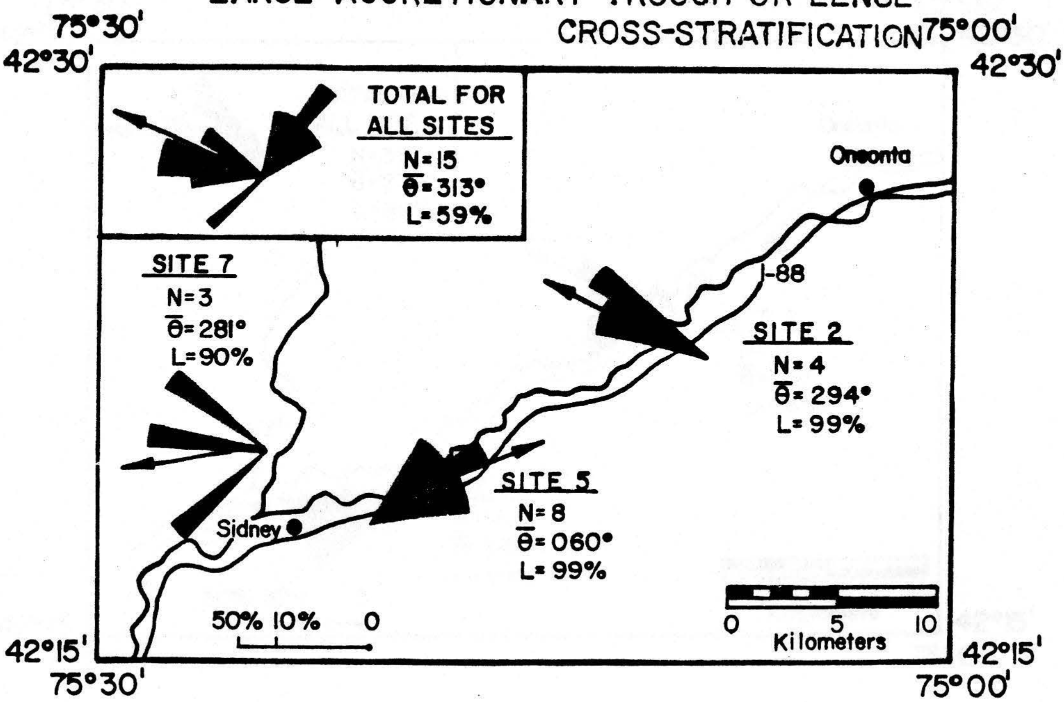


Figure 28

LARGE-SCALE PLANAR CROSS-STRATIFICATION

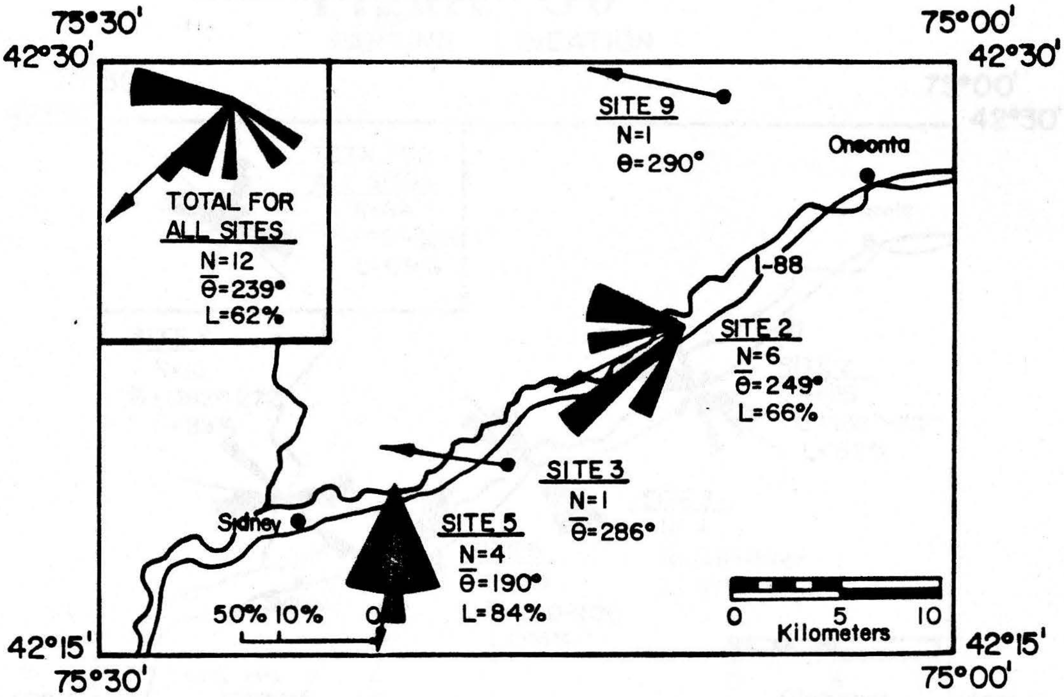


Figure 29

SMALL-SCALE CROSS-STRATIFICATION

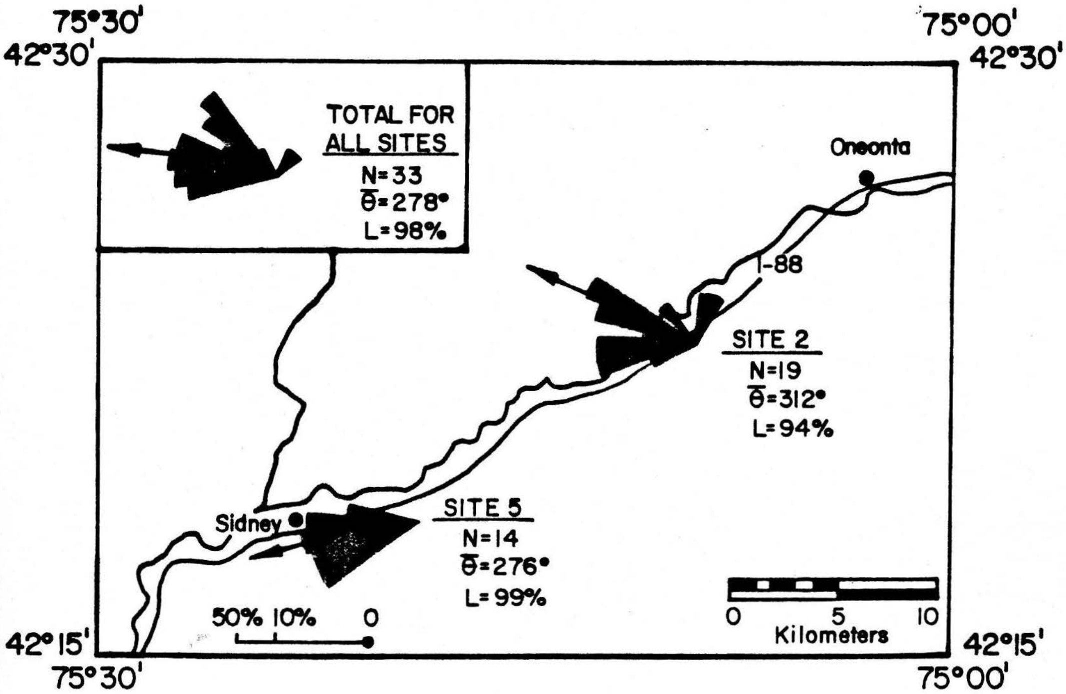
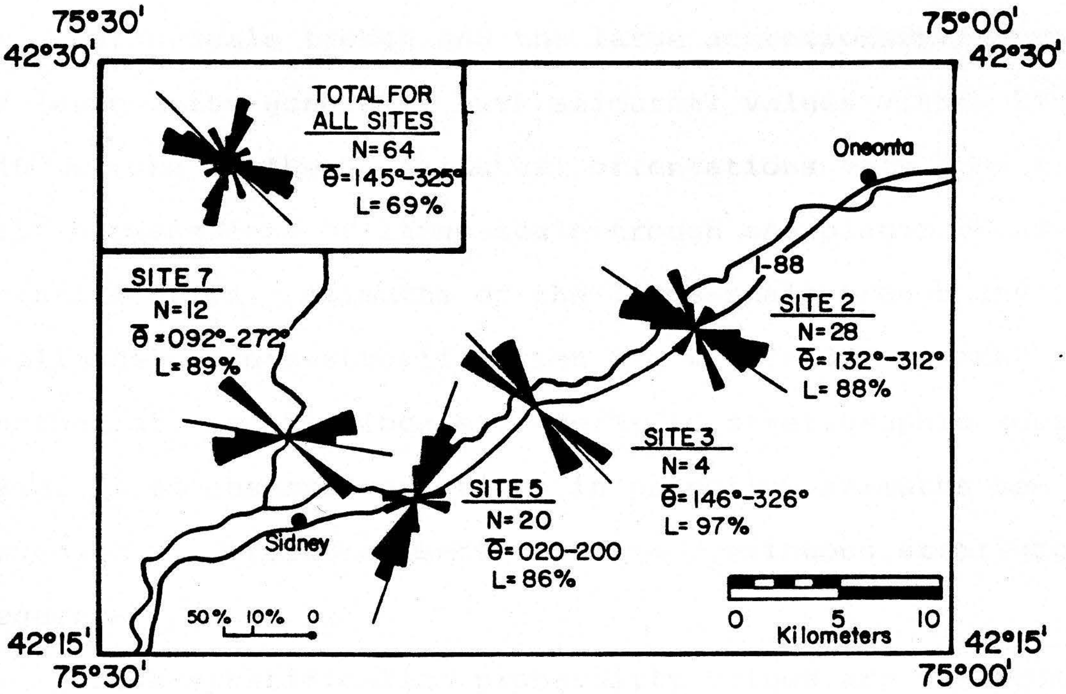


Figure 30

PARTING LINEATION



(94% - 99%). The resultant vector azimuth is 278°. Parting lineation has a resultant vector azimuth of 145° - 325° and fairly low dispersion values (86% - 97%).

Large-scale trough and the large accretionary trough or lense units generally have azimuthal values within 20° - 110° of one another. Azimuthal orientations vary from 10° - 115° between sets of large-scale trough and planar cross-stratification. Azimuths of the large-scale trough and small-scale cross-stratification are within 30° of one another at specific locales. Refer to stratigraphic sections (Fig. 7) to observe variations in paleoflow azimuths between cross-stratified sets within a continuous stratigraphic sequence.

Cross-stratification probability values are variable from location to location. Probability that the observed azimuthal orientations of the large-scale trough and small-scale cross-strata, as well as parting lineation, is high. This indicates that these measurements give a true depiction of the actual flow direction of the fluvial system. Large accretionary trough or lense units and planar cross-strata and inclined planar stratification values are low.

Interpretation

The paleocurrent data is interpreted as reflecting fluvial deposition in low sinuosity, braided channels. This is supported by the unimodal current rose diagrams and low dispersion values of the cross-stratification.

The orientations of cross-stratification indicate a northwesterly transport direction. The grand vector mean azimuth of 293° reflects the trend of the fluvial system. This grand vector mean is based on 150 cross-stratification measurements (excluding parting lineation). Parting lineation orientations, southeast - northwest, are in alignment with the general trend. The large-scale planar cross-stratification deviates about 70° from the trend with a southeast orientation.

Unidirectional channel paleoflow is implied by the orientation of large-scale trough cross-strata produced by megaripple deposition. The best indicator of channel paleoflow direction is thought to be reflected by the azimuths of large-scale trough cross-stratification (High and Picard, 1974). Small-scale cross-stratification is an equally good paleoflow indicator and this appears to be applicable in this study (Coleman, 1969; Williams and Rust, 1969; Rust, 1972; High and Picard, 1974). The close agreement in mean vector azimuthal results for the large-scale trough (298°) and small-scale (278°) cross-stratification, in association with low dispersion values, indicates the general paleochannel trend.

The cross-strata azimuths of the large accretionary units indicate deviation in flow from that implied by adjacent trough cross-strata. Dispersion is low. This reflects deposition of low-stage bar foresets with crests oriented at a low angle to the trend of the main channel.

This has been documented in Australian ephemeral streams (Williams, 1971), the Platte River (Smith, 1971; 1972), and the South Saskatchewan River (Walker, 1976; Cant, 1978a).

The planar and inclined planar orientations to the southwest and the high dispersal values reflect an anomalous flow pattern. This results from migration, deposition, and shallow flow off high-stage linguoid bars with lobate crestlines. Dispersive foreset orientations result from flow expansion and linguoid bar growth. Dispersion of azimuths, up to 100° or more, within interbedded multiple sets of inclined planar stratification is high. Planar cross-stratified sets diverge up to 115°, averaging 70°, away from those of adjacent structures. This type of dispersion pattern associated with planar cross-strata and inclined planar stratification has been reported in both Recent and ancient fluvial deposits (Collinson, 1970; Williams, 1971; Smith, 1971; 1972; Walker, 1976; Jones, 1977; Miall, 1977; Cant, 1978b). Smith (1972) demonstrates that high-stage bars, once exposed, show high dispersion in cross-strata foreset orientations.

The orientation of parting lineation and small-scale cross-stratification is interpreted to result from shallow upper flow regime and lower flow regime deposition, respectively. Parting lineation azimuths and the high dispersion imply high velocity, sheet-like flow off bar surfaces. The small-scale cross-strata orientations reflect both late stage flow on bar surfaces and alluvial flood basin deposition.

A noticeable difference in vector mean cross-stratification orientations exists between the eastern locations and the most western location (Site 7). Data suggest that the earlier paleoflow at Site 7 was more southwesterly and later, at the remaining sites, more northwesterly. Rapid channel shifts and associated changes in the trend of flow direction often result from avulsion processes. Based on stratigraphic relationships, this is interpreted to reflect a general paleoflow orientation change resulting from avulsion of the fluvial system as it migrated laterally across the alluvial fan surface.

PETROLOGY

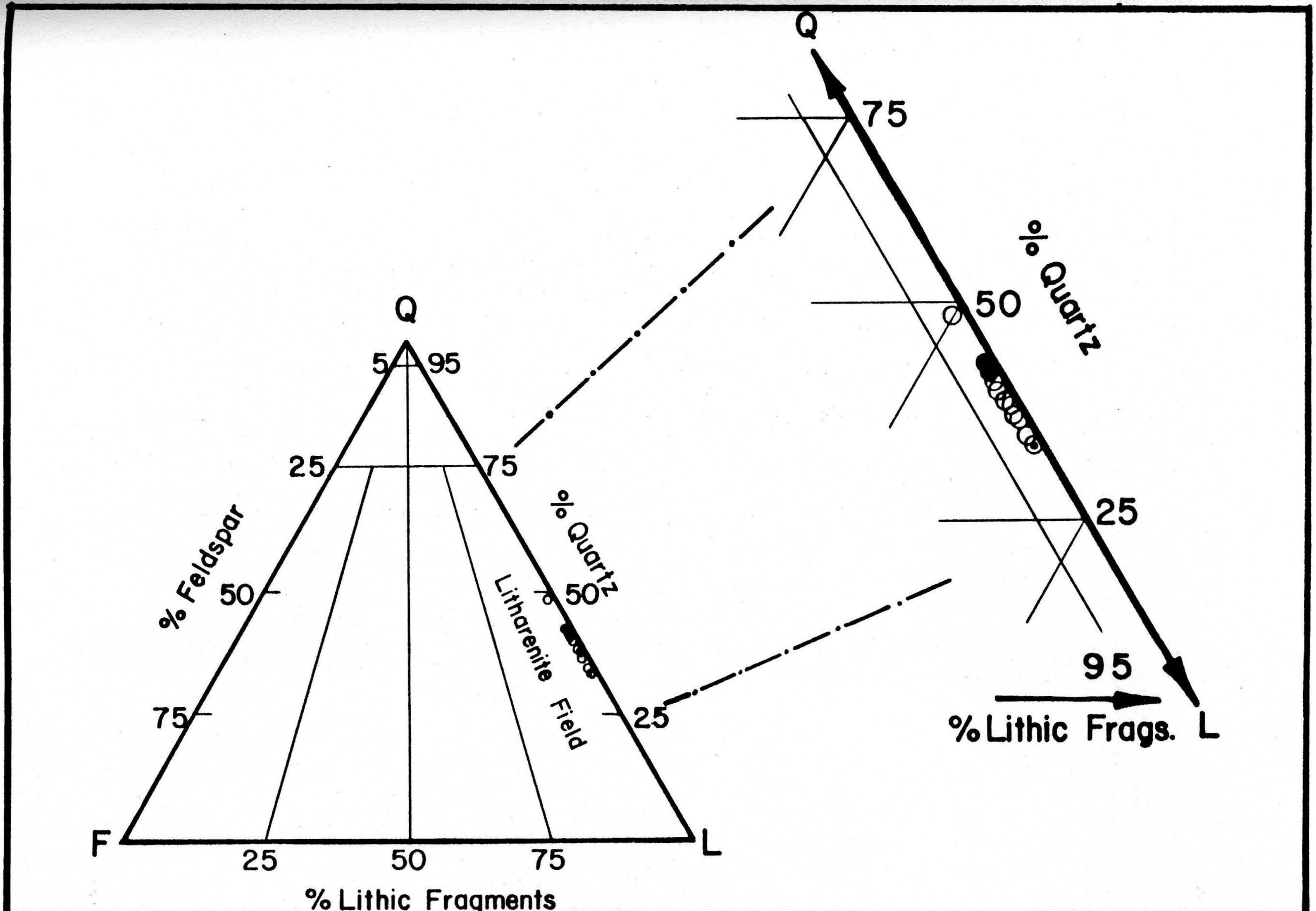
Composition and Texture

Sandstone Description: The sandstones of the Oneonta Formation can be classified as lithic sandstones (Pettijohn, 1954); low-rank lithic graywackes (Krynine, 1945); or litharenites, specifically phyllarenites (Folk, 1974). Results of modal analysis reveal the sandstones average 39% quartz, 1% feldspar, and 60% lithic fragments (Q_{39} - F_{1} - L_{60}) when calculated following the procedure of Graham and others (1976). Quartz mica tectonites (phyllite and schist), argillite - shale, and aggregate quartz are the predominate lithic fragments. Figure 31 illustrates the composition of the sandstones on a Q - F - L ternary diagram. Figure 32 shows the general aspects of the sandstones in thin-section. Table 4 summarizes the grain parameters and Table 5, the characteristics of the analysed sandstones (Table 5 in back pocket).

Accessory minerals make up less than 10% of the total rock composition of the sandstones, averaging 8.0%. Primary detrital micas, particularly chlorite and muscovite, are dominant. Other identifiable, although rare, accessory minerals include epidote, sphene, and blue amphibole.

Calcite and hematite are the primary cementing agents. Cement never exceeds 8% in any sample and averages 2.1% of the total rock composition. Calcite cement is irregularly distributed throughout the samples. It occurs as optically continuous crystal which encase other detrital grains

Figure 31. Composition of the Oneonta Formation sandstones plotted on Quartz (Q) - Feldspar (F) - Lithic fragments (L) ternary diagram. Data based on modal analysis of fifteen selected sandstones. The lack of feldspar and abundance of lithic fragments and quartz is evident as the sandstones plot close to the Q - L tie line. Detailed plots of sandstone compositions are shown on the right. Open circles denote single data points, closed circles denote double data points, and bullseye circles denote triple data points.

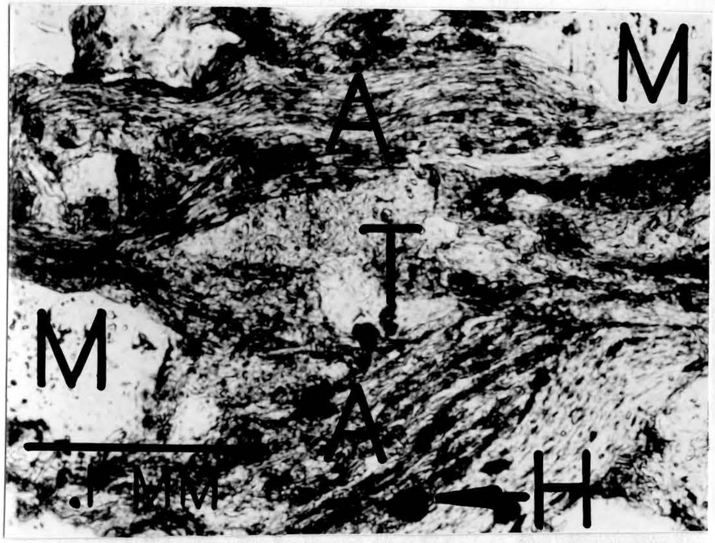


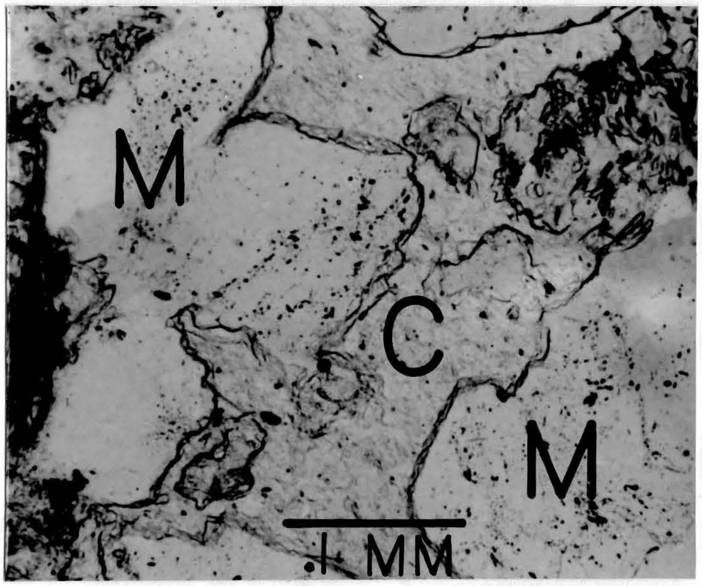
Q
5
95
25
75
% Feldspar
50
% Quartz
50
Litharenite Field
75
25
F
L
25
50
75
% Lithic Fragments
Q
75
% Quartz
50
25
95
% Lithic Frags.
L

Figure 32. Photograph of the general characteristics of the medium-grained sandstone of the Oneonta Formation. The sandstone is largely composed of quartz and lithic fragments. Monocrystalline quartz (M) is surrounded by a well-developed pseudomatrix of squashed quartz mica tectonites (T) and argillite - shale (A) fragments. Hematite is also present. Plane polarized light. Scale is .1 mm.

Figure 33. Development of calcite cement (C) in the medium-grained sandstone of the Oneonta Formation. Cement is optically continuous and encloses detrital fragments of monocrystalline quartz (M) and quartz mica tectonites (T). Plane polarized light. Scale is .1 mm.

Figure. 34. Photograph of medium-grained siltstone of the Oneonta Formation. Angular monocrystalline quartz (M) is dispersed in phyllosilicate hash (P). Hematite is extensively distributed in the form of fine-grained pellicles. Plane polarized light. Scale is .1 mm.


M
A
T
M
A
H
.1 MM


M
C
M
.1 MM


P
M
.1 MM

TABLE 4

GRAIN PARAMETERS FOR TERNARY DIAGRAMS

$Q = Q_m + Q_p$, where:

Q = Total Quartz Grains

Q_m = Monocrystalline Quartz Grains

Q_p = Polycrystalline Quartz Grains

F = Total Feldspar Grains

$L = L_m + L_s$, where:

L = Unstable Aphanitic Lithic Fragments

L_m = Metamorphic Lithic Fragments (Quartz mica tectonites)

L_s = Sedimentary Lithic Fragments (Polycrystalline Mica, Argillite - Shale, and Carbonate)

$L_t = L + Q_p$, where:

L_t = Total Aphanitic Lithic Fragments

TABLE 6

GRAIN PARAMETERS	ONEONTA FORMATION	TECTONIC PROVENANCE
Q	39.1%	Moderate, 25% - 50%
F	0.9%	Low, < 25%; commonly < 10%
L	60.0%	Moderate, ~ 50%
C/Q	0.6	High, 0.5 +
P/F	Moderate to High	Variable
V/L	Not Applicable	Moderate, ~0.5

C/Q = Polycrystalline Quartz/Total Quartz

P/F = Plagioclase Feldspar/Total Feldspar

V/L = Volcanic Lithic Fragments/Total Unstable Lithic Fragments

(Fig. 33). Both replacement of quartz by calcite and calcite by quartz occurs. Hematite occurs as pellicles surrounding both argillite - shale and carbonate fragments. It is also dispersed as discrete clusters of grains forming hematite-rich layers interlaminated with detrital-rich layers. Hematite is responsible for the red coloration of the finer-grained sandstones. Secondary quartz is present as a cementing agent in the form of overgrowths. It is relatively insignificant volumetrically. Minor amounts of phyllosilicate cement, in the form of authigenic chlorite, is also present.

The detrital quartz fraction averages 39.1% of the framework grains. It is composed of 39.8% monocrystalline quartz and 60.2% polycrystalline quartz. The quartz grains are very angular to subangular with low sphericity. Silica overgrowths obscure many grain boundaries. Moderate alteration of feldspar to sericite is seen on some granitic grains. Monocrystalline quartz has vacuole trains, vermicular chlorite, and needles of rutile indicative of plutonic origin. Extinction is straight to slightly undulatory. Polycrystalline quartz grains are diverse in nature and have straight, sutured, and granulated intragrain boundaries. Foliate metaquartzite and aggregate quartz are common. Extinction is straight to undulatory.

Feldspar is uncommon and comprises less than 1% of the sandstone framework. Potassium feldspar and twinned plagioclase dominate. Some twinned plagioclases are fractured and have strained extinction features. Scarce untwinned plagioclase is distinguished from quartz by its cloudy and more altered appearance. Perthite is present but very rare. The feldspars are often slightly altered by chloritization and/or sericitization.

Detrital lithic fragments dominate the framework composition of the sandstones, averaging 60.0%. The lithic fragments are subangular to rounded with low sphericity. Grain boundaries are difficult to delineated due to extensive phyllosilicate replacement. Quartz mica tectonites; largely sericite - chlorite - quartz phyllite, quartz - chlorite - and quartz - muscovite schists; are the predominate lithic constituents (45.6%). Argillite - shale and aggregate quartz are present in subequal amounts, 22.1% and 19.2%, respectively. Polycrystalline mica (8.7%) and foliated metaquartzite (3.3%) are present. Carbonate and unidentified fragments each comprise less than 1% of the total lithic composition. Both volcanic - hypabyssal and chert fragments are absent in the sandstones. Igneous intrusive fragments (granite/granitoid) are present and tabulated as either quartz or feldspar after the method of Dickinson (1970). Thus, they do not constitute a modal percentage of the total lithic composition. Many of the lithic fragments have altered to chlorite. No truely pervasive matrix exists in the sandstones. Rather, a pseudomatrix of deformed ('squashed') and partly recrystallized lithic fragments is common (Dickinson, 1970) (Fig. 32).

Siltstone description: The composition and texture of the Oneonta Formation siltstones is similar in many respects to that of the sandstones. Angular to subangular silt-sized quartz fragments, lithic fragments, and detrital chlorite and muscovite are dispersed in a phyllosilicate hash (Fig. 34). A well-developed subparallel grain orientation is obvious in many cases but absent where biogenic disruption of bedding is extensive.

Notable dissimilarities between the sandstones and siltstones include differences in the amounts of total quartz, particularly polycrystalline quartz; and phyllosilicates present. Siltstones tend to be less quartz-rich and more micaceous than the sandstones. The siltstones also contain a higher percentage of hematite. Extremely fine-grained hematite pellicles are ubiquitously dispersed throughout the siltstones giving rise to their red coloration. The green and gray siltstones lack hematite.

Petrologic Interpretation Regarding Provenance

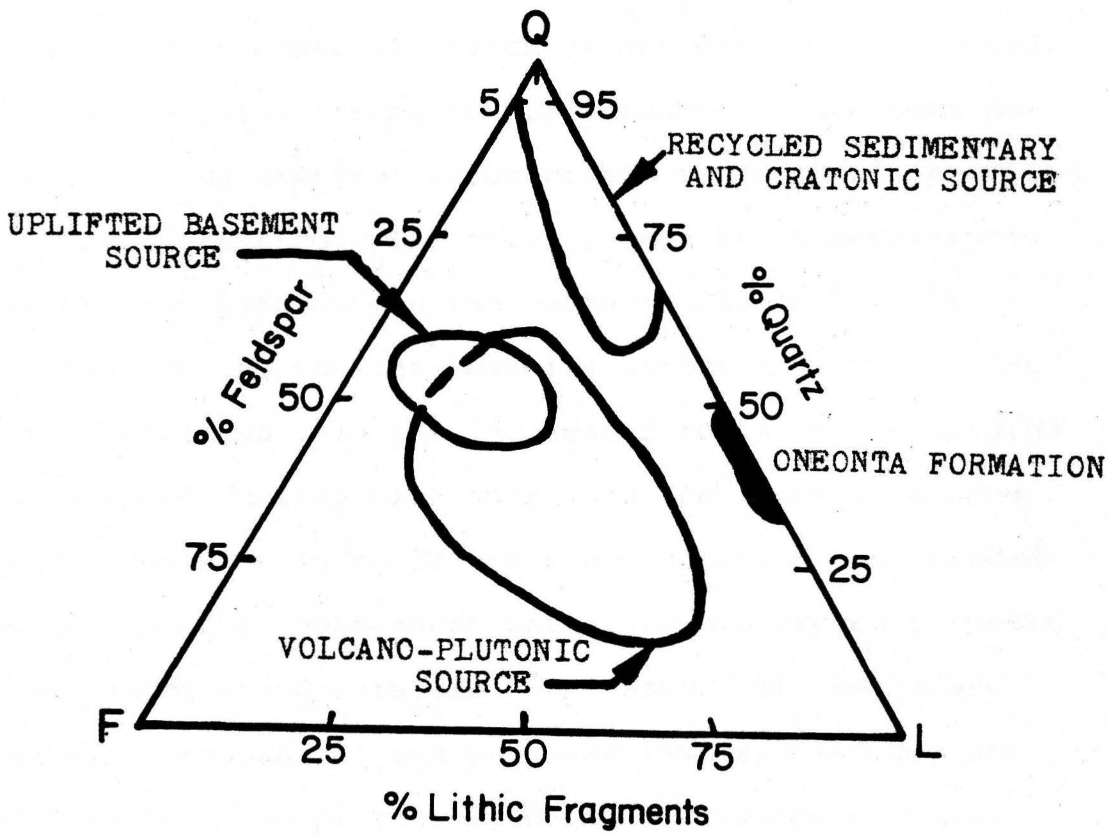
The petrology and inferred source of the Oneonta Formation presented in this study is in concurrence with previous provenance studies of associated Catskill molasse rocks (Mencher, 1939; Meyer, 1963; Allen and Friend, 1968; Ethridge, 1977).

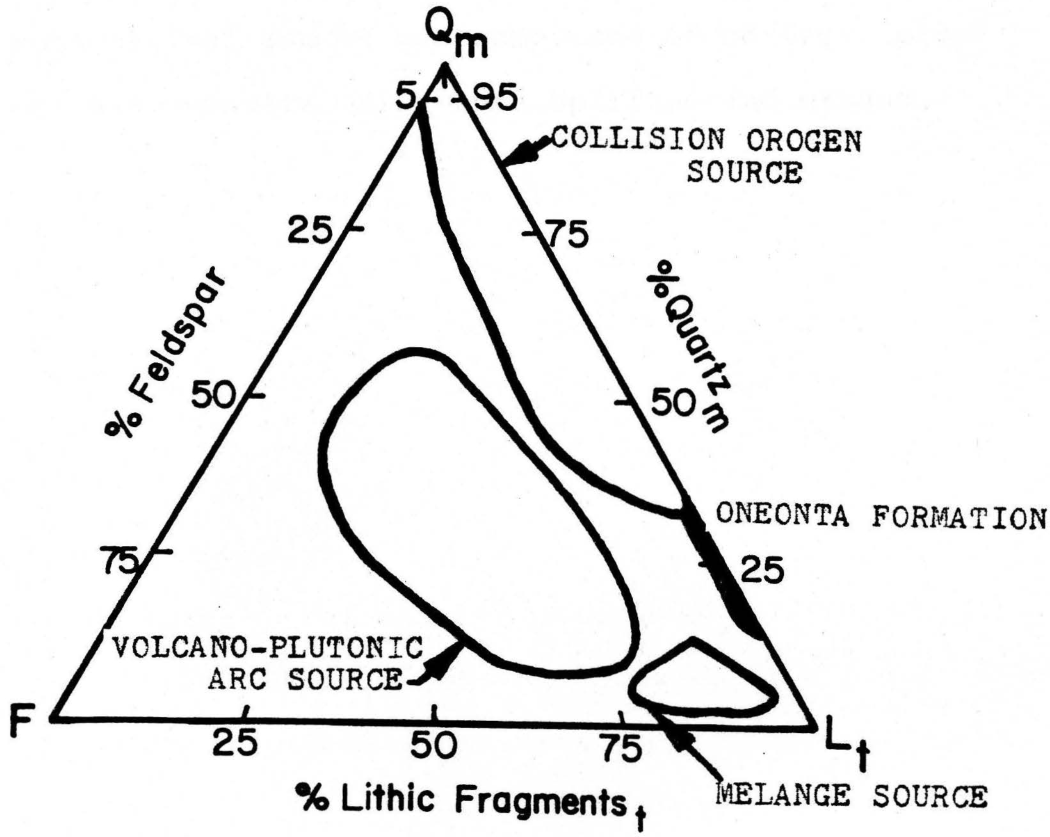
The petrologic characteristics of the Oneonta Formation strongly indicate a source terrain predominately composed of sedimentary and low-grade metamorphic rocks with a minor plutonic component. Results of grain parameter values in this study support the concept that the sandstones were derived from a tectonic provenance within an orogenic belt as discussed by Dickinson (1970) (Table 6). The moderate quartz, high lithic fragments, and extremely low feldspar percentages; as well as high C/Q and P/F ratios; are indicative of detritus produced by an uplifted, supracrustal cratonic sourceland. The extremely low percentage of feldspar and absence of volcanic lithic fragments imply a lack of extrusive igneous exposure in the source area.

Q - F - L and Q_m - F - L_t ternary diagrams respectively emphasize the compositional maturity and provenance of the sandstones (Graham et al., 1976). Fields of sandstones derived from recognized tectonic provenances are plotted on the diagrams allowing for comparison between them and the sandstones of the Oneonta Formation. Figure 35 indicates the Oneonta Formation sandstones are immature. The moderately low Q/L ratio and abundance of lithic fragments reflect this compositional immaturity. Figure 36 shows the field of the sandstones on a Q_m - F - L_t ternary diagram indicating provenance. The field of the Oneonta Formation sandstones is thought to fall near the L_t corner as they reflect the initial orogenic unroofing of sedimentary and low-grade metamorphic material and early stage deposition in adjacent basins. Extreme detrital reworking was inhibited by rapid sedimentation. Extensive physical and chemical weathering of lithic detritus into its constituents did not

Figure 35. Q - F - L ternary diagram illustrating the compositional immaturity of the Oneonta Formation sandstones. Compare the Oneonta sandstone field to that of recycled cratonic and collision, uplifted basement, and volcano - plutonic orogen detritus (Dickinson et al., 1979). Orogenically mature sandstones exhibit a higher Q/L ratio and lower lithic constituent percentage than present in the Oneonta Formation. The high percentage of lithic fragments indicates rapid sedimentation resulting in deposition before extensive physical or chemical weathering of grains occurred.

Figure 36. Q_m - F - L_t ternary diagram indicating provenance of the Oneonta Formation sandstones. Collision and volcano - plutonic arc orogen sources after Dickinson and others (1979) are plotted. Note the overlap of the Oneonta Formation field with that of the lower portion of the collision orogen provenance field. The high lithic fragment, low monocrystalline quartz, and virtually non-existant feldspar percentages suggest a collision orogen provenance for the Oneonta Formation.


Q
5
95
RECYCLED SEDIMENTARY AND CRATONIC SOURCE
UPLIFTED BASEMENT SOURCE
25
75
% Feldspar
% Quartz
50
50
ONEONTA FORMATION
75
25
VOLCANO-PLUTONIC SOURCE
F
L
25
50
75
% Lithic Fragments


Qm
5
95
COLLISION OROGEN SOURCE
25
75
% Feldspar
% Quartz m
50
50
ONEONTA FORMATION
75
25
VOLCANO-PLUTONIC ARC SOURCE
F
Lt
25
50
75
% Lithic Fragments t
MELANGE SOURCE

occur. This resulted in a lower Q_m/L_t ratio than is seen or expected in other collision orogen derived sandstones.

The detrital fragments are thought to have been derived from two distinct areas within the general orogenic collisional setting. The primary area was extrabasinal. Paleocurrent information indicates it lay to the east - southeast of the present Catskill structural front. The supracrustal and very shallow-seated rocks of the sutured and uplifted Acadian highlands were the specific source. This source area is no longer present having been eroded and destroyed by subsequent unroofing and orogenic events in the Permian and Jurassic - Triassic. The secondary area was intrabasinal and provided reworked sedimentary detritus from the previously deposited Devonian rocks. This intrabasinal source was comprised of earlier, proximal molasse deposits which were uplifted and eroded.

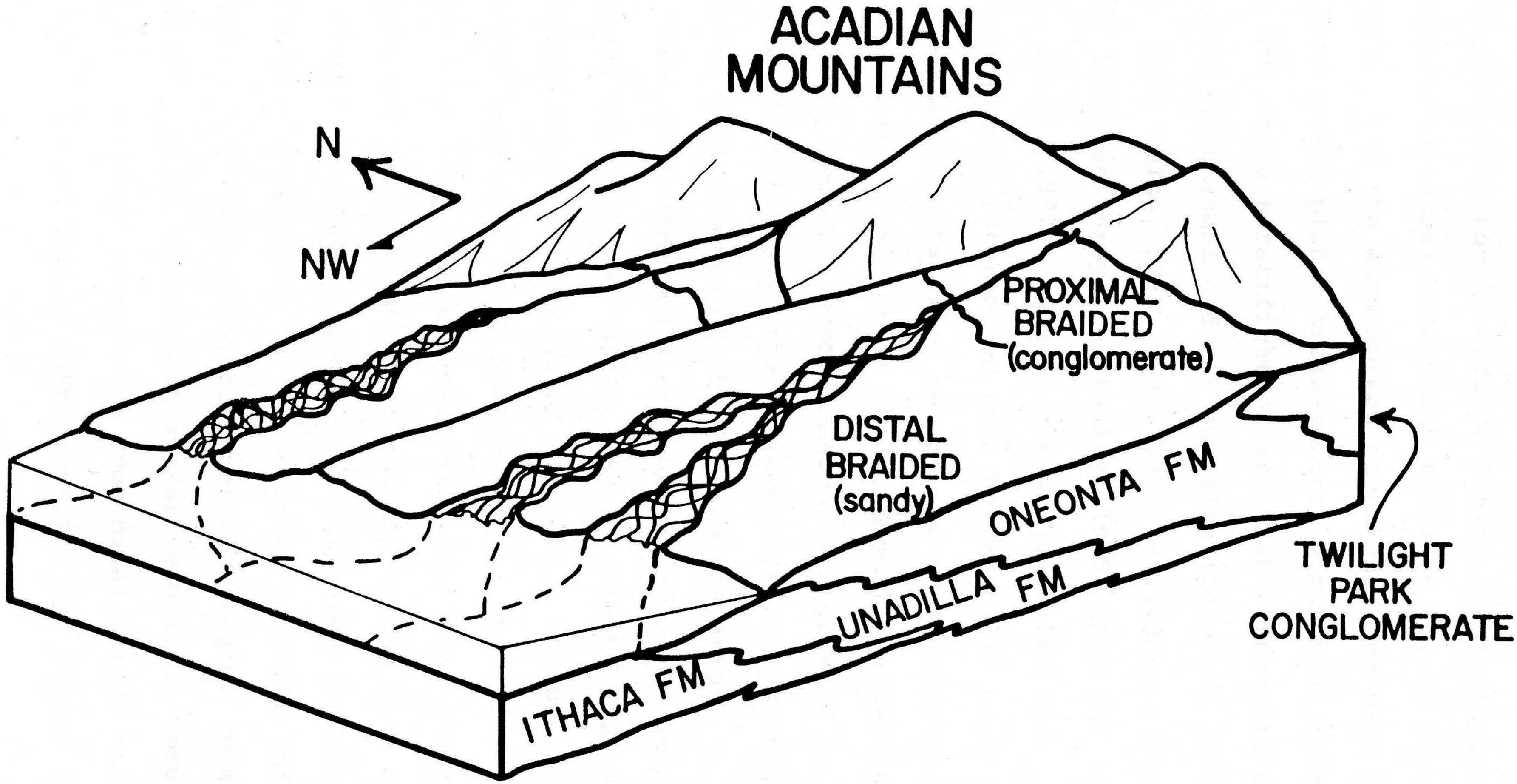
DISCUSSION

The nine lithofacies identified in the Oneonta Formation are interpretated to represent channel, bar, and associated alluvial flood basin deposits of a sandy, distal braided fluvial system. Low sinuosity, multiple channels were responsible for sediment dispersal across a low slope, alluvial fan. The paleogeography implied for the depositional site of the Oneonta Formation is presented in Figure 37.

Sandy, distal braided deposits are often difficult to differentiate from deposits of meandering streams. These two environments are often transitional in Recent deposits and may be complexly interbedded in ancient deposits. Criteria used to differentiate the two types of deposits include facies abundance and vertical occurrence, lateral and vertical accretion deposits, scour surfaces, and channel abandonment deposits and inferred behavior (Miall, 1977). Evidence from the Oneonta Formation supports a braided interpretation. This interpretation is based on lithofacies, paleocurrent, and petrologic information.

The distal equivalents of many coarse-grained braided deposits are identified on the basis of grain size and cross-stratification parameters (Smith, 1970). The lateral stratigraphic correlation and associated high percentage of medium- to very fine-grained sandstones in the Oneonta Formation channel lithofacies indicates it is a sandy, distal equivalent of the Twilight Park Conglomerate. The complex interfingering of channel and bar deposits with flood

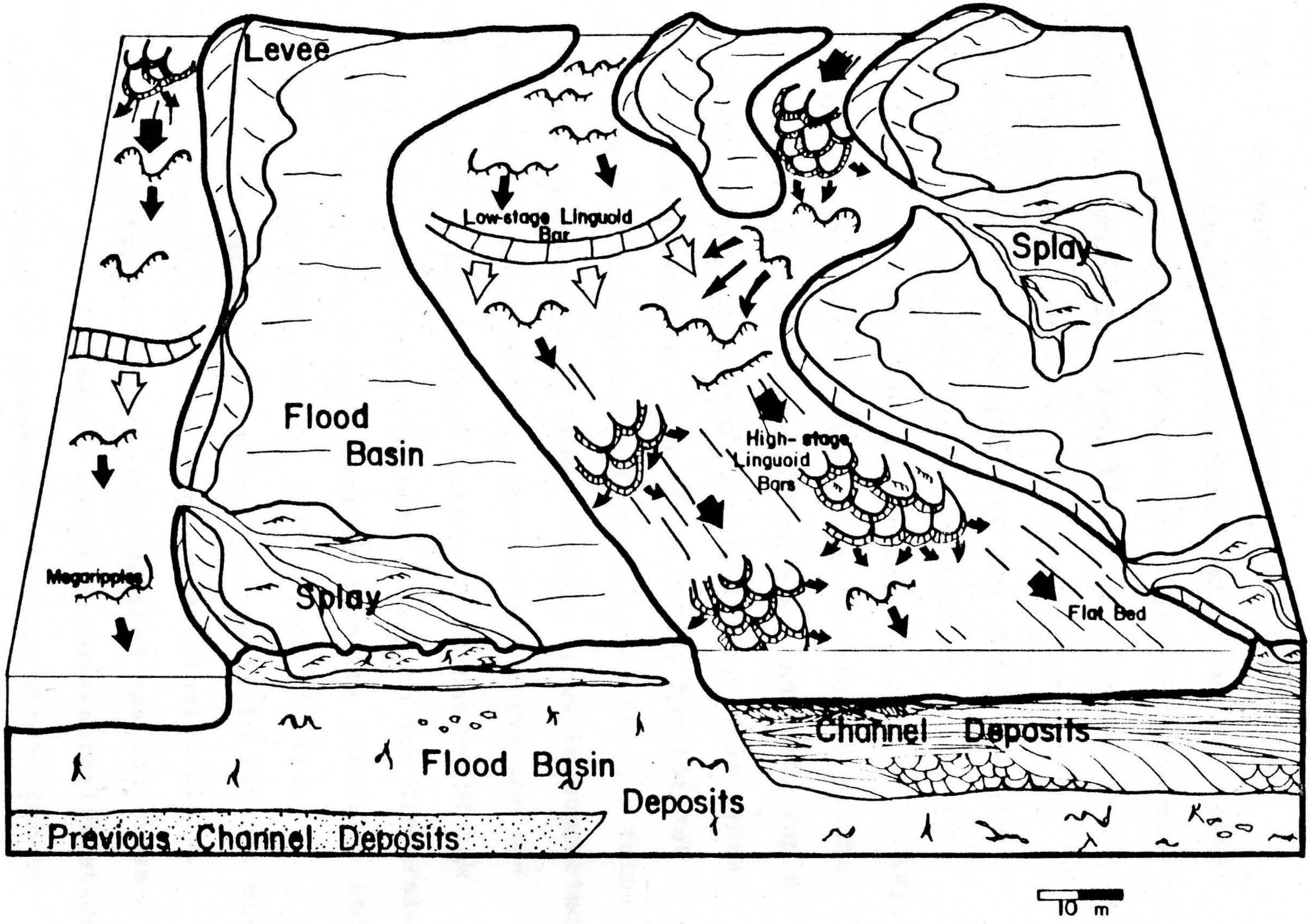
Figure 37. Paleogeographic reconstruction of the Oneonta Formation and adjacent formations during the early Late Devonian. Coalescing alluvial fan deltas originating in the Acadian Mountains prograded to the west and northwest into a shallow cratonic sea. Distance from the shoreline to the mountain front is approximately 100 km. The diagram is not to scale.


ACADIAN
MOUNTAINS
N
NW
PROXIMAL
BRAIDED
(conglomerate)
DISTAL
BRAIDED
(sandy)
ONEONTA FM
UNADILLA FM
ITHACA FM
TWILIGHT
PARK
CONGLOMERATE

basin deposits; poorly-defined fining upward sequence of channel sandstones; high width to depth ratios of channel deposits; and the wide-spread occurrence and high percentage of large-scale planar cross-strata, horizontal bedding, and very low-angle stratification are highly suggestive of distal braided channel and bar deposits (Coleman, 1969; Collinson, 1970; Smith, 1970, 1971, 1972; Williams, 1971; Boothroyd, 1972; Boothroyd and Ashley, 1975; Cant and Walker, 1976; Miall, 1977). The wide troughs filled with inclined stratification interbedded with horizontally bedded and very low-angle stratified sandstones are characteristic of linguoid bar deposition in sandy, distal braided channels (Boothroyd, personal communication). Figure 38 is a block diagram reconstructing the braided fluvial system and associated environments of the Oneonta Formation.

Braided environments are characterized by extreme fluctuations in discharge (Miall, 1977). Flashy discharge is suggested by several lines of evidence. Features including numerous erosional scour contacts, cut- and fill-structures, highly dispersed intraclasts, thin lenticular shales, and extreme and frequent lithofacies transitions both vertically and laterally support substantial discharge fluctuation. Sedimentary structures in the Oneonta Formation indicate abrupt changes from upper to lower flow regime related to rapid changes in stage depth and/or velocity. Complete channel sandstone successions from basal, crude trough cross-stratified pebbly intraclast through planar and hor-

Figure 38. Block diagram of depositional environments and the fluvial system of the Oneonta Formation in the study area. Multilateral and multistoried channel and bar deposits are enclosed by flood basin deposits. Megaripples, high- and low-stage linguoid bars, and upper flow regime flat bed formed in response to flashy discharge events and dominate the channel deposits. Overbank flood and crevasse processes resulted in alluvial flood basin development. Extensive vegetation was established on both subareally exposed high-stage linquoid bar tops during low-stages of flow and in the flood basin.


Levee
Low-stage Linguoid Bar
Splay
Flood Basin
High-stage Linguoid Bars
Megaripples
Splay
Flat Bed
Channel Deposits
Flood Basin Deposits
Previous Channel Deposits
10 m

izontally bedded fine-grained sandstone reflect higher topographic locations in the channel (equivalent to decreasing flow depth) and increasing flow velocities. A greater percentage of horizontal bedding and low-angle stratification than large-scale trough cross-strata suggests intense, short-duration, flashy flow rather than steady, longer-duration flow. Flashy-discharge flood events create laterally wedging out and interfingering relationships between the large accretionary units and planar cross-strata with the trough cross-strata (Fig. 18). This is common in the channel and bar lithofacies of the Oneonta Formation. The interbedding also indicates rapid rates of decreasing discharge (Jones, 1977). This cross-stratification is largely unmodified except for foreset erosion implying a stranding and exposure of the bar form.

Flashy discharge with high velocity flows is supported by paleocurrent data results. The Oneonta Formation exhibits unimodal, low variance patterns indicative of low sinuosity channels. Unidirectional flow with low dispersion is documented in many Recent braided deposits (Williams and Rust, 1969; Rust, 1972; Smith, 1972; Bluck, 1974).

Rapid discharge fluctuations can result in lateral migration of channels and bars across the alluvial plain. This lateral movement creates well-defined epsilon cross-stratification (Allen, 1963). Epsilon cross-stratification is often attributed to meandering channels which migrate freely across the alluvial plain. There is no reason why low sinuosity streams and bar forms within the channels could not generate this stratification (Collinson, 1978; Jackson, 1978). The presence of epsilon cross-strata in the channel and bar deposits of the Oneonta Formation would indicate both lateral accretion and deposition during a fluctuating hydraulic regime.

The sandstone to siltstone ratio calculated for the Oneonta Formation is 1:1. The amount of alluvial flood basin material present is thought to be due to avulsion of the fluvial system on the alluvial plain. Preservation of overbank deposits is controlled by the frequency of avulsion and subsidence rates (Collinson, 1978). If the rate of migration of avulsion is greater than subsidence, any alluvial flood basin deposits that exist will be obliterated. In the case of the Oneonta Formation, preservation of the alluvial flood basin deposits may be due to extreme avulsion, rapid susidence rates, or a combination of both processes. Avulsion, rather than lateral migration of the system, enhances the preservation of flood basin deposits and is thought to be the major operative process. The active channels and bars occupied a small percentage of the alluvial fan at a specific time allowing extensive flood basin deposits to accumulate on the remaining areas of the fan.

The nature of alluvial flood basin deposits implies periodic occurrence of channel breaching and overbank deposition. Overbank flooding and crevassing mechanisms were responsible for formation of the alluvial flood basin. Both processes have been documented to be operative in Recent, distal braided environments (Williams, 1971; Boothroyd and Ashley, 1975). The periodicity of channel breaching is indicated by the absence of long period calcrete horizon (stage 2 or older) development. This suggests that pedogenic formational conditions were stable for periods less than 10^3 years. Instability and inhibition of further calcrete development resulted from changes in the groundwater regime related to channel breaching as well as avulsion of the fluvial system.

The intensity of erosion and deposition may reflect the absence of extensive terrestrial vegetation in the more proximal interfluve source areas of the Oneonta Formation. Although vegetation colonized distal Devonian alluvial environments, floods originating upslope would produce sheet-like deposits of a braided nature (Schumm, 1968). This would also result in large amounts of fine-grained material being distally deposited (Rust, 1978). Extensive formation, with subsequent preservation, of the fine-grained flood basin lithofacies present in the Oneonta Formation may represent this style of alluviation.

Petrologic information suggests that there was little long-term reworking of detritus by the fluvial system. The compositional and textural immaturity, as well as high percentage of lithic fragments, implies minimal abrasion and transport. Rapid, intense erosion with little weathering has been proposed in the source and depositional sites of Acadian molasse deposits by Woodrow and others (1973).

SUMMARY

Detailed sedimentological analysis of the Upper Devonian Oneonta Formation resulted in identification of nine lithofacies. These lithofacies are interpreted as channel, bar, and alluvial flood basin deposits. Complex interfingering of channel and bar deposits with flood basin deposits; poorly-defined fining upward channel and bar sequences; interbedding of lower flow regime generated large-scale cross-strata with abundant upper flow regime horizontally bedded and very low-angle stratification; numerous minor erosional features; and sandstone grain size support a distal braided environment. Rapid discharge fluctuations of a flashy nature are suggested by the types, amounts, and lateral and vertical associations of stratification. The unidirectional paleoflow with low variance indicated by the Oneonta Formation data is common to many braided systems. The high amount of fine-grained flood basin material reflects a braided alluviation style with high preservation potential. Petrologic information indicates a collision orogen provenance consisting of a sedimentary, low-grade metamorphic, and very shallow seated plutonic terrain. The data imply that the Oneonta Formation was deposited by a braided fluvial system on a distal alluvial fan.

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TABLE 5

RESULTS OF MODAL POINT COUNTS OF SELECTED SANDSTONES OF THE ONEONTA FORMATION

SAMPLE NUMBER	1	2	3*	4*	5*	6	7	8	9*	10	11	12	13*	14*	15*	MEAN AND STANDARD DEVIATION
% FRAMEWORK AND CEMENT																
MONOCRYSTALLINE QUARTZ	19.9	13.5	13.0	12.5	13.6	11.1	13.5	14.9	14.7	12.4	14.0	16.0	9.9	10.9	13.4	14.0 ± 2.4
POLYCRYSTALLINE QUARTZ	17.5	15.7	19.1	23.5	23.1	20.5	23.8	22.5	28.0	18.9	23.3	20.0	21.4	28.0	23.0	21.1 ± 3.4
FELDSPAR	1.2	0.7	0.9	0.8	0.9	0.7	0.7	0.6	0.9	1.0	0.5	0.7	0.8	1.3	0.5	0.8 ± 0.2
LITHIC FRAGMENTS	48.8	56.9	53.0	56.8	55.2	58.4	56.9	52.7	43.6	59.1	50.6	49.7	58.8	50.6	56.2	54.0 ± 4.5
ACCESSORY MINERALS	8.3	11.5	12.6	5.7	6.3	8.7	5.1	9.1	12.8	8.1	4.5	7.3	9.1	8.4	5.5	8.0 ± 2.6
CEMENT	4.4	1.7	1.3	0.8	0.9	0.7	0.0	0.2	0.0	0.5	7.2	6.2	0.0	0.8	1.4	2.1 ± 2.3
% FRAMEWORK (QFL)																
QUARTZ	43	34	37	38	40	35	39	41	49	34	42	42	34	43	39	39 ± 4.2
FELDSPAR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.5	1 ± 0.1
LITHIC FRAGMENTS	56	65	62	61	59	64	60	58	50	65	57	57	65	56	60.5	60 ± 4.2
% TOTAL QUARTZ																
MONOCRYSTALLINE QUARTZ	53	46	41	35	37	35	36	40	34	39	38	44	32	28	37	40 ± 6.1
POLYCRYSTALLINE QUARTZ	47	54	59	65	63	65	64	6[illegible]	66	61	62	56	68	72	63	60 ± 6.1
% L_t																
1. Polycrystalline Mica	7.9	9.3	11.1	9.7	10.8	9.3	10.5	8.[illegible]	9.8	8.4	8.3	4.4	10.2	9.3	9.7	8.7 ± 1.6
2. Quartz Mica Tectonite	40.6	48.1	52.1	46.8	45.9	48.6	47.0	41.[illegible]	50.0	42.6	43.5	46.0	42.6	51.4	47.8	45.6 ± 3.6
3. Foliated Metaquartzite	5.0	2.3	0.9	1.6	2.7	2.8	3.2	2.[illegible]	3.9	3.5	3.0	5.3	3.7	3.7	3.5	3.3 ± 1.1
4. Argillite - Shale	24.8	22.5	15.4	20.2	21.6	21.5	19.7	23.8	18.6	23.2	23.9	23.9	22.2	18.7	20.4	22.1 ± 2.6
5. Aggregate Quartz	20.8	17.1	19.7	21.0	18.0	15.9	18.4	22.6	16.7	21.3	19.6	19.5	20.4	15.9	18.6	19.2 ± 2.0
6. Carbonate	0.0	0.8	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.9	0.9	0.0	0.3 ± 0.4
7. Indeterminate - Misc.	1.0	0.0	0.9	0.0	0.9	1.9	1.3	0.9	1.0	1.0	0.7	0.9	0.0	0.0	0.0	0.8 ± 0.6
% L_t - 7 (Indeterminate - Misc.)																
Qp (3 + 5)	26	19	21	23	21	19	22	26	21	25	23	25	24	20	22	23 ± 2.4
Ls (1 + 4 + 6)	33	33	27	31	33	31	31	33	29	32	33	29	33	29	30	31 ± 2.0
Lm (2)	41	48	53	47	46	50	48	42	50	43	44	46	43	51	48	46 ± 3.5
MEAN GRAIN SIZE	ms	fs	vfs	fs	vfs	fs	fs	ms	fs	ms	ms	ms	vfs	ms	fs	
SORTING	p	m	m	m	m	m	m	m	w	m	m	m	m	m	m	

* Based on 200 counts/section for total; 100 counts/section for lithic fragment % determinations.
Remaining samples based on 600 and 300 counts, respectively.

Grain size:
- vfs- very fine sandstone
- fs- fine sandstone
- ms- medium sandstone

Sorting:
- p- poorly sorted
- m- moderately sorted
- w- well sorted

FIGURE 7. MEASURED SECTIONS OF THE ONEONTA FORMATION. SECTIONS ARE SHOWN RESPECTIVE TO THEIR RELATIVE BASAL ELEVATIONS. ALL CONTACTS BETWEEN LITHOFACIES ARE SHARP UNLESS DENOTED AS GRADATIONAL. SITES CORRESPOND TO THOSE IN FIGURE 2.