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Sedimentological and plant taphonomic evaluation of the early Middle Devonian Trout Valley formation

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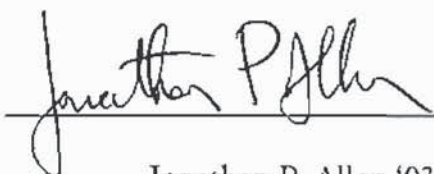
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A SEDIMENTOLOGICAL AND PLANT TAPHONOMIC EVALUATION OF THE
EARLY MIDDLE DEVONIAN TROUT VALLEY FORMATION

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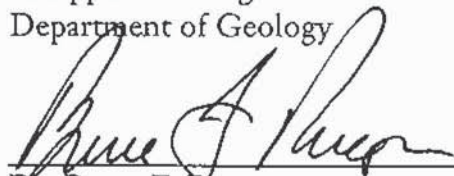


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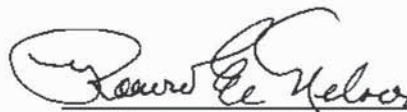
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A SEDIMENTOLOGICAL AND PLANT TAPHONOMIC EVALUATION OF THE
EARLY MIDDLE DEVONIAN TROUT VALLEY FORMATION

Jonathan P. Allen '03

A Thesis

Submitted to the Faculty of the Geology Department of
Colby College in Fulfillment of the Requirements for
Honors in Geology

Waterville, Maine

May 10, 2003

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A sedimentologic and plant taphonomic evaluation of the Early Middle Devonian Trout Valley Formation, Maine

Abstract

The Trout Valley Formation of Emsian-Eifelian age, outcropped in Baxter State Park, Maine, consists of fluvial and coastal deposits preserving early land plants. Massive, crudely bedded conglomerate represents deposits of proximal braided channels on an alluvial fan complex. Lithic sandstone bodies in channel-form geometries represent deposits of river channels draining the Acadian highlands whereas associated siltstones represent overbank deposits, intertidal flats, and tidal channels. Localized lenticular quartz arenites represent nearshore shelf bar deposits that were storm influenced. The majority of plant assemblages preserved mainly in siltstone lithologies are allochthonous and parautochthonous, with only one autochthonous assemblage identified in the sequence. Plant remains are found in both fluvial and estuarine environments with trimerophytes (*Psilophyton* and *Pertica quadrifaria*), rhyniophytes (*Taeniocrada*) and lycopods (*Drepanophycus* and *Kaulangiophyton*) as the most common plants in estuarine environments near tidal channels. However, they are found also in fluvial settings. The presence of tidal influence in deposits where parautochthonous and autochthonous assemblages are preserved suggests that these plants may have been tolerant of brackish conditions. However, the effects of this physical parameter on the growth and colonization of plants in the Middle Devonian is unknown.

Introduction

The Devonian marked a time of rapid early vascular land-plant diversification. The appearance of the first vascular land plant *Cooksonia* in the Late Silurian (Edwards, 1980) to the radiation of the trimerophytes, rhyniophytes, and zosterophyllophytes in the Devonian marked an important event in life history. According to Beerbower (1985) and DiMichele and Hook (1992), the increased root and rhizoid activity stabilized substrates and increased both physical and chemical weathering as well as nutrient availability. This activity has been proposed to account for the decreased atmospheric concentration of CO₂ at the end of the Paleozoic (Elick et al., 1998) and the initiation of Carboniferous glaciation. In addition, major anoxic events during the Middle to Late Devonian also have been considered to be, in part, the result of Devonian land-plant radiation (Algeo and Scheckler, 1998).

Despite the importance of early land plants, there have been few studies that detail their ecologic setting (e.g., Andrews et al., 1977; Gensel and Andrews, 1984; Edwards and Fanning, 1985). Presently, the environments and habitats in which these plants grew have been interpreted to range from coastal lowland marshes to terrestrial freshwater settings such as stream banks, exposed bar forms, and backwater swales (Edwards, 1980; Gensel and Andrews, 1984; Beerbower, 1985; DiMichele and Hook, 1992). Such studies, however, lack both a sedimentological framework and details concerning the plant taphonomic relationships in these sequences. Using these studies, Early Devonian land-plant communities have been interpreted as consisting of an array of vegetational patches, where each was dominated by a single taxon (DiMichele and Hook, 1992). The landscape is envisioned to have consisted of these low-diversity patches, where plants

developed a space-occupation pattern referred to as "turbing in," allowing them to control access to limited nutrients and water (DiMichele and Hook, 1992). This interpretation has been based largely on the Trout Valley Formation flora of Maine, a Middle Devonian series of rocks outcropped in Baxter State Park.

The Trout Valley Formation has been the focus of numerous paleobotanical studies since Dorf and Rankin (1962) first described its fossiliferous character and geologic setting. They described the sequence as a heterogeneous mix of light blue gray-to-black shale, siltstone, sandstone, and conglomerate, with sideritic sandstone and ironstone comprising a small portion of the section. Lithologic changes were noted to be abrupt, and occurred both vertically and laterally. Fossilized plant remains were reported as being fairly common in thin zones of limited lateral extent (Dorf and Rankin, 1962). Based on the lithologies, geologic setting, and the assemblage of fossil plants, along with the reported absence of marine invertebrates in the section, Dorf and Rankin (1962) interpreted the depositional environment as a shallow, brackish water setting on the slope of a volcanic island.

Previous studies focused on the morphology and anatomy of the fossil plants recovered from these rocks (Andrews et al., 1968; Gensel et al., 1969; Kasper and Andrews, 1972; Kasper et al., 1974; Andrews et al., 1977; Kasper and Forbes, 1979; and Kasper et al., 1988). Two new genera and six new species of early vascular and non-vascular land plants were identified. Locality data were given as collections along Trout Brook, in most instances, and the actual lithology in which the specimen was preserved was not identified. Hence, not only was the basic sedimentologic character of the assemblage not documented, but neither an integrated sedimentologic nor taphonomic

study of this flora had been conducted. All knowledge of the depositional context of the plant fossils was based upon the original interpretations by Dorf and Rankin (1962).

The fossils of the Trout Valley Formation have been used to reconstruct the stereotypical early Devonian plant community. Therefore, the details surrounding the plant fossils in depositional context must be understood. Without such an integrated sedimentologic and taphonomic analysis, such interpretations have very little data upon which the claims can be substantiated. Plant fossil assemblages may be preserved in both their growth position and habitat (autochthonous), in their growth environment but not *in situ* (paraautochthonous), or as transported material out of their growth environment (allochthonous). This information is pivotal in interpreting the paleocommunities in which these fossil plants lived. There is no indication, however, in the published literature whether a certain assemblage horizon represents an allochthonous accumulation of detritus that was transported or an autochthonous assemblage that was buried *in situ*. Plant taphonomic studies were not yet envisioned when the collections were made, and the foci of the studies published were biological, not geological. Only recently have such studies of pre-Carboniferous plant assemblages been conducted (e.g. Powell et al., 2000; Jarvis, 2000; Griffing et al., 2000; Hotton et al., 2001). Hence, the lack of detailed geological information on the Trout Valley Formation has led to the present study.

The project goal has been to conduct an integrated examination of the sedimentology, stratigraphy, and plant taphonomic character of the Trout Valley Formation to answer the question of whether these rocks can be used as a model for Early to Middle Devonian plant communities. Hence, this paper will address the previously proposed hypotheses that the depositional setting of the formation is a terrestrial brackish

marsh and that the fossil plant assemblages represent autochthonous assemblages (Andrews et al., 1977).

Regional Geologic Setting and Age

The strata of the Trout Valley Formation are part of a thick succession of clastic rocks deposited from early erosional stages in a foreland basin northwest of the Acadian orogen (Bradley et al., 2000). The paleolatitude for the southern tip of Laurussia, where these sediments were deposited, was approximately 20°-30° S in the Emsian (Scotese and McKerrow, 1990); hence, climate was presumably subtropical. The aerial distribution of the formation truncates major tectonic structures in the Traveler Rhyolite, and an unconformity between these units has been interpreted (Rankin, 1968). The Trout Valley Formation is of latest Emsian to earliest Eifelian age based on plant fossils (Kasper et al., 1988) and palynomorphs corresponding to the *douglastownese-eurypterota* spore assemblage zone (McGregor, 1992).

Study Area/Materials and Methods

The Trout Valley Formation is located in the northwest section of Baxter State Park in northern Maine located in T6 R9, T5 R9, and T5 R10 (Frost Pond and Wassataquoik, Maine, USGS 7.5' quadrangles). This study was conducted in agreement with park officials; any and all material collected from the Trout Valley Formation is the sole property of the Baxter State Park Authority. Unauthorized collecting in the park is strictly prohibited.

Sixteen outcrops are exposed presently along Trout Brook, South Branch Ponds Brook, and Dry Brook (Fig. 1). The outcrop localities of Dorf and Rankin (1962) and Andrews et al. (1977) were used in field reconnaissance, and several additional outcrops

not reported previously were found and described. Photo mosaics were taken of all exposed outcrops on which bounding surfaces were identified; these bounding surfaces were subsequently traced onto acetate overlays. These overlays were then used as an aid in the interpretation of bed geometries and depositional environments. Millimeter- to meter-scale descriptions of all outcrops were then coupled with photo mosaics for stratigraphic interpretation. Using the regional dip of 15° for the area (Bradley et al., 2000), true outcrop thickness was determined, missing sections extrapolated, and a stratigraphic model developed.

Hand samples of all sedimentological facies and all plant-bearing lithologies were collected for laboratory analysis. Sedimentologic analysis included lithologic identification and description of primary sedimentary structures, presence or absence of bioturbation, thin section analysis for grain size determination (transect method) and micro-stratigraphic analysis (fining/coarsening sequences, sedimentary structures, etc.), and mineralogic composition using x-ray diffraction analysis.

Fossil-bearing samples were split along bedding planes for taphonomic analyses. Characteristics used included the relationships between plant material and sediments, arrangement of axes in sediment (prostrate or erect, flat-lying or dispersed three-dimensionally), concentrated or dispersed assemblages, isomeric versus heteromeric part composition, examination of cross-cutting relationships, and sediment fining/coarsening sequences relative to plant axes (Krassilov, 1975). Thin section analysis also was used to evaluate the microstratigraphic relationships between organic materials and the sediments, using both petrographic and binocular stereo microscopes.

Paleocurrent analysis was done using the software program Oriana (version 1.06).

Sedimentology

Overview

The Trout Valley Formation consists of a minimum 550 m-thick section along Trout Brook and South Branch Ponds outcropping over an area of approximately 15 km². Outcrops are restricted laterally, with the longest exposure no more than 100 m in length. The vertical extent of any particular outcrop is 7.1 m in height with an overall dip to the northwest of 15°. At least three normal faults have been observed along Trout Brook, with a maximum displacement of 1.3 m. A drag fold is present at one locality; however, although the same facies occurs both above and below the fold, the offset is not known.

Four facies (Table 1) are described as genetic units assembled using sedimentology as well as macro- and microscopic features including large-scale bedforms. The sedimentary sequence is exposed above the basal contact with the Traveler Mountain Rhyolite in the southeast and continues upsection to the west and northeast (Fig. 1). The basal-most facies consists of conglomeratic lithics that are overlain by a coarse lithic sandstone facies organized within channel-form geometries and tabular units. A quartz sandstone facies, consisting of lenticular bodies, overlies the coarse lithic sandstone facies and is, in turn, overlain by a siltstone facies of various physical properties (Fig. 2).

Conglomerate Facies

Directly overlying the Traveler Rhyolite is an extraformational conglomerate of undetermined thickness (Fig. 2). The contact between the Traveler Rhyolite and the conglomerate is abrupt, which Rankin and Hon (1987) interpret as an unconformity. Clasts are poorly sorted, range in size from 3-15 cm, are subrounded to rounded, and

ovate to platy in shape. Overall, this facies fines upwards from cobble-sized to pebble-sized clasts at the contact with the overlying coarse sandstone facies. The conglomerate is predominantly clast supported within a coarse sandstone matrix. The facies appears massive; however, crude bedding is observed in the upper portion of the conglomerate near the contact with the lithic sandstone facies (Fig. 3A). Clast imbrication also is observed with the best development occurring in the upper portion of the facies (Fig. 3B). Clast composition is entirely rhyolite.

Interbedded lenticular, dark gray sandy siltstone occurs in the upper parts of the conglomerate section. These are restricted laterally and are in sharp erosional contact with successive overlying conglomerate beds. Siltstone lenses are 15-80 cm thick with cm-scale undulose bedding in which plant fossils assigned to *Taeniocrada* sp. are preserved. The contact between the conglomerate facies and the overlying lithic sandstone facies is an abrupt erosional contact (Fig. 4).

Lithic Sandstone Facies

Medium gray to dark gray (N5-N3) lithic sandstone overlies the conglomerate facies with grain size commonly fining upwards from an extraformational granule conglomerate to medium- and fine-grained sandstone. The conglomerate, restricted to the basal parts of units that exhibit channel-form geometries, is clast-supported, with framework clasts composed of rhyolite, quartz, and other lithics in a coarse sandstone matrix. Granule clasts are poorly sorted and sub-angular to sub-rounded in shape. Sandstones overlie the granule conglomerates and comprise the largest proportion of this facies. Clast size ranges from very coarse to very fine sand, but medium- to fine-grained clasts account for the dominant grain size. Sand clasts are poorly to moderately sorted

with sub-angular to sub-rounded shaped grains. Petrographic analysis shows clasts are composed predominantly of rhyolite and quartz, but other lithics are present with minor mud component. Hence, the sandstones are lithic arenites or wackes depending on the locality.

One genetic unit (Fig. 5) consists of granule conglomerate fining upsection into medium- to fine-grained sandstone that may be overlain by a dark gray massive, heavily bioturbated, very coarse siltstone, the thickness of which varies from 0.8-2.5 m.

Although this siltstone may be several meters in thickness, often it is missing because of erosion by an overlying sandstone body. In many cases, the fine-grained sandstone is not present because of erosional truncation by overlying sequences. The contact between the conglomerate and sandstone commonly is gradational; however, abrupt erosional contacts have been observed that may be accompanied by deformational loading structures, including flame structures.

The lithic sandstones display channel-form geometries within which are lateral accretionary beds on the order of 0.5-1.5 m in thickness. Medium-scale trough cross-stratification, on the order of 0.1-0.3 m, and lenticular bedding are common at the bases of each genetic unit, with fossiliferous coarse siltstone lenses, similar to those found in the conglomerate facies, often in the troughs. Lenticular beds range in thickness from 0.2-1.0 m with offset crests that are 1.5 m apart. Planar sandstones in the finer-grained units are of 8-10 cm in thickness, and fine into trough cross-stratified beds. All cross-beds have a concave lower contact with lenticular geometries and are variable in orientation. Imbricated ripples also occur in the finest-grained intervals. Reactivation

surfaces at the upper contact are observed locally. Paleocurrents measured on crossbeds (N=15) are to the northwest.

Quartz-rich Sandstone Facies

Massive lenticular sandstone bodies occur in at least two areas (localities 11, 12; Fig. 2). Petrographic analysis indicates the sandstones are medium- to fine-grained quartz arenites (locality 12) and wackes (locality 11) that weather to a pale brown (5YR 5/2), which is darker in color than the coarse sandstone facies. Sand clasts are rounded and subrounded-to-rounded in shape and well sorted.

The sandstones occur as large waveforms that are en echelon stacked (Fig. 6), with wavelengths of approximately 16 m. Lenticular bodies range in thickness from 0.8 to 2.5 m at the crests, pinching out laterally. Bed tops are ripple laminated with modified and smoothed ripple crests. Hummocky cross-stratification on the scale of 10 cm between crests also is present on the upper portion of the beds (Fig. 7). Paleocurrents (N=20) based on measurements taken from current ripples are to the north, but vary from the northwest to northeast. Several troughs are filled with a dark gray siltstone preserving plant fossils of *Psilophyton*. Vertical and lateral relationships between this and other facies are not clear because of its isolated outcrop exposure. Heavily bioturbated siltstone has been observed to overlie this facies, but the contacts between these two units are not exposed normally.

Siltstone Facies

The most common facies is comprised of siltstone, although this varies in its physical features within the stratigraphic section. Three subfacies have been identified based on differences in overall geometry, primary sedimentary structures, fossil content,

and relationship with adjacent facies. Siltstones are light to dark gray (N7-N3), quartz-rich, siliceous, and generally carbonaceous.

Subfacies 1 The predominant subfacies, comprising approximately 70% of the siltstone facies, overlies the lithic sandstone in sharp erosional contact and occurs as laterally continuous beds. It is a medium gray to dark gray (N5-N3), very coarse siltstone with an admixture of very fine sandstone. The siltstone is massive near the contact with the underlying lithic sandstone facies and in thin section can be seen to be heavily bioturbated with fecal pellet aggregates. At some localities, however, thin section analysis shows micro-fining upward sequences on the order of <1 cm. This siltstone coarsens upwards into a planar bedded (3-5 mm beds), very coarse siltstone or very fine sandstone which, in turn, is overlain by larger tabular cross-stratified beds. These tabular beds display climbing ripple stratification, starved ripples, and micro cross-stratification as observed in thin section (Fig. 8). Bed sets range in thickness from 1-6 cm. Symmetrical ladder ripples, with crests 3-5 cm apart, are well developed at the tops of these beds, and mark bed boundaries. Paleocurrents (N=23) obtained from crossbeds are to the northwest and the northeast. In addition to modified ripple structures, trace fossils are common including vertically compressed burrows approximately 5 mm in diameter (? *Skolithos*). Burrow densities are 120 burrows per 10 cm² (Fig. 9). Horizontal traces, approximately 2 mm in diameter, (? *Helminthopsis*) are less common in mud drapes. Mud cracks also have been observed at one locality. Pedogenic features at locality 10 include slickensides, and petrographic analysis shows the presence of geopetally oriented roots and sideritic glaebules ranging from 0.5-1.5 mm in diameter (Fig. 10).

Subfacies 2 The second siltstone subfacies occurs in channel-form geometries. Sequences of light gray (N7) to dark gray (N3), parallel-bedded (1-2 cm beds) siltstones grade upsection into couplets of alternating thick cross-stratified siltstone (18-30 cm thickness) that fine into rippled siltstone, 1-6 cm thick (Localities 1, 2, 4). Low-angle cross-stratification ($\sim 10^\circ$) is common with cross-bed sets of 2-4 cm in thickness. Individual cross-beds approximately 5 mm in thickness are preserved at the upper bounding surface of these couplets. Herringbone cross-stratification is present at one locality (Fig. 11), but overall paleocurrent directions obtained from crossbed measurements (N=21) vary from the northwest to northeast. The couplets are overlain by fossiliferous rippled siltstone of variable thickness (Fig. 12). Fossils within the rippled siltstone and include *Taeniocrada* sp., *Psilophyton forbesii*, *P. princeps*, *P. sp.*, and *Kaulangiophyton akantha*.

Subfacies 3 The third subfacies occurs in one isolated locality exposed only at low water. This is a dark gray (N3), heavily bioturbated coarse siltstone that occurs as large mega-ripple bedforms. Ripples are 17 cm in thickness at the crests and thin to approximately 3 cm over a 6 m wavelength. Paleocurrents (N=12) are to the south. Preserved in bedform crests are numerous dispersed macroinvertebrates including bivalves, gastropods, ostracods, and an eurypterid (Selover et al., 2002). Overlying this unit is a light gray, thinly bedded, bioturbated siltstone.

Plant Taphonomy

Overview

Twelve plant-megafossil taxa have been reported from the Trout Valley Formation (Table 2), with *Psilophyton* and *Pertica* dominating assemblages. Plants are

preserved in all facies; however, concentrated assemblages occur in both the lithic sandstone and siltstone facies.

Conglomerate Facies

Plant-bearing intervals occur in the upper most part of the section where fine grained deposits are found near the contact with the lithic sandstone facies. Plant remains occur in lenses of dark gray, coarse siltstone that pinch out laterally over a distance of a few meters (Fig. 13A). Compressions of *Taeniocrada* sp. comprise the majority of monotypic assemblages (Fig. 13B). However, remains of *Psilophyton* sp. also occur on some bedding planes along with *Taeniocrada*. Hence, both homogenous and heterogeneous assemblages are present in these channel fills. Plants are found as moderately well-preserved fragments, ranging in size from 5-20 mm on the surface of bedding planes. Remains are concentrated at the base of siltstone lenses (approximately 15 cm in larger lenses) and become increasingly sparse upsection. Plant axes are disordered and occur in random orientations. Typically, a non-fossiliferous interval overlies the concentrated debris before the siltstone is truncated erosionally by overlying pebble conglomerate.

Lithic Sandstone Facies

Plant remains generally occur within channel-form geometries of the lithic sandstone facies. Plant assemblages are preserved in coarse sandstone that fines into siltstone and can be traced laterally for several meters across an outcrop. Different plant taxa are preserved at different stratigraphic horizons depending on the locality. *Pertica quadrifaria* commonly occurs at the base of these plant-bearing intervals. Recoverable fragments average 13 cm in length; however, axes up to 50 cm in length have been

collected (Fig. 14A) and consist of both main and lateral axes that occur parallel to bedding. Primary axes of *Pertica* from a single locality are preserved in random orientations (Fig. 14B). Some specimens display second order dichotomizing branching. The concentration of axes increases upsection as the sediment fines to a medium-fine sandstone. *Psilophyton* sp., *P. princeps*, and to a lesser degree *P. forbesii* are typical in this facies (*Drepanophycus* sp. at locality 5) and are best preserved in the medium-fine sandstone intervals. Axial fragments, 1-13 cm long, occur as disordered assemblages and are restricted to bedding planes (Fig. 14C). Axes have not been found cross-cutting bedding where *Psilophyton* is the dominant taxon. Sandstones fine upsection into siltstones where the number of *P. quadrifaria* and *Psilophyton* sp. axial remains decreases; overlying siltstone is nonfossiliferous.

Dense, mat-like intervals of *Pertica* and *Psilophyton* axes occur in coarse siltstone intercalated with medium-fine sandstone approximately 40 cm above the non-plant-bearing siltstone interval along South Branch Ponds Brook. Hence, axes are concentrated, disordered, heteromeric, and typically flat-lying. However, some axes are preserved in cross-cutting relationships with the bedding at angles to bedding varying from 10°-35°. This interval is then truncated by coarse sandstone in an overlying channel-form. Small, coarse-medium siltstone lenses occur in some areas just above the coarse siltstone with concentrated plant material that cross-cuts bedding (Fig. 14D). These lenses are overlain by a coarser siltstone in which *Pertica quadrifaria* is preserved parallel to bedding, similar in character to previously described assemblages.

Microstratigraphic analysis shows no identifiable relationships between plant material and the coarse sediments. Millimeter-scale plant fragments are dispersed

throughout the matrix in various directions, with orientations ranging from horizontal to vertical in thin section. In the coarse-to-fine siltstone, plants are oriented both horizontally and vertically. The degree of plant material concentration is dependent on locality. Plant material is typically concentrated in the coarser siltstone; however, plant material is concentrated in both the coarse and fine silt fraction of a micro-fining upward sequence in some localities and, at times, overlies the contact between coarse and fine sediments (Fig. 15A-B). In several sites, coarse silt is observed to have migrated over flat lying plant material, creating a scour surface on the down current side of the detritus that was filled subsequently with finer sediment (Fig. 15C). Plant material also is observed as casts, with axes infilled with fine mud and silt (Fig. 15D). These axes occasionally are contorted and overlie primary structures including ripples (Fig. 15E).

Siltstone Facies

Subfacies 1 In the dominant siltstone subfacies, plant remains occur in coarse siltstone that underlies planar-bedded, very coarse siltstone or very fine sandstone. Plant intervals vary in thickness, ranging from 10–40 cm. *Psilophyton forbesii* and *Taeniocrada* (cf. *T. dubia*) axes are preserved at the base of these beds and are more dispersed within the matrix. Plant axes are primarily in random orientations, and several axes of *Taeniocrada* restricted to the basal intervals of the siltstone show three-dimensional curvature. In association with *Taeniocrada*, *Psilophyton microspinosum*, although not abundant, is preserved in the coarse siltstone. Axes are sparse at the base of the beds and become more concentrated upsection. Fragments are parallel aligned and are restricted to bedding planes. The angles between the main axis and the laterals are very small, generally less than 10°. *Psilophyton forbesii* increases in concentration

through the fossiliferous siltstone interval and ultimately is well preserved in monotypic, isomeric assemblages with axes disposed in subparallel-to-parallel orientations. Axial fragments are 3-15 mm in width, at least 30 cm in length, and display second- and third-order branching. Several axes are preserved in a three-dimensional arrangement with axes inclined upwards. Approximately 10 cm above the base of the assemblages is a decrease in concentration of *Psilophyton* wherein the axes are increasingly disordered.

Plant axes occur in planar siltstone below tabular cross-stratified beds at locality 2. At the base of the unit in an interval approximately 14 cm in thickness, *Psilophyton* sp. occur as relatively sparse, flat-lying axes. Overlying this are up to four dense mat-like intervals consisting of very concentrated axial assemblages of *P. forbesii*, *P. dapsile*, *P. princeps*, and *Pertica quadrifaria*. Each interval varies from 1.5-3 cm in thickness and preserves a disordered plant assemblage. However, each layer is separated from the next by a non-fossiliferous interval. Inclined axes (10° - 45°) originate from flat-lying axes and can be traced across bedding for several centimeters (Fig. 16A). Axes also vertically cross-cut bedding, and in some instances, small axes (0.2-1.5 mm in width) cross-cut bedding in a sigmoidal orientation (Fig. 16B-C). *Pertica quadrifaria* is concentrated at the base of the mat-like accumulations showing no preferential orientation; this taxon becomes sparse in stratigraphically higher beds. Orientations of *P. forbesii* and *P. dapsile* become more ordered in the upper most mat-like accumulations. Axial orientations (N=36) range from 50° - 266° , with predominant north and northwest directions. These are similar to paleocurrent measurements taken within this facies that are oriented to the northwest and northeast (Fig. 1).

In thin section, plant material is scattered within the coarser silt with up to several millimeters of matrix separating stratigraphically successive axes, and relatively concentrated in the fine silts where less than 15 mm of sediment is found between overlying axes. Plant material is parallel to bedding, and generally parallels the bedding contact between the coarse and fine silts in millimeter-scale fining upward sequences (Fig. 17A). Several axes appear to be sub-horizontal relative to bedding, although they overlie small-scale, poorly defined cross-stratification (Fig. 17B). Contorted axes occur in both coarse and fine intervals. Rooting structures are observed vertically cross-cutting bedding, and organically stained rooting structures disrupt bedding (Fig. 17C). Three different horizons of rooting structures are observed in a series of fining upward sequences with each originating from the top of the sequence (Fig. 17D).

Plant-bearing horizons, similar to locality 2, occur at locality 11 (Fig. 1). Plant remains in a 25 cm interval are very concentrated, disordered, and isomeric. This plant assemblage is dominated by *Psilophyton* sp. (? *P. princeps*), with minor contribution from *P. forbesii*. Axes are inclined upward, cross-cutting bedding. Plant remains are associated with sideritic glauconites in the upper portion of this plant-bearing interval. Several geopetal structures are preserved in thin-section that cross-cut bedding into the subjacent coarser sediment (Fig. 18).

Subfacies 2 This subfacies contains *Psilophyton forbesii* in concentrated, well-preserved, monotypic, isomeric assemblages. Observations have been limited to bedding surface exposures on 0.5 m² float blocks. Float was excavated bedding plane by bedding plane to evaluate plant and sediment interactions. Axes are very concentrated throughout the rippled siltstone intervals of channel fills and occur parallel to each other on every

bedding surface (Fig. 19), although successive bedding surfaces display different axial orientations. Plant-bearing intervals generally are no more than 2-3 cm in thickness; each is overlain by barren siltstone intervals that are 3-5 cm in thickness and are defined by ripple structures with wavelengths of 2-2.5 cm. Primary structures in these barren intervals include bi-directional, ladder, and current modified ripples. Overlying plant-bearing beds are restricted to the troughs of meso-scale bedforms on the order of 30 cm in wavelength with no indication that plants extend into waveform crests. While *P. forbesii* is the dominant and, at times, the only taxon present, *Psilophyton* sp., *P. princeps*, *Taeniocrada* sp., and *Kaulangiphyton akantha* also have been observed within this facies (Table 2).

Thin section analysis shows plant axes in various orientations. Plant material may be distorted and recurved, and soft-sediment deformation indicating overturing of beds is found in association with plant parts. Plants typically occur at the top of a fining upwards sequence. Coarse silt appears to have migrated over several plant axes (? lateral axes), creating a scour surface on the down current side of the organic remains. This is similar to the processes occurring in the fine sediment plant-bearing intervals of the lithic sandstone facies. Rooting structures also are observed in a geopetal orientation disrupting bedding, originating from flat-lying aerial axes.

Subfacies 3 Plants remains in this third subfacies are small, <1 cm in greatest dimension, and occur only as isolated fragments. Due to their fragmentary nature and poor preservation, no systematic identifications have been possible. Axes observed showed no preferential orientation, were parallel to bedding, and found only in the bedform crests of the waveforms that constitute the major geometry of this unit.

Discussion

Overview

Dorf and Rankin (1962) interpreted the depositional environment of the Trout Valley Formation as a shallow, brackish water setting on the slope of a volcanic island. Subsequently, all plant remains described from the sequence also were attributed to this setting. Andrews et al. (1977) later re-evaluated the depositional environment, based on geology of the formation by Dorf and Rankin (1962) as well as an extensive investigation of the morphology and anatomy of the fossil plants over a series of papers (Andrews et al., 1968; Gensel et al., 1969; Kasper and Andrews, 1972; Kasper et al., 1974; Andrews et al., 1977; Kasper and Forbes, 1979; and Kasper et al., 1988). They interpreted a terrestrial brackish or fresh-water marsh setting surrounded by modest elevations for the assemblages. Using the dense, parallel-aligned assemblages of *Psilophyton*, the dominance of a single taxon in many localities with relatively minor additional species, isolated pockets of single taxa, the high preservational quality of plant remains, and modern marsh analogues, Andrews et al. (1977) concluded that these Early Middle Devonian assemblages represented monotypic, low-diversity communities. The presence of parallel-aligned axes was interpreted to represent dense stands of plants periodically flattened and preserved *in situ* by floods (Andrews et al., 1977). This interpretation has been propagated as an archetypical model for plant burial in the Devonian, and has been cited by various authors when interpreting the paleoecological significance of early land plants (Edwards, 1980; Gensel, 1982; Gensel and Andrews, 1984; Edwards and Fanning, 1985; Gensel and Andrews, 1987; Kasper et al., 1988; DiMichele and Hook, 1992; Hotton et al., 2001).

Sedimentologic and taphonomic evidence has been shown to be pivotal in making paleoecological interpretations, and both are needed to reconstruct the original relationships among fossilized organisms (Wing et al., 1992; Behrensmeyer and Hook, 1992; Gastaldo et al., 1995). Data from the present study require that modifications be made to the interpreted environments in which plant assemblages are preserved in the Trout Valley Formation. This study has identified a range of terrestrial to nearshore marine environments wherein well-preserved plant debris is restricted primarily to two environments: fluvial and estuarine/tidal settings. Within these settings, only one unequivocal autochthonous plant assemblage has been identified.

Environments of Deposition

Conglomerate Facies The conglomerate facies was deposited within channels and superimposed migrating longitudinal bars along an alluvial fan perimeter with the influence of proximal braided channel systems entrenched in a large alluvial fan complex. This environment is associated with steep gradients and high stream velocities (Rust 1972, 1978; Boothroyd and Nummedal, 1978), and is characterized by thick deposits in which imbricated clasts define crude bedding (Steel and Thompson, 1983; Nemec and Steel, 1984). Vos and Tankard (1980), López-Gómez and Arche (1997), and Yagishita (1997) have described similar conglomerates as proximal fan deposits. The poor sorting and well-rounded, oblate to prolate shape of the clasts are features of shallow, gravel braided channels (Pettijohn et al., 1987; Miall, 1996), which is indicative of a braided fluvial influence.

It may be argued that this facies represents mass flow deposits, because conglomerates with massive or crudely horizontal bedding have been interpreted as mass

flow deposits by Miall (1978), Middleton and Trujillo (1984), and Todd (1989). However, the presence of siltstones is evidence for deposition within channels and longitudinal bars. The interbedded fossiliferous siltstones, due to their lenticular geometries that are pinched out by conglomerate and erosionally truncated, are interpreted as overbank flow deposits, which are not features associated with mass flow deposits. The upper most of the conglomerates mark the transition from alluvial fan channels into a fluvial braided channel system.

Lithic Sandstone Facies The lithic sandstone facies represents migrating fluvial channels across an alluvial and/or coastal plain setting. The dominance of granule conglomerates within channel-form geometries indicates a high proportion of channel-lag and bar deposits similar to those described in time-equivalent settings from Schoharie Valley, New York (Bridge and Jarvis, 1998), the Battery Point Formation, Quebec (Griffing et al., 2000), and from other deposits (Miall, 1977, 1996). Lateral accretionary beds up to 1.5 m in thickness indicate channels were at least 1.8 m deep, and because there is no evidence that the tip of these bars are rooted, which implies they were submerged, channels were undoubtedly deeper. Fining upward sequences that consist of granule conglomerate overlain by medium- to fine-grained sandstone display both vertical and lateral variation, as well as primary structures such as large scale cross-beds, trough cross-stratification, and planar bedding. These features are indicative of bar forms and channel fills (Reineck and Singh, 1980; Cant, 1982; Miall, 1996; Chakraborty, 1999). Siltstone lenses in which plant fragments are preserved may represent either overbank deposits along the margin of the channel or abandoned channel-fill sequences.

The coarse-grained nature and paleocurrent variance indicate that these sandstones were deposited in a relatively shallow braided channel system (Nyambe, 1999). According to Rust (1978), the dominance of framework-supported grains is a key diagnostic feature to distinguish braided from meandering systems. In addition, the lithic components of this facies are of the same mineralogy as the clasts of the conglomerate facies, which suggest continued mechanical weathering and accumulation within a more mature braided environment. Nyambe (1999) reported a similar association in which the dominant clasts within a coarse sandstone facies were derived from a micro-conglomerate, indicative of a braided fluvial influence.

The relatively low variance in paleocurrent direction is also more indicative of a braidplain channel as opposed to a meandering system (Miall, 1978). This is because channel migration in the latter results in highly variable paleocurrent orientations reflecting the degree of channel sinuosity. Paleocurrent direction has been inferred to reflect mean channel direction (Rust, 1972; Chakraborty, 1999) and, as such, mean channel direction in the Trout Brook Formation was to the northwest. This orientation is toward the inferred paleoshoreline (Bradley et al., 2000). Imbricated ripples directed to the northwest also support this interpretation.

Reactivation surfaces have been found in the upper part of this facies and may represent evidence for change in direction of discharge or environments influenced by other processes (McCabe and Jones, 1977; Weimer et al., 1982). In addition, fine-grained sand ripples, similar to those found in estuarine deposits (see below), fine upwards into bioturbated siltstone. Their presence may indicate tidal influence within the

upper part of the facies. Hence, this part of the interval may have been deposited at the transition between fluvial and tidal environments.

Quartz-rich Sandstone Facies The stratigraphically restricted quartz-rich sandstone facies conforms with features characteristic of nearshore shelf sand bars that have been influenced by storm-generated processes. Their thin lenticular nature, lithologic composition, minimal amount of terrestrial detritus, and en echelon arrangement are consistent with reported nearshore deposits (Reineck and Singh, 1980; McCubbin, 1982; and others). Measured paleocurrents toward the north and northeast differ from the underlying lithic sandstone facies and indicate sediment transport was parallel to inferred shoreline (Bradley et al., 2000). The variance in paleocurrents suggest that these sand bars migrated laterally across the shelf and possibly shoreward. However, the absence of shoreface deposits precludes an interpretation of onshore sand-wave migration.

These rocks are compositionally more mature than other sandstones in the formation, and this feature is attributed to the constant reworking in a fully marine environment. However, the composition and physical features indicate that they were not deposited as beach sands (Davis, 1985; Pettijohn et. al, 1987). Rather, the absence of internal bedding structures, the presence of modified and smoothed ripples at bed contacts, and hummocky cross-stratification at the upper bed contacts indicate that these deposits were above wave-base and influenced by storms (Dott and Bourgeois, 1982; Aigner, 1985; Nottvedt and Kreisa, 1987; Collinson and Thompson, 1989; Duke et al., 1990). The absence of marine fossils and biogenic structures also is indicative of deposition under storm-generated processes (Duke and Prave, 1991). The presence of

thin siltstone intercalated between bedforms in which plant fragments are preserved indicates that detritus was transported to these bars from a terrestrial source. The small size of the plant fragments (1-3 mm) suggests that the material settled out during quiescent periods following deposition and reworking of sand waves, indicating that, at times, the area was unaffected by wave activity. Although tidal or estuarine channel deposits occur in other parts of the section, the presence of storm-generated structures and the absence of tidal structures suggests a nearshore regime for these units (Cotter and Driese, 1998).

Siltstone Facies Subfacies 1 This siltstone subfacies was deposited in a coastal setting probably within an estuarine intertidal flat regime. The sediments are fine-grained, including very fine sand and coarse silt. Primary and biogenic structures and the lateral extent of beds are similar to deposits from the North Sea (Weimer et al., 1982) and others (van Straaten, 1954; Baldwin and Johnson, 1977; Reineck and Singh, 1980; Clifton, 1982; Terwindt, 1988). The presence of unidirectional and wave currents, abundance of vertically compressed trace fossils cf. *Skolithos* and horizontal traces (?*Helminthopsis*), and broad shallow channels indicate a coastal setting.

The near absence of macrofauna, the low degree of bioturbation, and dominance of *Skolithos*-type ichnofacies in the coarse siltstones/fine sandstones are typical of deposits in coastal areas such as tidal flats (Miller 1984; Miller and Woodrow, 1991; Bridge and Jarvis, 1998; Griffing et al., 2000).

Parallel and tabular cross-stratified beds laterally adjacent to siltstone subfacies 2 (see below) are interpreted as channel bank deposits associated with shallow migrating tidal channels fining into intertidal runoff channel deposits. These are overlain, in turn,

by tidal flat deposits. Both of these accumulations are deposited during either flood or ebb tidal processes. In addition, the presence of starved ripples also is indicative of tidal flat deposits where there is a mix of sand and mud (Singh and Singh, 1995).

Sedimentation on tidal flats during tidal slack water is characterized by ladder ripples and wave-modified ripples. The suppressed undulatory nature of these ripple structures in Trout Brook indicates relatively low flow strength (Boothroyd, 1985), which is associated with slack water periods.

One paleosol has been identified in the siltstone facies, and is characterized by slickensides and sideritic glaebules. These features combined with the amount of plant material present, which includes vertically orientated roots penetrated down into the siltstone from thin carbonaceous horizons and root traces, is indicative of an ancient soil (Retallack, 1986, 2001). Sideritic nodules are characteristic of permanently waterlogged soils (Altschuler et al., 1983; Moore et al., 1992), due to the nature of the stagnant groundwater allowing the chemical reduction of such minerals and of intermediate redox states (Retallack, 2001). The presence of iron carbonates is a potential product of original soil formation (Ludvigsen et al., 1998). This paleosol is best described as an inceptisol based on these aforementioned features.

Subfacies 2 The second subfacies represents tidal channel deposits. Channel-form geometries characterized as broad (up to 6 m) and shallow (0.5 m) and en eschelon stacked, as well as herringbone cross-stratification indicating bi-directional flow, are evidence for this type of setting (Boothroyd, 1985; Singh and Singh, 1995). The alternating nature of the sequences of parallel-bedded siltstone, grading into couplets of cross-stratified and rippled siltstone from channel to channel, represent the changes in

hydrodynamic conditions from higher flow velocities and open channels to lower flow velocities following channel filling. The presence of well preserved plant axes, ranging from small (1-2 mm) fragments to large (19 cm) entire plants, suggests detritus originated via erosion of the tidal channel margin during high-velocity conditions.

Subfacies 3 The third siltstone subfacies records the migration of megaripples within a transitional channel. Megaripples are very common in tidal flat channels deposits (Boersma et al., 1968; Reineck and Singh, 1980; Terwindt, 1981) and represent deposition during high-energy events within tidal or tidally influenced channels. The presence of marine and brackish macroinvertebrates including *Phthonia sectifrons* and an eurypterid cf. *Erieopterus sp.* in the crests of ripples (Selover et al., 2002), indicate that these animals were transported into these channels and concentrated at megaripple crests. Their concentration at the crests, rather than in the megaripple troughs, supports an interpretation of a high energy-event emplacement. Measured paleocurrents are to the south, which are opposite those measured in the underlying facies, and suggest flood-dominated or possibly a storm influenced event(s). The transition from this fossiliferous, mega-rippled siltstone into overlying bioturbated siltstone records the transition from high to relatively low-energy deposits (Miller and Woodrow, 1991). The bioturbated siltstone most likely was reworked at the margins of these channels.

Plant Taphonomy

Fluvial Assemblages

The plant taphonomic data indicate that all plant assemblages within fluvial environments are allochthonous. The quality of preservation, degree of fragmentation,

and arrangement of axes are all characteristic of transported plant assemblages (Bateman, 1991; Berensmeyer and Hook, 1992; Gastaldo et al., 1995).

Lithic Sandstone Facies The plant-bearing intervals are thin (a few centimeters in thickness), laterally extensive over several meters, and are stratified with respect to plant size. Larger plant fragments occur at the bottom of the assemblages and decrease in size up through the plant-bearing interval. Plants are found primarily flat-lying, with few axes oriented at some angle to bedding. This stratification is a reflection of settling of the various sized plant detritus from suspension during waning flood stages. As overbank velocity decreases, the larger and denser detritus, such as *Pertica quadrifaria* axes, will settle first followed by the smaller *P. quadrifaria* and *Psilophyton* sp. axial fragments. Plant parts will be parallel to bedding unless the axes retained their structural fidelity and three dimensional architecture. In this latter case, axes may be oriented subhorizontal to bedding. The presence of interbedded medium sandstone throughout these plant intervals, occurring both with large and small axes, indicates flood-stage velocities fluctuated. Plant assemblages are dominated by axial components deposited within both channels and overbank settings during high velocities, because of high sedimentation rates and large volumes of plant material (Alexander et al., 1999).

The orientation of plant material cross-cutting bedding is not believed to be a response to burial of autochthonous communities. No evidence has been observed within the rocks for subjacent rooting structures or pedogenic processes. The plants that cross-cut bedding are generally fragments, approximately 5-6 cm in length, originate from flat-lying axial fragments, and cross-cut bedding at low angles. Hence, based on their relationship with the sediments, these assemblages are interpreted as transported, having

maintained their structural integrity rather than a phototropic biological response to burial.

An interpretation of allochthony also is supported by the microstratigraphic relationships between plant material and their entombing sediments. Plant fragments are scattered in random orientations within the matrix suggesting these organisms were disrupted before deposition. If plants were buried in place, plant material would be expected to be concentrated at the contacts of a rich organic horizon and coarser sediments, with downward projecting roots anchoring them in place. Additionally, axes underwent decay and hollowing, and subsequently were infilled with coarse silt and mud. The fact that these plants were decayed may indicate deposition in channels and reworking into overbank deposits (Kosters, 1989; Alexander et al., 1999). Plant debris introduced from the floodplain would be entrained directly into the floodwaters and incorporated into the suspended load of the channel. When they settled to the bedload following saturation and decayed, the hollow void was infilled by migrating bedload sediment (Degges and Gastaldo, 1989). Under high discharge, these could be re-entrained and transported into overbank settings. These infilled axes, as well as other flat-lying detritus, are contorted and overlie primary ripple structures indicating settling from suspension load transport. The site of transport was also in flux. Scouring on one side of plant material has been observed implying a baffling effect that deflected sediments over the top of the plant fragment. Scouring on the down-flow side resulted in subsequent infill by finer grain-sized sediment and burial. All of this evidence points towards allochthonous accumulations in this setting.

Estuarine/Tidal Assemblages

Estuarine environments may be affected by fluvial and marine processes, and plant assemblages preserved in the Trout Valley Formation span the spectrum of possible preservational modes. The majority of assemblages are interpreted as parautochthonous with only one allochthonous assemblage identified in the third siltstone subfacies, and only one autochthonous assemblage encountered in the entire formation.

Siltstone Facies Subfacies 1 Plant assemblages in this siltstone subfacies are characterized by concentrated, well-preserved axial fragments, in both random and preferred orientations, that may be flat-lying, inclined, or vertically cross-cutting the bedding. These accumulations are interpreted as parautochthonous assemblages. The relative size sorting seen in the fluvial assemblages with the larger plants, such as *Pertica quadrifaria*, concentrated at the bottom and smaller plants, such as the *Psilophyton*, concentrated at the top of the plant-bearing intervals is seen in this subfacies of siltstone, but to a lesser extent. This feature is a reflection of decrease in flow velocity and the difference in velocities that each plant part experienced when settled out of suspension. The small angle between dichotomizing areas of *Psilophyton microspinosum*, which is not typical of the plant (Andrews et al., 1977), is also attributed to transport and abiotic influence.

Axes are found in three-dimensional arrangement throughout the assemblages where they are seen to cross-cut the bedding. However, the bedding is not interrupted by these inclined axes suggesting original axial orientation during burial, and not a response mechanism by the plant to burial. Plant response to burial has been observed in several assemblages from the Battery Point Formation (Hotton et al., 2001), as well as other

localities within the Trout Valley Formation. Such responses are characterized by evidence of anchorage, preservation of complete axes in fine detail, and axes oblique or perpendicular to the bedding plane (Hotton et al., 2001). However, these features are not found in these siltstone subfacies assemblages.

There is no evidence of decay within these assemblages, as opposed to the fluvial assemblages that contain a large number of infilled axes. This suggests that plants were alive during burial.

The mat-like assemblages also are interpreted as parautochthonous accumulations. The presence of barren siliciclastic intervals between each plant-bearing horizon suggests that these are not *in situ* assemblages. A basal layer of organic detritus from dead biomass generally characterizes *in situ* assemblages. Such an organic layer is not observed in any one of these plant-bearing intervals, either in macroscopic or microscopic view.

Subfacies 2 Parautochthonous assemblages in this subfacies are characterized by concentrated well-preserved axial segments with laterals in sub-parallel to parallel-aligned orientations. Additionally, the relationships between the plants and enclosing matrix support this interpretation. The parallel-aligned nature of the plant axial fragments, especially associated with *Psilophyton* taxa, is instructive as to how these plants were deposited. Several lines of evidence suggest that the alignment is a result of transport and not *in situ* burial as previously interpreted (Andrews et al., 1977).

Although only float block material was available for study, no rooting structures were found in the stratigraphic sequence below the parallel-aligned axes. Each horizon on which large fragments were preserved is underlain by coarser clasts devoid of

rhizomes or rhizoids. Aerial axes are found in three-dimensional arrangement throughout the plant-bearing interval, where inclined axes are both sub-horizontal and vertical. However, as seen in siltstone subfacies 1, these are in their original axial orientation rather than a biological response to burial.

The presence of barren intervals above and below each assemblage, in which wave and tidally modified primary structures are preserved, also suggests transport. The plant material only occurs in the troughs of large-scale ripples indicating a relationship between transport and settlement as the current velocities decreased (Gastaldo, 2002). Although these assemblages occur within interpreted tidal channel deposits and may have represented colonization of incipient wetlands, the absence of rooting horizons, the multiple stratified assemblages intercalated with barren intervals, and restriction of plant axes to ripple troughs suggest some degree of transport.

However, it is believed that the plants were not transported out of their habitat. It appears that these plants were neither dead nor decayed at the time of transport and burial. Nearly all the plants retain their three-dimensional architecture along with the presence of epidermal features (e.g., spines), intact terminal and lateral sporangia, and lateral branching. The sedimentary features indicate a transported assemblage, but the microstratigraphic analysis suggests that these plants were still alive when they were buried. Rooting structures that originate from flat-lying aerial axes appear to be regenerative and although this phenomenon has not been observed in other Devonian plant assemblages, it has been documented to occur in Carboniferous *Calamites* (Gastaldo, 1992). Hence, these plants are envisioned to have lived on the margins of tidal channels, and as these channels eroded during high velocity spring flood or tidal cycles

enhanced by storm processes, sediments and plant material would be incorporated into the channel.

Subfacies 3 The poorly preserved nature of the plant remains, their random orientations, and the concentration of material only in bedform crests in this subfacies of siltstone, along with their association with marine and brackish macroinvertebrates, indicate that this is an allochthonous assemblage. The admixture of small bivalves and gastropods along with a juvenile eurypterid is interpreted as representing transitional estuarine forms whereas the plant material had been resident in the water column for some time (Gastaldo, 1992). The plant material is the result of deposition during high-velocity events within tidal/transitional channels.

Comparison to other Devonian Plant Localities

There are several time-equivalent Devonian plant localities from northern Maine, New Brunswick, and Quebec. However, only one of these localities, the Cap-aux-Os Member floral assemblage of the Battery Point Formation from Gaspé Bay, Quebec, has been studied in detail (Griffing et al., 2000; Hotton et al., 2001). Therefore, a comparison between the Trout Valley Formation and the Cap-aux-Os Member flora is most appropriate.

Both localities are interpreted as deposited in similar settings; migrating fluvial channels across coastal plains. The majority of plant assemblages in the Trout Valley Formation are allochthonous and parautochthonous, with only one unequivocal autochthonous assemblage. In the Cap-aux-Os Member there are a significantly greater number of autochthonous assemblages preserved. The Trout Valley Formation and Cap-aux-Os Member floras are very similar systematically. However, the depositional

environments in which these plants are found differ. Plant remains are preserved in both fluvial and estuarine environments in the Trout Valley Formation. Most taxa, with the exception of *Kaulangiophyton akantha*, *Psilophyton dapsile*, and *P. microspinosum*, are encountered in both fluvial and estuarine environments, whereas these latter taxa are restricted to estuarine settings. In the Cap-aux-Os Member, plant megafossils occupy specific areas of the landscape, which is inferred to represent clade-related niche-partitioning (Hotton et al., 2001). Trimerophytes and rhyniopsids occupied fully fluvial ephemeral, near-channel environments, whereas monotypic zosterophyll assemblages are found in mud-dominated settings such as backswamps and marshes (Griffing et al., 2000; Hotton et al., 2001). Both the Trout Valley Formation and the Cap-aux-Os Member show *Prototaxites* to occur in exclusively terrestrial fluvial environments.

Summary and Conclusions

The Trout Valley Formation of north-central Maine was deposited initially in a relatively steep alluvial fan complex with high-velocity channels flowing to a coastal plain setting in which estuarine environments dominated. The presence of nearshore shelf sands in addition to the increasing proportion of fine clastics upsection, is indicative of increasing marine influence in the area.

Plant megafossils are found in both fluvial and estuarine settings, with three taxa - *Kaulangiophyton akantha*, *Psilophyton dapsile*, and *P. microspinosum* - found exclusively in the latter. *Psilophyton forbesii* also is seen in higher concentrations in estuarine settings, although it also occurs in fluvial plant assemblages. Those plant taxa found in both environments suggests that these plants had a range of environmental habitats in which they could occupy. Trimerophytes are preserved in primarily estuarine

environments; however the presence of such taxa as *Pertica quadrifaria*, *Psilophyton princeps*, and *Psilophyton* sp. in fluvial channel deposits suggests that these plants also may have occupied terrestrial freshwater habitats, as well. This conclusion is contrary to the types of environments in which these plants are found in Quebec (Griffing et al., 2000; Hotton et al., 2001). One explanation for this disparity may be that fluvial channels are less likely to preserve plant remains due to associated high energy and oxygenated waters. However, the major concentration of trimerophyte remains within Trout Valley are in estuarine environments indicating that these plants tolerated the freshwater-marine transitional zone where they may be subjected to brackish conditions. However, the effects of this on the plants is not known. Trout Valley rhyniophytes and lycopods also are seen to follow this trend as *Kaulangiophyton akantha* occupied exclusively estuarine settings, and *Drepanophycus gaspianus*, *Drepanophycu* sp., *Leclercquia complexa*, and *Leclercquia* sp. found in both fluvial and estuarine settings.

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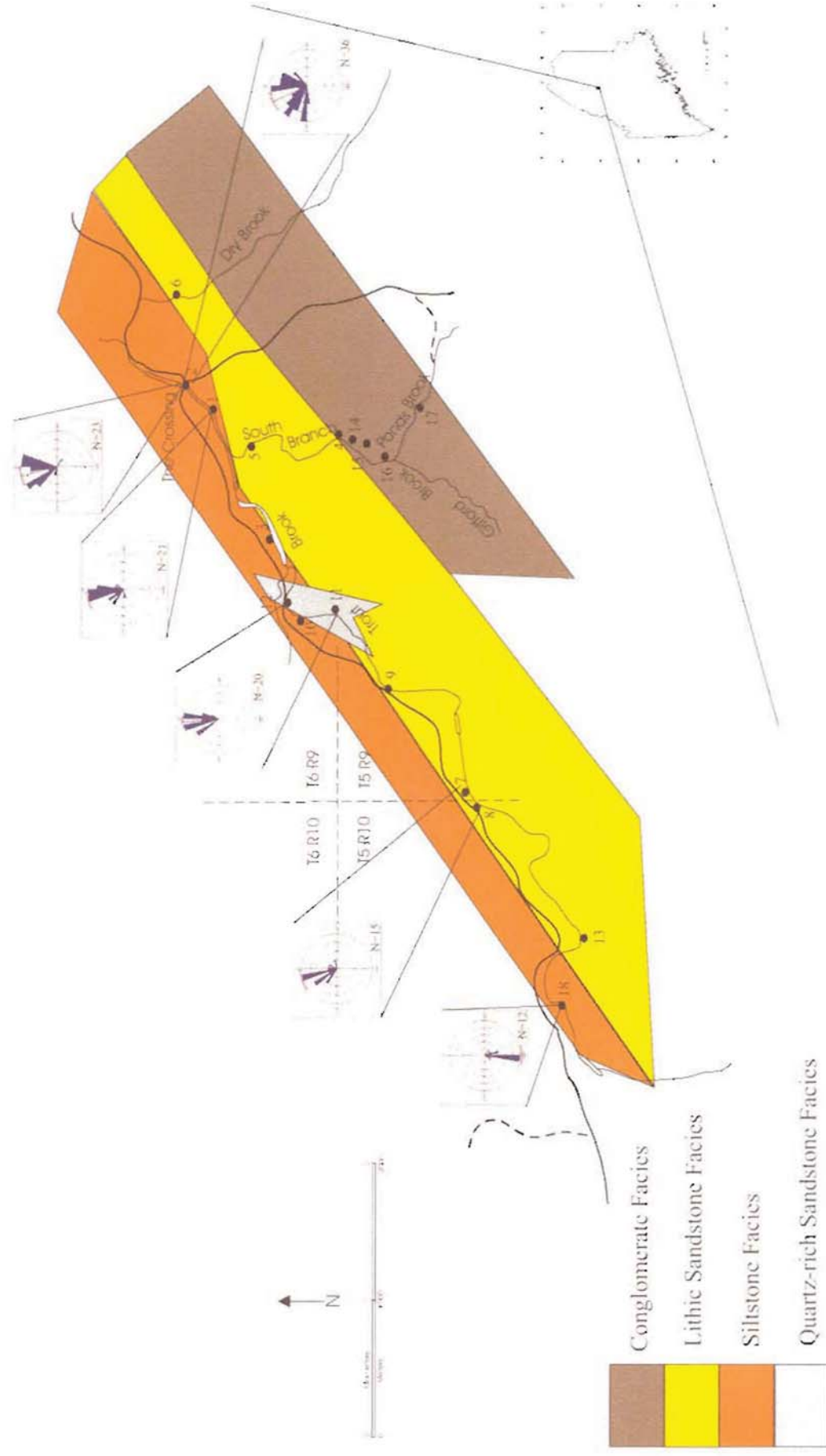


Figure 1- Facies map for all localities studied in the Trout Valley Formation. Paleocurrents for different facies are displayed on the left, while axial orientation measurements are displayed on the right.



Figure 2- Extrapolated stratigraphic section for the Trout Valley Formation.



Figure 3- A: Photograph with overlain line drawing displaying crude bedding in the upper conglomerate facies. **B:** Upper portion of the conglomerate facies near the contact with the lithic sandstone facies. Inset displays closeup example of imbrication.



Figure 4- Contact between conglomerate and lithic sandstone facies. 2 m scale.



Figure 5- Typical fining upward sequence truncated by channel form, locality 8. Bounding surfaces are difficult to discern due to the similarity of weathering pattern and color between lithologies. 2m scale.



Figure 6- Photomosaic of locality 11 displaying lenticular geometry of the massive sandstone facies. Arrow in center points to siltstone lens located in the trough of sandstone waveform. 2 m measure at left for scale.



Figure 7- Float block of massive sandstone facies displaying modified ripples on the top of the bed (longer arrows) and hummocky cross-stratification (smaller arrow). 1m scale.

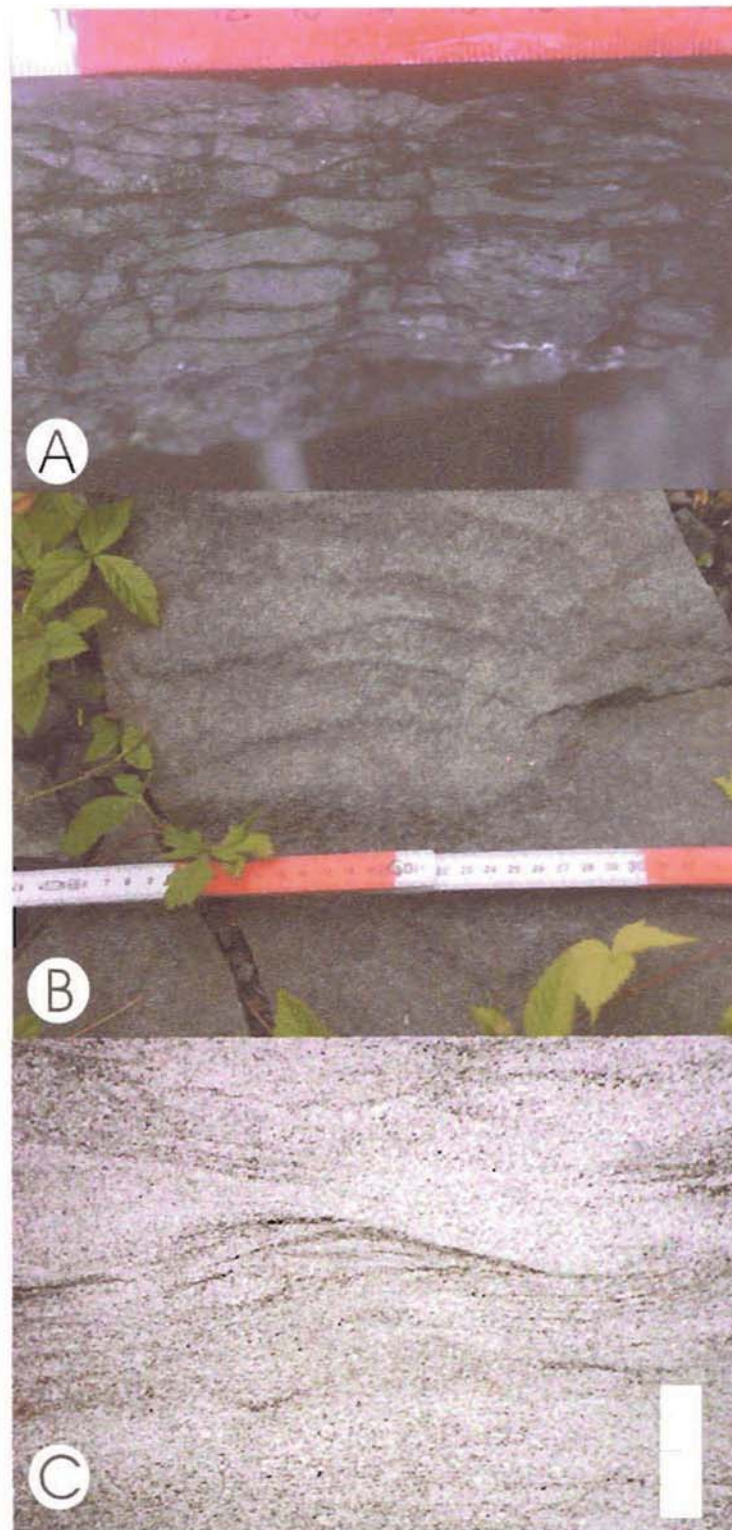


Figure 8- Features of siltstone facies, subfacies 1. **A:** Climbing ripples. 1 m scale **B:** Ladder and starved ripples on very fine sandstone/coarse siltstone bedding surface, locality 9. 1 m scale **C:** Micro cross-stratification observed in thin section of the very fine sand to coarse siltstone. 1 mm scale.



Figure 9- Trace fossils from siltstone facies. **A:** Burrows (arrows) on vertical surface in siltstone, locality 1. **B:** *Skolithos* (arrows) on homogeneous siltstone, burrows are approximately 5mm in diameter, locality 9. **C:** Horizontal traces (? *Helminthopsis*). **D:** Infilled meniscate burrow in thin section. 1 cm scale.

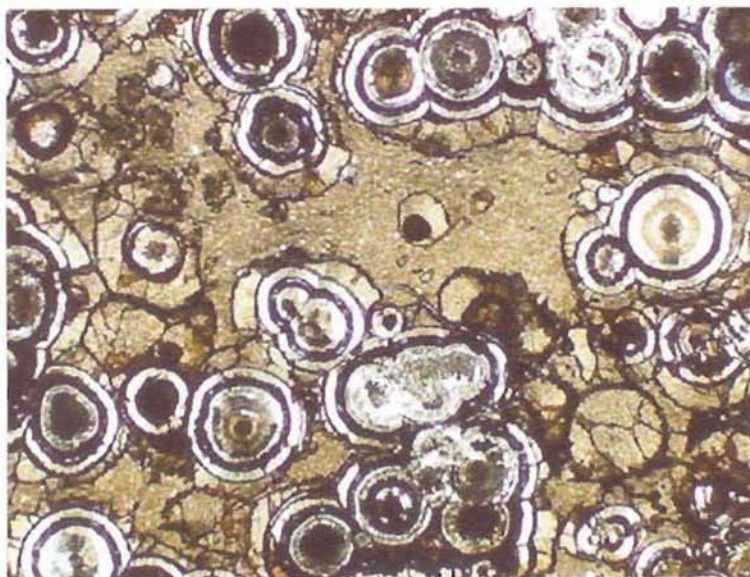


Figure 10- Sideritic nodules, approximately 0.5-1.5 mm in diameter occurring in siltstone facies, variation 1, locality 11. 2x

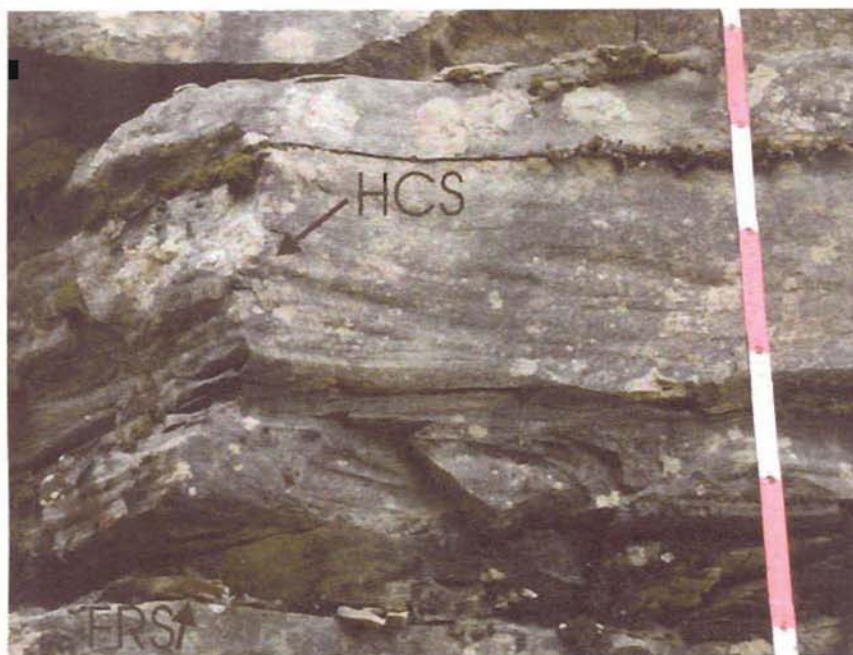


Figure 11- Herringbone cross-stratification (HCS) overlying fossiliferous rippled siltstone (FRS), locality 1

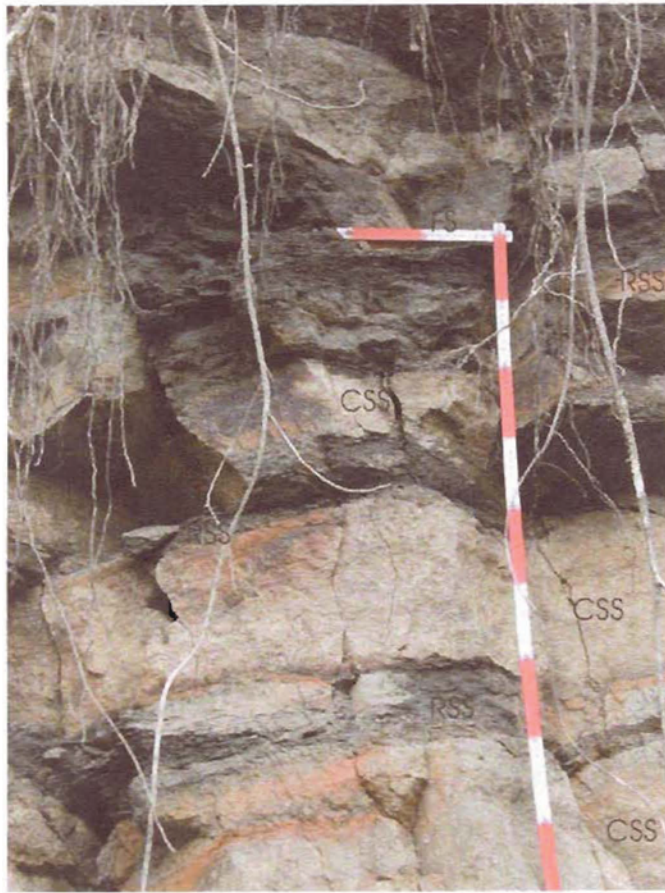


Figure 12- Alternating beds of cross-stratified siltstone (CSS) and ripple-stratified siltstone (RSS), locality 1. Fossiliferous horizons (FS) are found at the tops of the ripple-stratified beds. 1 m scale.

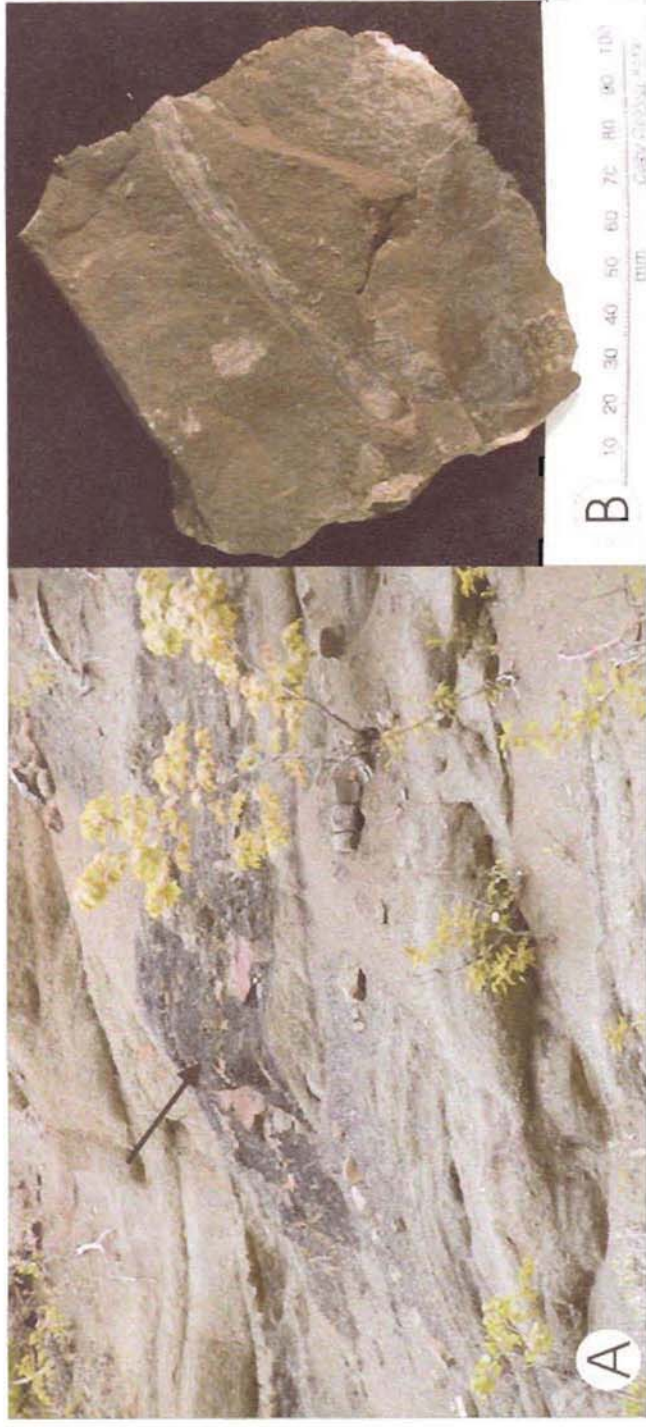


Figure 13- A: Plant-bearing siltstone lens occurring in the upper conglomerate. Notice the conglomerate truncated the siltstone lens (arrow). **B:** Typical nature of *Taeniocrada* sp. found within fossiliferous lens.



Figure 14- Lithic sandstone plant macrofossils. **A:** Large main axis with laterals of *Pertica quadrifaria* in fine sandstone, lower most sandstone section, GA 12. **B:** Typical fragmented main axes and laterals of *Pertica quadrifaria* in very fine sandstone/coarse siltstone intercalated with medium sandstone, base of plant bearing intervals. **C:** Fragmentary nature of plant axes in lithic sandstone facies. **D:** Inclined axes of *Psilophyton* sp. in upper plant-bearing interval.

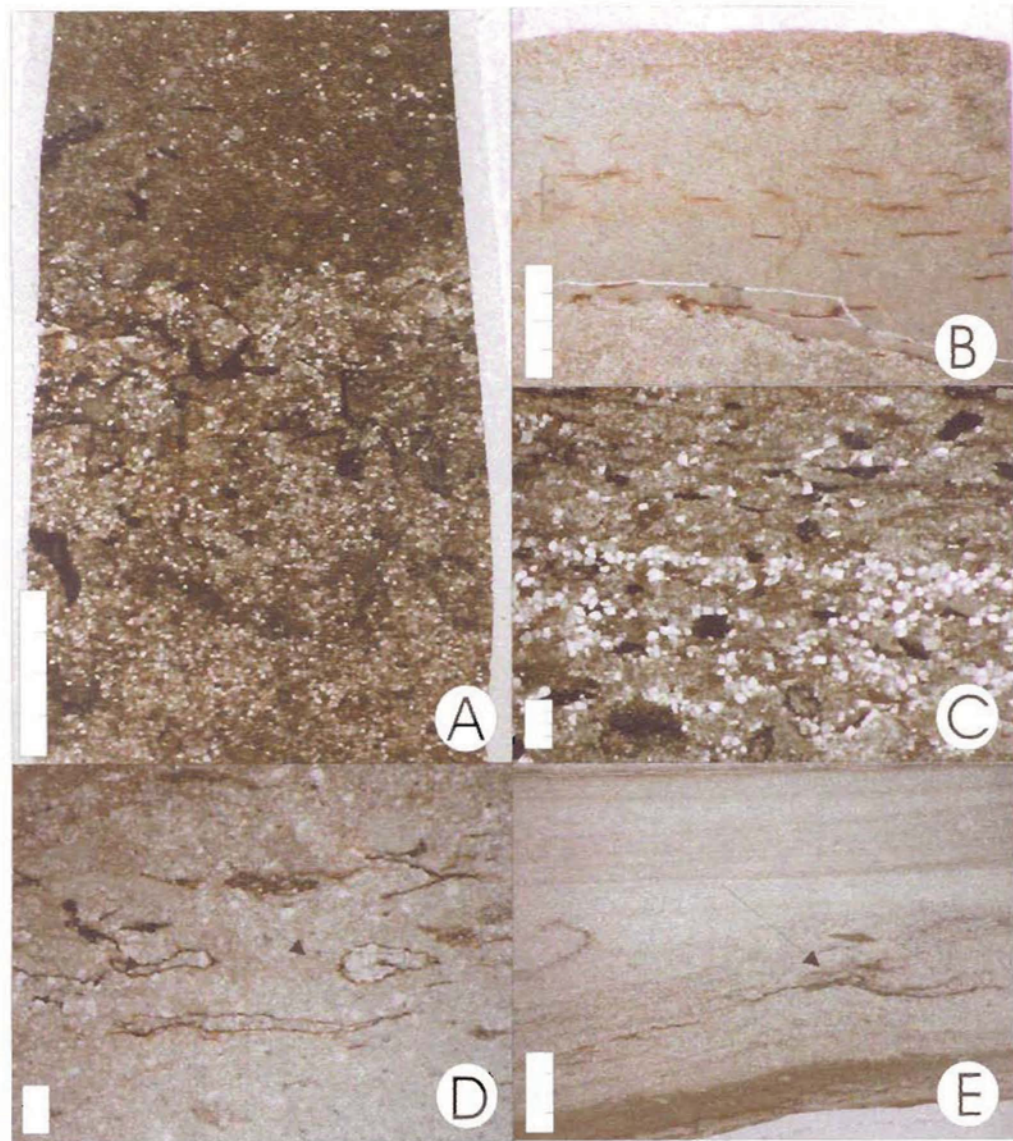


Figure 15- Lithic sandstone plant microfossil photographs. **A:** Typical dispersal and arrangement of plant matter in this facies. 1 cm scale. **B:** Plant matter oriented parallel to the contact between the coarse and fine sediments. 1 cm scale. **C:** Silt going over plant material, scouring the other side. 1 mm scale. **D:** Infilled plant axes. 1 mm scale. **E:** Contorted plant material overlying primary ripple structure. 1 cm scale.

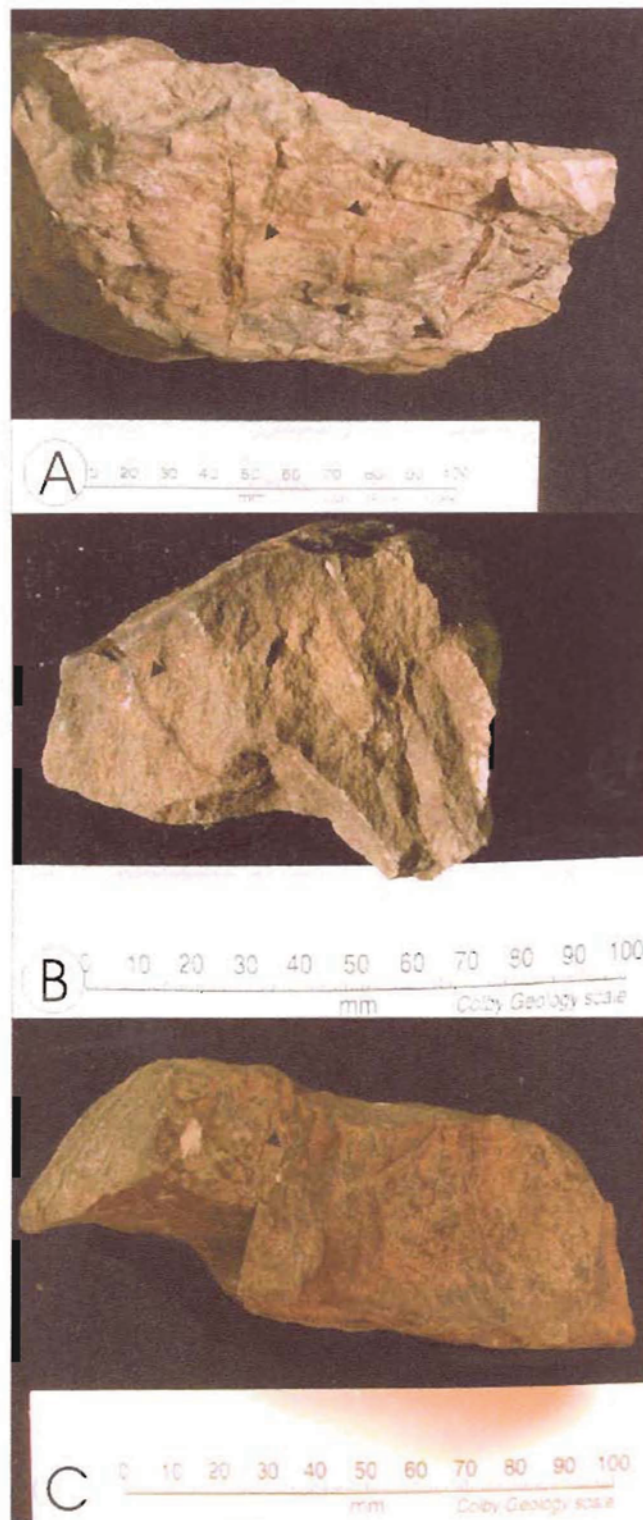


Figure 16- Plant macrofossil photographs from siltstone facies. **A:** Oblique view of inclined *Psilophyton* axes penetrating bedding, first variation of siltstone. **B:** Naked, sigmoidal root trace extending down from flat-lying bedding surface. **C:** Possible root bifurcation.

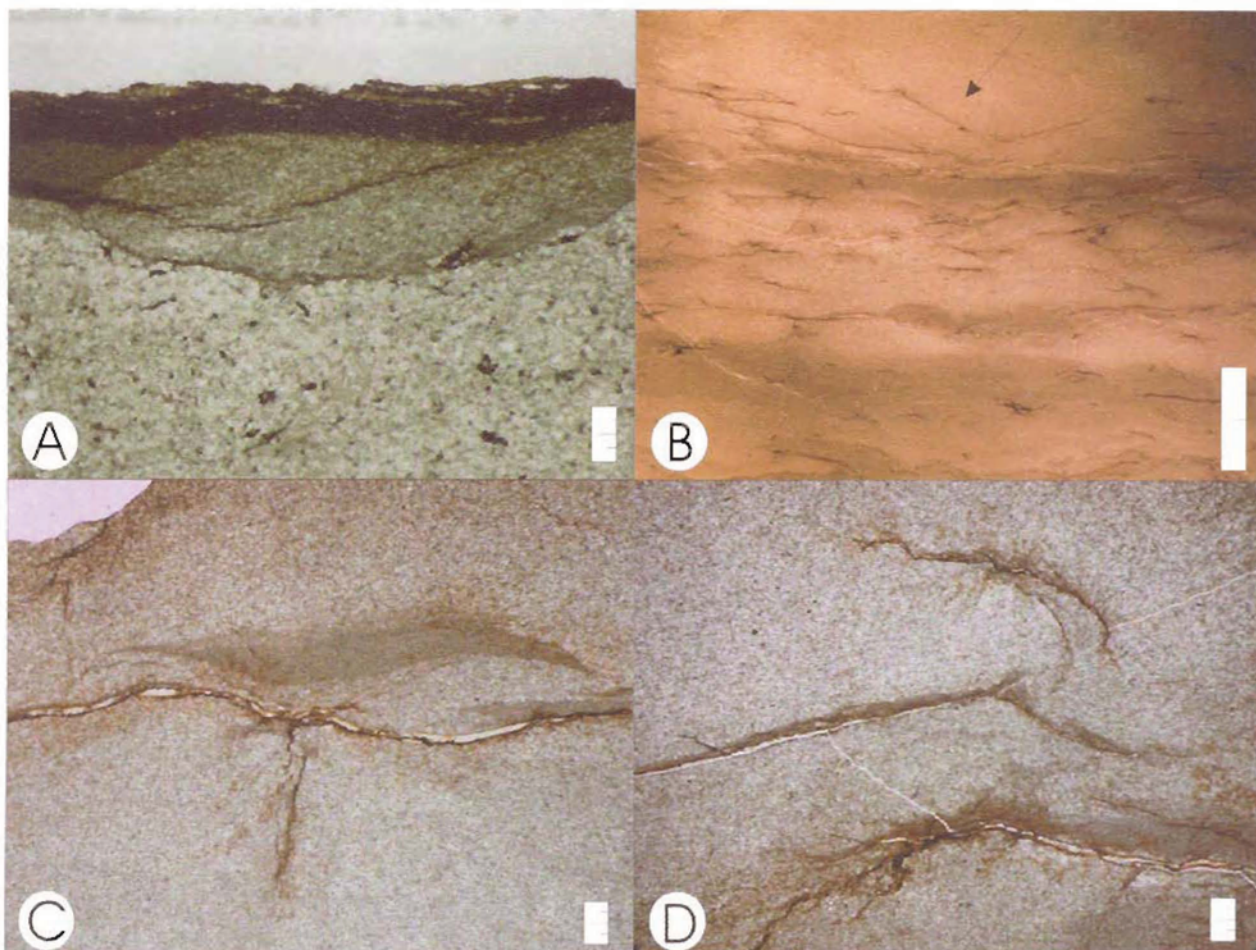


Figure 17- Microscopic plant photographs from siltstone facies. **A:** Plant material paralleling bedding contact between coarse and fine silt. 1 mm scale. **B:** Sub-horizontal axes (arrow) overlying poorly defined micro-cross-stratification. 1 cm scale. **C:** Rooting structures vertically disrupting bedding below a starved ripple. 1 mm scale. **D:** Three fining upwards sequences with weathered rooting structures. 1 mm scale.

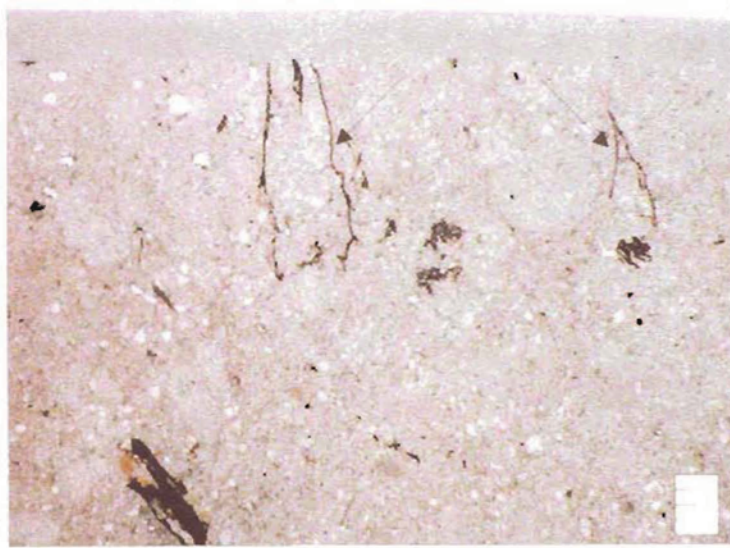


Figure 18- Geopedally oriented roots from *in situ* assemblage (arrows), locality 10. Roots on right display well-defined bifurcation. 1 mm scale.



Figure 19- *Psilophyton forbesii* axes parallel oriented, siltstone, subfacies 2.

Facies	Lithology	Locality	Munsell Color	Sedimentary Characteristics	Mineralogy	Fossils	Trace Fossils	Depositional Environment
Conglomerate	Clast-supported, poorly sorted, pebble-cobble extralaminar rhyolite conglomerate with interbedded siltstone lenses	GA 14, GA 15, GA 16, GA 17	Medium gray-dark gray (N5-N3)	Massive or crudely developed horizontal stratification, imbricated clasts, fines successively conglomerate beds.	Rhyolite	Plant debris	N/A	Channels and longitudinal bars on a proximal braided alluvial fan complex
	Clast-supported, poorly sorted granule conglomerate; poor-moderate sorted, sub-angular-sub-rounded, coarse-line lithic arenites and wackes	GA 4, GA 5, GA 6, GA 7, GA 8, GA 9, GA 13	Medium gray-dark gray (N5-N3)	Fining upward sequences in channel-form geometries. Lateral accretionary surfaces, trough cross-stratification, lenticular and planar bedding, deformational loading structures, reactivation surfaces. Lenticular geometries, megamorphic waveforms, ripple laminated, smoothed and modified ripples, hummocky cross-stratification	Rhyolite, quartz, clinoclone, muscovite	Plant debris	Meniscate burrows	Migrating braided channels
Quartz-rich Sandstone	Fine-medium grained quartz arenites and wackes	GA 11, GA 12	Pale brown (%YR 5/2)		Quartz, muscovite	N/A	N/A	Nearshore shell sand bars under storm-influenced processes
Siltstone subfacies 1	Very coarse siltstone, subordinate amounts of very fine sandstone	GA 2, GA 3, GA 10	Medium gray-dark gray (N5-N3)	Laterally continuous beds, planar bedding, trough cross-stratification, ripples (climbing, silken slides, siltitic glaebules). Parallel bedding, alternating cross-stratified siltstone with ripple laminated siltstone, low-angle cross-stratification, herringbone cross-stratification.	N/D	Plant axes, root traces	(?) Skolithos, (?) Helminthopsis, meniscate burrows	Estuarine intertidal flat
	Coarse-fine siltstone	GA 1	Light gray-dark gray (N7-N3)		N/D	Plant debris, oysters, gastropods, ostracods, and a single eurypterid	N/A	Tidal channels
Siltstone subfacies 3	Coarse siltstone	GA 18	Dark gray (N3)	Megaripple bedforms	N/D		N/A	Transitional channels

Table 1- Summary of rock lithology, sedimentary and biogenic features, and interpreted depositional environments.

Plant Megafossils		Facies					
		Conglomerate	Lithic Sandstone	Quartz-rich Sandstones	Siltstone var. 1	Siltstone var. 2	Siltstone var. 3
Thallophytes							
<i>Protaxites</i> sp.*	X						
Embryophytes							
<i>Sciadopityon</i> sp.*					X		
Bryophytes							
<i>Sporogonites</i> sp.*					X		
Rhyniophytes							
<i>Taeniocrada</i> sp.		X	X		X	X	
<i>Taeniocrada</i> cf. <i>dubia</i>					X	X	
<i>Taeniocrada</i> cf. <i>decheniana</i>							
Trimerophytes							
<i>Perica quadrifaria</i>			X		X		
<i>Psilophyton diapsile</i>					X		
<i>P. forbesii</i>			X		X	X	
<i>P. microspinosum</i> *					X		
<i>P. princeps</i>			X		X		
<i>Psilophyton</i> sp.			X		X	X	
Lycopods							
<i>Drepanophycus gasplanus</i>			X		X		
<i>Drepanophycus</i> sp.			X				
<i>Kaulanglophyton akantha</i>					X		
<i>Kaulanglophyton</i> sp.					X	X	
<i>Lectercquia complexa</i> *							
<i>Lectercquia</i> sp.			X		X		
Unidentified			X		X		X

* - reported by other authors, but not found in present study.

Table 2: Association of plant remains and facies in the Trout Valley Formation.