

*Alluvial fan and piedmont sedimentation in
the Tynemouth Creek Formation
(Lower Pennsylvanian) of southern New Brunswick*

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The Tynemouth Creek Formation (formerly the Tynemouth Creek and McCoy Head Formation) is re-defined and detailed stratigraphic and structural sections through representative parts of the formation are presented. The Tynemouth Creek Formation is of Lower Pennsylvanian age and is at least 800 m thick. It is dominantly clastic, shows an overall upward-coarsening from siltstones and sandstones into conglomerates and was deposited in an alluvial fan and piedmont setting. Six sedimentary facies are recognized. (1) Coarse, polymict, clast-supported conglomerates dominate the upper part of the formation. (2) Tabular and channelized pebbly sandstones, up to 8 m thick represent braided channels, the former characterized by unstable banks and laterally migrating channels while the latter may have formed on the upper fan when periodic tectonic movement caused rejuvenation of the streams and resultant channel incision. (3) Erosive-based sandstones up to 30 m thick occur near the base of the formation and are interpreted as point-bar deposits of large meandering rivers that existed on the floor of the basin beyond the alluvial fan toe. (4) Thin-bedded sandstones and siltstones were deposited on the banks and in abandoned channels of rivers which locally supported dense growths of *Calamites*. (5) Red siltstones and sheet sandstones were laid down in interchannel and distal fan areas, the former by low-energy flooding and perhaps wind action; the latter by sheet floods. Paleosols and calcitic nodules are characteristic of this facies. (6) In areas starved of clastic sediment, shallow lakes occasionally formed and accumulated thin bioclastic (ostracode/gastropod/spirorbid) or algal limestones. Palaeocurrents are unimodal with a mean flow towards the north-west. The Tynemouth Creek Formation probably represents a sector of a large alluvial fan that built northward from the southern, fault-bounded margin of the Cumberland Basin. The upward-coarsening of the sequence may record continued tectonic rejuvenation of the source area, causing fan progradation and deposition of coarse, fan-head conglomerates over finer, lower fan sediments. A climate of alternating wet and (?hot) dry seasons is inferred from the sedimentary evidence as a whole.

La formation de Tynemouth Creek (autrefois les formations de Tynemouth Creek et de McCoy Head) est redéfinie et des coupes stratigraphiques et structurales détaillées, représentatives de la formation, sont présentées. La formation de Tynemouth Creek remonte au Pennsylvanien inférieur et mesure au moins 800 m d'épaisseur. Les roches détritiques y dominent et on perçoit une granulométrie croissante passant des roches limoneuses et des grès aux conglomérats, le tout déposé en milieu de piémont et de cône de déjection.

On reconnaît six faciès sédimentaires. (1) Des conglomérats polymictiques grossiers, se soutenant, caractérisent le sommet de la formation. (2) Des grès caillouteux tabulaires et cannelés mesurant jusqu'à 8 m d'épaisseur représentent des chenaux anastomosés. Les grès tabulaires sont marqués par des berges instables et une migration latérale des chenaux, tandis que les grès cannelés ont probablement été mis en place sur la portion supérieure du cône, à la suite d'épisodes tectoniques qui provoquèrent le rajeunissement et l'encaissement des cours d'eux. (3) Dans la partie inférieure de la formation, on trouve des grès à base érosive atteignant jusqu'à 30 m d'épaisseur. Ceux-ci sont interprétés comme les bancs de sable en pointe de grandes rivières à méandres qui coulaient dans le bassin, au delà de l'extrémité inférieure du cône de déjection. (4) Les grès et roches limoneuses finement lités furent déposés le long des rives et dans les chenaux abandonnés des rivières où poussait une végétation luxuriante de *Calamites*. (5) Des roches limoneuses rouges et des grès en nappes furent déposés entre les chenaux ainsi qu'à la périphérie du cône de déjection: les premières par des crues de faible énergie et peut être par l'action du vent; les seconds par des crues en nappes. Des nodules calcitiques et des paléosols caractérisent ce faciès. (6) Dans les régions dépourvues de sédiments détritiques, des lacs peu profonds se formèrent à l'occasion et de minces calcaires bioclastiques (ostracodes/gastropodes) ou à alques s'y accumulèrent.

Un groupement unimodal des paléocourants est noté, avec un vecteur moyen vers le nord-ouest. La formation de Tynemouth Creek correspond probablement à la portion d'un grand cône de déjection qui s'est édifié en direction nord, à partir de la bordure faillée du Bassin de Cumberland. La granulométrie croissante de la séquence correspond peut être à un rajeunissement tectonique continu de la région source, accompagné de la progression du cône ainsi que de la déposition de conglomérats grossiers du cône supérieur sur les sédiments plus fins de la partie inférieure du cône. Un climat marqué par l'alternance entre saison humide et saison sèche (chaude?) est déduit à partir des données sédimentologiques.

INTRODUCTION

The Tynemouth Creek Formation belongs to the Pennsylvanian Cumberland Group, and is probably of Westphalian A or B age (Barss, pers. com.). It outcrops in a relatively small, elongate area on the south coast of New Brunswick, 20 km east of Saint John. This area is 21 km long and 8 km wide and lies immediately to the south of the Caledonia Highlands (Fig. 1). The present paper describes the results of a detailed sedimentological study of the Carboniferous strata exposed between Rogers Head and Emerson Creek (Fig. 2). Similar sediments are exposed from 1.8 km east of Rogers Head to 600 m north of Quaco Head (Fig. 1). These rocks are currently under investigation and will be described in a subsequent paper.

The geology of the area was originally mapped in detail by Bailey (1865) with subsequent work by Ells (1907), Bailey and Matthew (1918), Bell (1927), Hayes and Howell (1937), and Alcock (1938). Kelly (1967) reviewed, in general terms,

the stratigraphy of the Maritime Provinces while Belt (1968) described the principal lithofacies and depositional environments of the Carboniferous rocks of the same area. The stratigraphy and sedimentology of the Pennsylvanian of southern New Brunswick was studied by Poll (1970, 1972). Ruitenberg *et al.* (1979) in a study of the geology and mineral deposits of the Caledonia area briefly examined the coastal exposures of the Tynemouth Creek Formation and followed the stratigraphic nomenclature of Poll (1970).

STRATIGRAPHY

Sediments of the Tynemouth Creek Formation, are generally in faulted contact with both older and younger rocks. At the western margin of the area, at Emerson Creek, (Fig. 2) it is in faulted contact with the West Beach and Balls Lake Formations of Mississippian or Pennsylvanian age (Alcock, 1938). Twenty km to the east, at Rogers Head (Fig. 2) beds low in the Tynemouth Creek Forma-

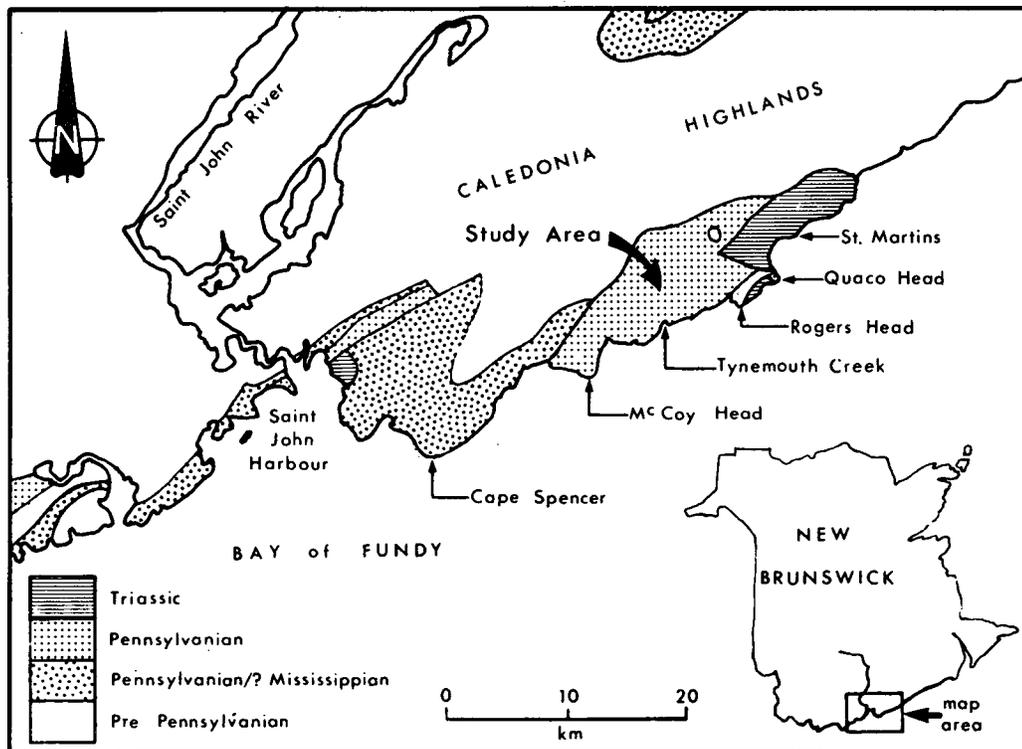


Fig. 1 - Map of the Saint John area, New Brunswick, showing the distribution of Pennsylvanian rocks and the location of the study area.

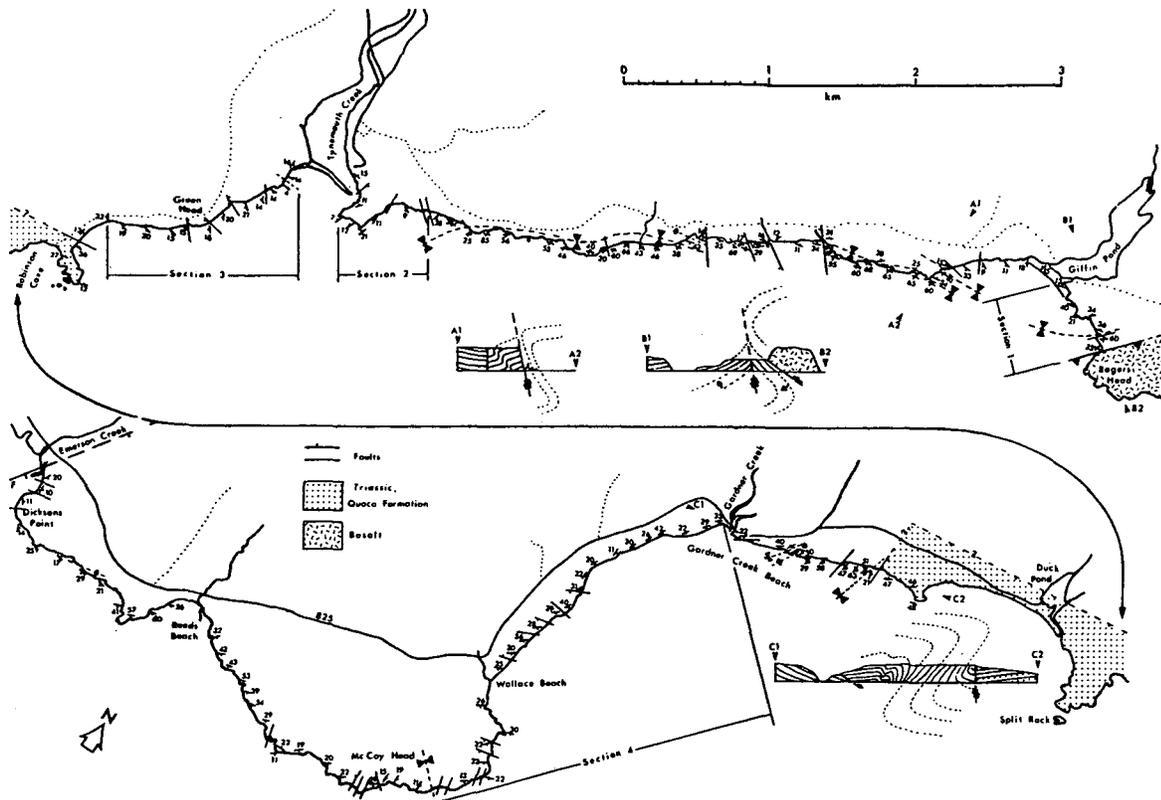


Fig. 2 - Detailed map showing coastal exposures and structure of the Tynemouth Creek Formation. The position of the four measured stratigraphic sections, and three sketch cross-sections are shown. As yet, no means of accurately correlating sections 1-4 has been found.

tion are overturned and faulted against rubbly and amygdaloidal basalts of unknown (?Precambrian, ?Devonian) age.

The Tynemouth Creek Formation comprises siltstones, sandstones and conglomerates and shows an overall upward-coarsening. The highest beds are exposed on McCoy Head and comprise coarse, thick-bedded conglomerates. The lower part of the Formation is dominantly red or reddish-brown. Towards the top however, yellow and grey sediments become more common.

Bailey (1865) ascribed the Tynemouth Creek Formation to the Lower Carboniferous while Ells (1907) considered it to belong to the Perry Formation, of Upper Devonian age. Subsequently, Bailey and Matthew (1918) ascribed the Tynemouth Creek Formation to the upper part of the Perry Formation which was thought to be of Lower Carboniferous age. Recent

palynological work (Barss, pers. com.) indicates a Lower Pennsylvanian (?Westphalian B) age.

The Tynemouth Creek Formation was divided into a lower, 'McCoy Head Formation', composed mainly of conglomerates, and an upper, 'Tynemouth Creek Formation' dominated by sandstones and siltstones (Hayes and Howell 1937, Alcock 1938). Poll (1970) recognized the essential lithologic continuity of these two formations and informally grouped them as the McCoy Head Formation (Poll 1972). Detailed examination of the sediments confirms that (i) the two 'Formations' of Hayes and Howell (1937) are clearly intergradational and (ii) that the sandstones and siltstones of the 'Tynemouth Creek Formation' in fact underlie the conglomerates of the 'McCoy Head Formation'. The cliffs in the immediate vicinity of Tynemouth Creek exposed excellent examples of all the prin

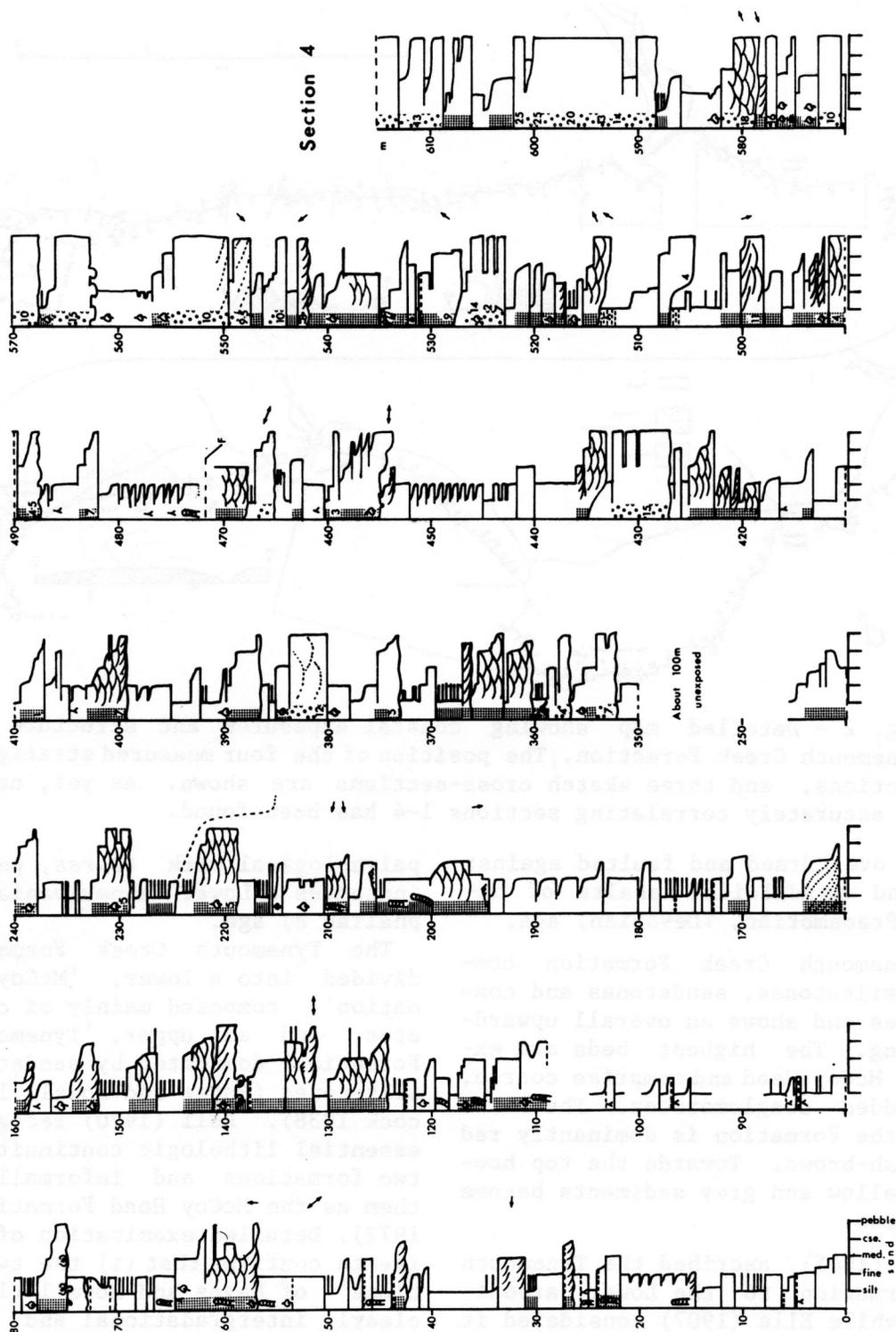
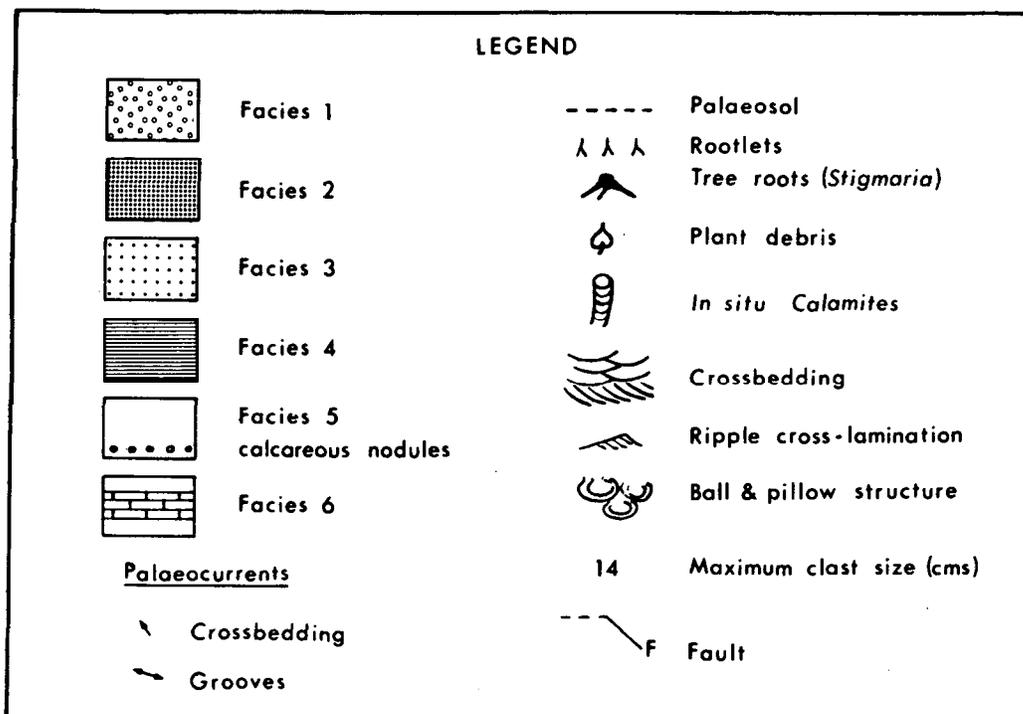


Fig. 3 - Stratigraphic section no. 4. Note overall upward-coarsening of the sequence with interchannel sediments and palaeosols dominant in the lower part, replaced by braided-river sandstones and streamflow conglomerates towards the top.



cipal rock types that characterize the formation. This is not the case at McCoy Head, where the succession is dominated by coarse sandstones and conglomerates. It is therefore proposed that the term 'Tynemouth Creek Formation' be adopted to denote all the strata of Lower Pennsylvanian age exposed between Emerson Creek and Rogers Head. The progressive upward coarsening of the formation, clearly seen in Section 4 of this work, (Fig. 3) illustrates the intergradational nature of the two facies and shows that there is no logical basis for their separation.

STRUCTURE

Folding

The coastal exposures of the Tynemouth Creek Formation were mapped at 1:10,000 using a base-map constructed from aerial photographs. A simplified version of this map is given in Fig. 2. The Tynemouth Creek Formation to the east of Tynemouth Creek is deformed by one or more large, northward-facing, asymmetrical folds, the axes of which trend ENE-WSW. Beds on the northern limb of each fold are usually overturned and dip to the south from 90° to 25°

(Fig. 4). Sedimentary evidence permits easy determination of way-up. Several smaller folds, with amplitudes of a few metres are associated with these major structures.

Between Giffin Pond and Rogers Head, the beds either dip NW at about 30°, or are overturned and dip SE at 50°. (Fig. 2) (cf. early structural section by Bailey 1865, section H). The hinge of the fold has sheared out and is seen as a high-angle reverse fault. Displacement on this fault seems to be only a few tens of metres, as similar sedimentary successions can be measured on either side. The lowest beds in this section are overturned and faulted against the basalts that form Rogers Head. The contact is a zone of sheared basalt and red siltstone, up to 50 cm thick. Thin beds of tuff are intercalated with the basalt and dip at about the same angle as the Tynemouth Creek Formation sediments, suggesting that both the latter and the basalts are part of the same large fold (Fig. 2). It is possible that there has been little differential movement between the two rock units; the sheared contact simply reflects the differential competence of

the two rock types during deformation.

Between Duck Pond and Gardner Creek Beach, sediments of the Tynemouth Creek Formation are deformed by a large, east-facing fold, the overturned limb of which is about 300 m thick (Fig. 2). Several smaller folds are associated with this structure. The synclinal axis of the major fold is seen a few metres west of a fault (unexposed) which separates the Carboniferous from down-faulted Triassic sediments of the Quaco Formation (Powers, 1916). The joint pattern in the rocks of this area has been the subject of recent study (Lajtai and Stringer 1981).

Between Wallace Beach and Reeds Beach, the Tynemouth Creek Formation is deformed into a shallow syncline, the axis of which plunges gently to the south-east. Between Reeds Beach and Emerson Creek faulting and deformation becomes progressively more intense and reaches a maximum adjacent to a major fault that separates the Tynemouth Creek Formation from the West Beach Formation (?Mississippian or Pennsylvanian).

Faulting

The Tynemouth Creek Formation is cut by numerous faults, most of which have a NW-SE orientation. Most faults are normal and the fault plane usually dips at a high angle. The throw on most faults is usually only a few metres and the sedimentary succession can be correlated across the fault within the dimensions of the exposure.

Occasional reverse faults are associated with major folds, for example, at Gardner Creek Beach and Rogers Head. A major fault, forming the SW boundary of the Tynemouth Creek Formation runs NNE along the east side of Emerson Creek and forms a prominent scarp for over 6 km.

In the area around Split Rock and Robinson Cove, a block of Triassic sandstone of the Quaco Formation (Powers 1916) is downfaulted against the Carboniferous. The fault, which dips at about 20° , 170° N, is well exposed in the cliff to the east of Robinson Cove.

Sandstone Dikes

Essentially uncompacted sandstone dikes are present in the Tynemouth Creek Formation and, almost invariably, are found in the immediate vicinity of, and approximately parallel to small normal faults. Sandstone dikes show a pronounced preferred orientation throughout the formation (Fig. 5) and probably reflect a regional stress pattern (cf. Harms 1965, Marschalko 1965, Peterson 1966, Eisbacher 1970, Powell 1973). Their association with normal faults suggests that the dikes, which are displaced by the faults, were intruded during a relatively early phase of tensional deformation, and may be considered as precursors of the normal faults that subsequently developed in the same areas.

SEDIMENTS

The sediments of the Tynemouth Creek Formation are divided into six facies, principally on the basis of bed thickness and geometry, sedimentary structures, grain size and composition. Note: To simplify description, each facies is described under an 'interpretive name', although objective description and interpretation are, as far as possible, kept separate. The sediments have suffered pervasive yet generally un spectacular modification through a variety

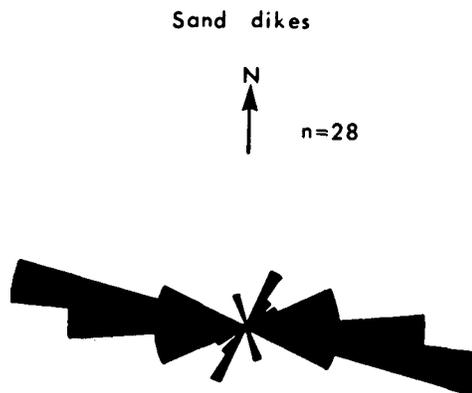
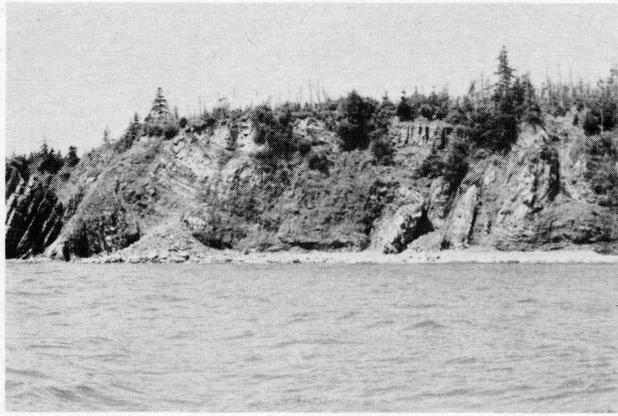


Fig. 5 - Rose diagram showing the orientation of late-stage (post-compaction) sand dikes. Dikes show a marked preferred orientation reflecting a regional tensional stress regime.



LEFT

Fig. 4 - View of cliffs (facing west) to the SW of Giffin Pond showing northward-facing folds. Beds at the extreme left are overturned.

RIGHT

Fig. 6 - Two, sharp and planar-based streamflood conglomerates of Facies 1 (base of conglomerates arrowed). Note upward gradation of conglomerates into sandstones.

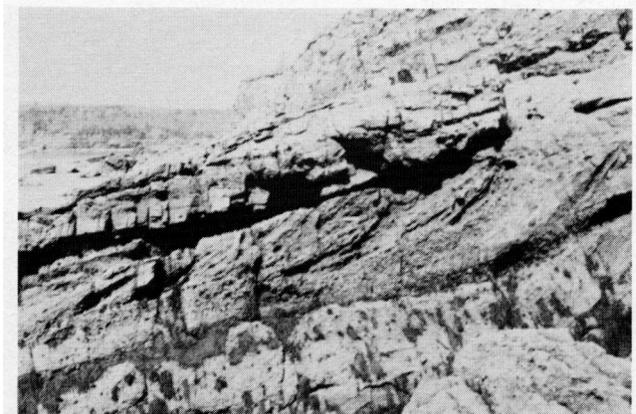


LEFT

Fig. 7 - Streamflood conglomerates showing erosion (arrowed) at base of unit.

RIGHT

Fig. 8 - Streamflood conglomerates of Facies 1 showing large-scale tabular cross-stratification.





LEFT

Fig. 9 - Sharp-based, clast-supported streamflow conglomerate showing normal grading and upward passage to coarse sandstone.

RIGHT

Fig. 10 - Lens of sandstone enclosed by conglomerates of Facies 1. Sandstone preserves small ripples which apparently developed at low stage in a shallow, water-filled depression.



LEFT

Fig. 11 - Trough-like structures preserved in medium sandstone, immediately above a streamflow conglomerate. The trough is filled with interbedded sandstone and siltstone containing *in situ* *Calamites* and small, soft-sediment slump folds (arrowed) on the flank of the depression.

of physical diagenetic processes, related to post-depositional compaction, dewatering and liquefaction (Plint and Poll 1982). Details of these changes are beyond the scope of this paper and will be presented elsewhere.

Facies 1 - Streamflood Deposits

Streamflood deposits comprise metre-bedded, clast-supported, polymictic conglomerates. Typically, conglomerates have a sharp base which may be planar (Fig. 6) or channeled (Fig. 7). Clasts range up to 250 mm in diameter. Mean roundness is around 0.5-0.6 and sorting relatively poor. Conglomerates form units laterally-traceable for tens to hundreds of metres, and from 1.5 to 10 m thick. Conglomerates sometimes display large-scale tabular cross-stratification (Fig. 9) and often show normal-grading, passing upwards into sandstone or pebbly sandstones (Fig. 9). Lenses of sandstone may be present within the conglomerates and occasionally preserve small ripples (Fig. 10, cf. Rust, 1972, fig. 4). At the top of a few conglomerate units, large dune-like forms are present. The sediment filling the troughs may show small, soft-sediment (slump) folds (Fig. 11). Conglomerates comprise a wide variety of clasts which include quartz, quartzite, granite, granophyre, rhyolite, basalt, mylonite and various meta-sediments, together with intraformational siltstone and limestone pebbles and un-metamorphosed arkosic sandstones and limestones, the latter yielding, in some instances, a fauna of Windsor (Lr. Carboniferous) age (Bell 1927). A detailed consideration of this pebble suite is, however, beyond the scope of the present paper.

Interpretation

The conglomerates of facies 1 are very similar to streamflood deposits described from recent alluvial fans (Blissenbach 1954, Bull 1964) and from ancient alluvial fan deposits (Bluck 1967, McGowen and Groat 1971, Steel 1974, Steel and Wilson 1976, Heward 1978, Gloppen and Steel 1981). Stream-

flood deposits represent deposition from a medium less viscous than a mudflow, with a relatively high water:sediment ratio. The pebbles and cobbles represent a traction load, while the sand usually present in the upper part of each conglomerate unit was carried in suspension and deposited during the waning phase of the flood (Bluck 1965, Heward 1978). Streamflood deposits are laid down both in and beyond the margins of large channels on the upper parts of alluvial fans (Bluck 1967, Steel and Wilson 1975).

Facies 2 - Braided River Deposits

These sediments comprise mainly coarse and medium sand which may be granular or pebbly. Pebbles, which seldom exceed a few centimetres in diameter, are typically well-segregated, forming distinct layers, interbedded with pebble-free sand (Fig. 12). Decimetre-scale trough cross-bedding is the most common primary sedimentary structure and is often associated with horizontal lamination. Sandstone beds may be either tabular or lenticular, and range up to 8 m thick. Tabular sandstones have a sharp, planar base, often with a pebble lag, and may be traced laterally for many tens or even hundreds of metres with little variation in thickness (Fig. 13). Locally, however, tabular sandstones thicken to form lenticular channelized masses, tens of metres wide (Fig. 14). The walls of channels range from gently inclined (Fig. 15) to near vertical (Fig. 16) and may be stepped, reflecting differential erosion of the underlying beds (Fig. 17). Sandstones may show an upward-fining, upward-coarsening or no obvious pattern. Channelized sandstones are usually trough cross-bedded and contain pebble-rich pockets which usually are richer in quartzose pebbles than streamflood conglomerates.

Interpretation

These sediments are very closely comparable to braided stream deposits, such as those described by Steel (1974) and Wilson (1980). Relative to streamflood

conglomerates, they are finer grained, better sorted and tend to have a more complex internal structure. Abundant cross-bedding indicates turbulent flow while horizontal lamination may have formed under upper flow-regime conditions. Abrupt lateral changes in grain size with pebble-filled pockets suggest local scouring and winnowing of fines.

On rare occasions (eg. Section 3, 76 m), channelized sandstones contain only intraformational limestone pebbles derived through reworking of caliche nodules (Facies 5). The absence of exotic clasts in these unusual sandstones suggests that some channels were headed on the fan surface and not supplied directly from the fan head (cf. Denny 1965, Allen and Williams 1979).

Laterally-extensive, tabular sandstones may be interpreted as the deposits of relatively shallow, perhaps ephemeral channels flowing on the lower part of the fan surface. Intermittent flow and unstable sandy banks permitted rapid lateral migration of the channels and the deposition of relatively thin yet laterally-extensive sandstone bodies (cf. Bluck 1967, conglomerate 'c'; Steel 1974, facies D1).

Channelized sandstones tend to occur in association with conglomerates in the upper part of the formation (upper Section 4, Fig. 3) whereas tabular sandstones are more common in the lower part of the formation, dominated by interchannel and interlobe deposits (Lr. Section 3, Fig. 18). In view of this,

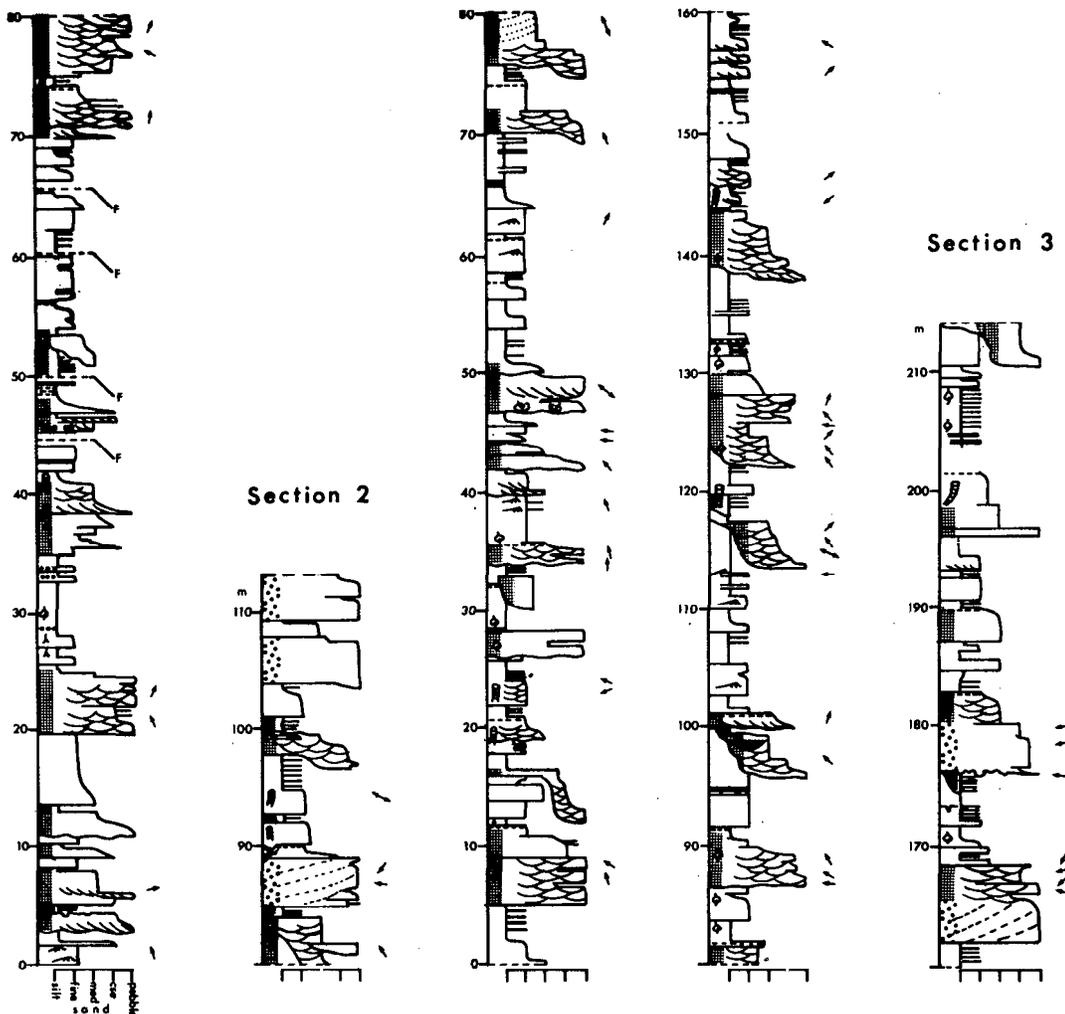
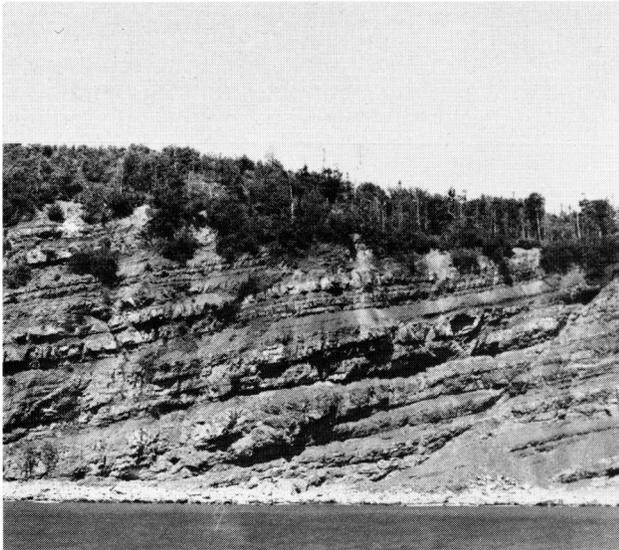


Fig. 18 - Stratigraphic sections 2 and 3, measured to the east and west of Tynemouth Creek.

RIGHT

Fig. 12 - Bedded pebbly sandstones of Facies 2 (braided river). Note plane lamination, cross-bedding and pebbly lenses.

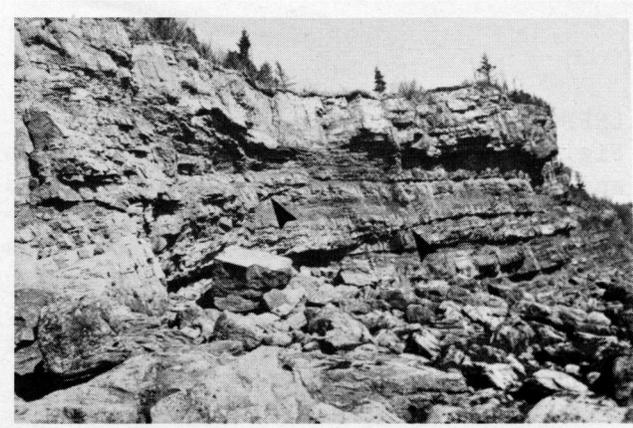
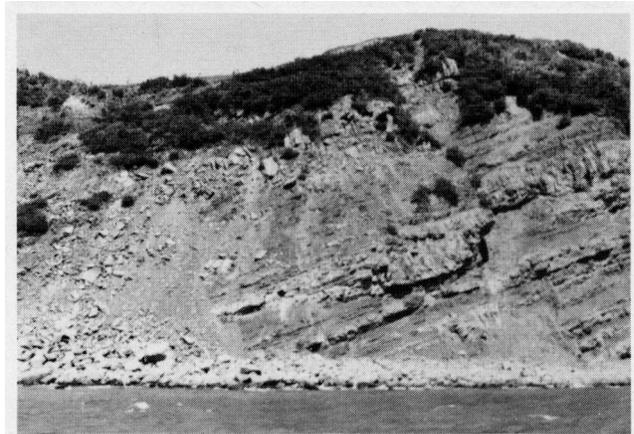


LEFT

Fig. 13 - Coastal exposure showing high lateral continuity of tabular sandstones of Facies 2.

RIGHT

Fig. 14 - Coastal exposure showing abrupt thickening of a tabular sandstone into a deeply-incised channel sandbody.



LEFT

Fig. 15 - Low-angle erosion - surface at the base of a channel filled with sandstones of Facies 2.

RIGHT

Fig. 16 - Steep-walled and sharp-based channel, filled with Facies 2 sandstones, incised into interchannel sediments of Facies 5.

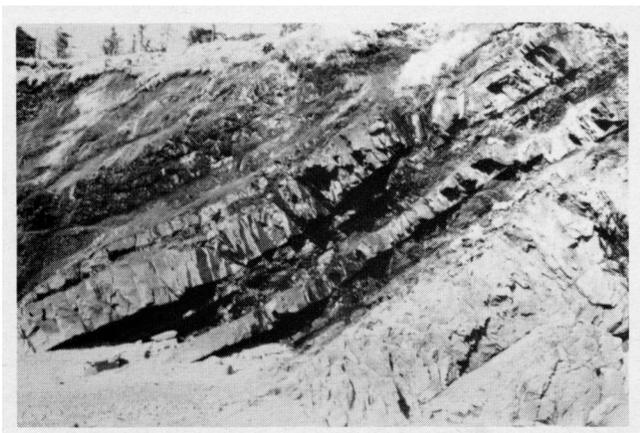


LEFT

Fig. 17 - Small channel, filled with Facies 2 sandstones, showing rapid lateral thinning (4 m to 0 m over 6 m horizontally) and stepped profile of channel wall.

RIGHT

Fig. 20 - Thick channel sandstone (base at 105 m, section 1) underlain by thick sequence of red, interchannel siltstones and fine sandstones of Facies 5, containing thin limestones of Facies 6 near the base.



LEFT

Fig. 21 - Interbedded grey siltstones and tabular, sharp-based and graded sandstones (72-80 m, section 1). Sandstones are interpreted as turbidites emplaced in an abandoned channel during floods. The upper part of the massive, channel sandstone is seen in lower right corner of picture.

it seems likely that channelized sandstones developed on higher, more proximal parts of the alluvial fan than did tabular sandstones (cf. Bull 1972). In this position, gradients would be higher and the erosive capacity of streams greater. Channel deepening may have been initiated by periodic tectonic uplift of the fan, leading to a rejuvenation of stream profiles, causing channels to incise into their own alluvium (Blissenbach 1954, Bull 1964). The steep walls of some channels resemble those of wadis and suggest rapid channel-bank erosion and subsequent infilling. Deposition of tabular sandstones may, therefore, have been lateral to major channels during flood stage, non-channelized overbank flow, or distal to such channels, beyond the point of channel incision where flow expanded into a number of shallow, anastomosing and laterally-migrating channels (cf. Bull 1972, Steel 1974).

Facies 3 - Meandering River Deposits

Some of the lowest beds of the Tynemouth Creek Formation are visible between Giffin Pond and Rogers Head (Figs. 2 & 19). The sediments of this section are distinct from those exposed at higher levels in the formation. They consist of yellow or grey, medium to coarse, granular sandstones which form units up to 30 m thick, interbedded with thick units of red siltstone (Fig. 20). Layers of small pebbles, both extra-formational (mainly quartzose) and intraformational (limestones and calcareous sandstones) are present at intervals. Four major sandstones are identified in this section. Each has a markedly erosive base which may cut down as much as 5 m. A pebble lag is usually present at or near the base but otherwise there is no orderly grain size change within each sandstone unit. Large scale trough and tabular cross-bedding are the principal sedimentary structures, while ball and pillow structure is also present at several horizons. Large logs of wood and smaller plant fragments are common throughout. At 22 m and 40 m in section 1 (Fig. 19), major sandstones are

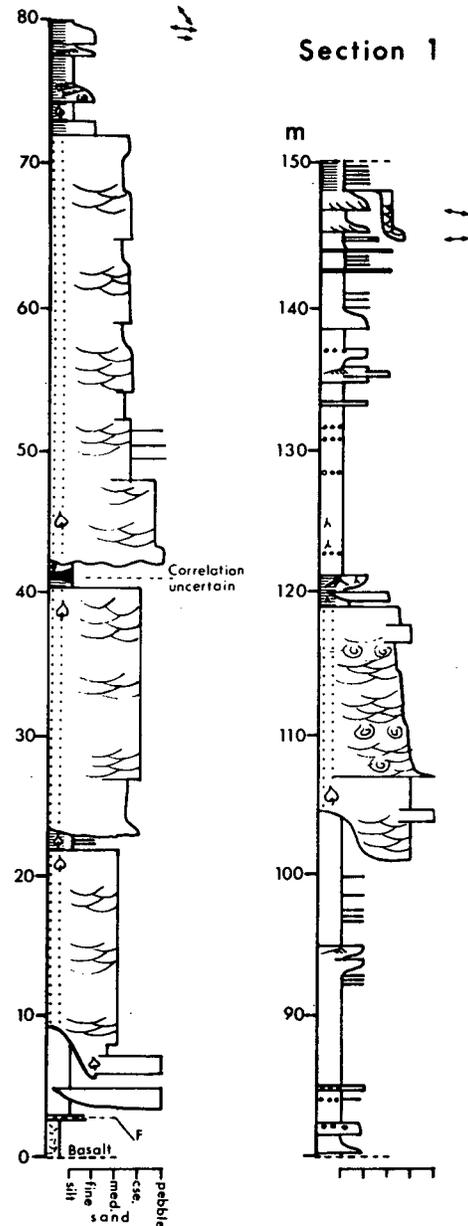


Fig. 19 - Stratigraphic section 1 measured between Giffin Pond and Rogers Head. Basalts are thrust over the overturned sediments.

separated by interbedded fine grey sandstones and carbonaceous siltstones, and at 41 m, a lenticular, allochthonous coal is present. At 72 m, medium-coarse sandstones are abruptly overlain by metre-bedded fine grey sandstones and laminated siltstones (Fig. 21) which persist to 80 m. These sandstones are graded and have a sharp base upon which small flute and groove-casts are preserved. Ripples, climbing ripples,

parallel-lamination and ball and pillow structure can be seen. Plant debris is common in both the sandstones and interbedded siltstones.

Interpretation

The sediments between 5m and 80 m in section 1 are interpreted as the point-bar deposits of major meandering rivers. The thickness, grain size and sedimentary structures suggest relatively deep channels with powerful currents. The fine-grained sediments at 22 m and 40 m are interpreted as abandoned channel, levee or swale deposits. Sandstones were introduced during flooding and mud settled out during intervening periods. In this low-lying, waterlogged environment, drifted vegetable matter accumulated to form the coal at 41 m.

The sediments between 72 and 80 m were probably deposited in an abandoned channel to which floods periodically introduced pulses of sediment. The sharp-based sandstones in this interval have many features typical of turbidites and it is possible that flood-generated density currents were responsible for their formation. The abrupt change in the sediments at 72 m (Fig. 19) suggests rapid abandonment of the channel, perhaps through 'neck' cut-off (Allen 1965). Above 80 m, there is a rapid change from grey to red, purple and green siltstones (Facies 5), which represent flood-plain environments.

A fourth channel sandstone, similar in lithology to those below occurs between 101 and 119 m in section 1 (Fig. 19). It is capped by 3 m of grey sandy siltstone which encloses lenses of medium sandstone and is penetrated by abundant *Stigmara* and other smaller roots. These sediments grade up into structureless red and grey siltstones with calcareous nodules which are of interchannel facies 5 and lacustrine facies 6. The sediments between 119 and 122 m are interpreted as levee deposits laid down adjacent to a meandering river. Levee deposits commonly contain plant roots (Fisk 1944, Coleman 1969, Ray 1976).

Facies 4 - Levee and Channel Plug Deposits

These very distinctive sediments comprise centimetre bedded fine sandstone and siltstone (Fig. 22). Sandstones are usually between 1 and 5 cm thick and have a sharp, slightly erosive base and gradational top. They may be structureless, ripple or plane-laminated. The interbedded siltstones are structureless and usually grey. Numerous sandstone stem-casts of *Calamites* are typical of this facies. The stems are often many tens of centimetres long, oriented approximately normal to bedding and are evidently in growth position (Fig. 23). This facies always occurs in close association with channel sandstones. Usually it overlies the sandstone with a gradational contact (eg. Section 3, 118-120 m, Section 4, 367-369.5 m). Occasionally however, lenticular bodies of Facies 4 are either enclosed within a channel sandstone or conglomerate (eg. section 3, 98 m, where a channel-shaped lens is 11 m wide and 1.7 m thick, section 4, 567-568 m, 573-577 m, Fig. 24) or lie immediately below and are erosively overlain by channel deposits (eg. section 2, 50-53 m, section 3, 174-176 m, Fig. 25).

Interpretation

When Facies 4 gradationally overlies channel sandstones, it most probably represents a levee or swale environment of which thinly-interbedded sandstones and siltstones are typical (Fisk 1944, Jahns 1947, Schumm and Lichty 1963, Allen 1965, Jackson 1976, Ray 1976). Each sandstone-siltstone couplet represents a flood event. A levee interpretation is strengthened by the occasional presence of slumped blocks of Facies 4 within channel sandstones of Facies 2 (Fig. 26).

Lenticular units of Facies 4, occurring above, within or below coarse-grained channel deposits are best interpreted as the fillings of abandoned channels. As with levees, deposition took place mainly during floods. The abundance of *in situ Calamites* indicates

favorable growth conditions, and in particular suggests a high ground-water table. The evidence suggests that growth of the plants kept pace with slow and relatively low-energy sedimentation for many years, during which the lower parts of the plant stems were buried to a depth of a metre or more.

When *Calamites*-bearing units of Facies 4 are abruptly overlain by massive channel or sheetflood sandstones of facies 2 or 5, *Calamites* stems often project into the massive sandstones for up to 50 cms (Fig. 23). This suggests that stands of plants were eventually overwhelmed by a rapid influx of sediment and that the higher portions of the stem were destroyed either by breakage or decay.

Facies 5 - Interchannel and Distal Fan Deposits

Interchannel sediments are characterized by a red colour, fine grain size and laterally-extensive beds (Fig. 27). Sediments consist of red siltstone which sometimes contains rootlets and small calcium carbonate nodules, interbedded with fine sandstone. Bedding may be on a millimetre, centimetre or decimetre scale, the latter being the most common. Sandstones are often silty and appear massive although ripples or cross-bedding are sometimes visible. Significant channeling is absent. Decimetre-bedded sandstones are usually sharp-based with tops gradational to siltstone. Quite commonly, upright *Calamites* stem casts are present in the lower parts of these sandstones (Fig. 23).

Well-developed thickening-up sequences are sometimes seen, the lowest beds of which may be grey and enclose a laminated carbonaceous siltstone or very thin coal (Fig. 28). Thickening-up sequences may be overlain by sandstones of Facies 2.

Paleosols are a distinctive component of this facies. They are usually structureless and characterized by a bleached, pale grey or green colour. Paleo-

sols are most commonly developed on the top of Facies 2 sandstones (eg. section 2, 74 m; section 3, 12 m, 21 m, 445 m, etc.) and usually have a well-lithified, irregular top surface, often pitted by molds of *Calamites* stems and small root-tubes (Fig. 29). On occasion, they are overlain by a very thin coal.

In other instances, a paleosol may be developed in a siltstone at the top of an upward-fining sequence (eg. section 2, 49 m; section 4, 507 m; 514 m). In exceptionally thick and well-developed examples (eg. section 4, 514 m), long, green-coloured 'tubes' (roots? or burrows?, Allen 1974) penetrate red siltstone to a depth of over 1 m (Fig. 30).

Interpretation

Sediments of Facies 5 are comparable to interchannel and distal fan sediments described from the Devonian of Scotland (Wilson 1980) and the Upper Carboniferous of Spain (Heward 1978). Siltstones clearly represent a low-energy environment that may have been either lateral or distal to channels, in which deposition from suspension occurred during periods of flooding. The interbedded sandstones are interpreted as sheetflood deposits (McGee 1897, Davis 1938, Blissenbach 1954, Heward 1978, Tunbridge 1981). The thickness of each sandstone sheet probably reflects both the distance from the source area and the magnitude of individual floods. The common occurrence of *in situ Calamites*, particularly in the thicker and often massive sheet sandstones suggests a very high instantaneous rate of sedimentation. Thickening-upward sequences may be interpreted as the result of fan lobe progradation, during which progressively greater volumes of sediment were supplied to the area fronting the lobe (Heward 1978).

Paleosols developed in vegetated areas when rates of erosion and sedimentation were very low and pedogenic processes were able to modify the sediment. The common occurrence of paleosols as cappings to sheetflood and, more commonly, channel sandstones (Facies 2),

probably reflects the construction and eventual abandonment of a fan lobe. This localized sedimentation resulted in both slight topographic elevation, and improved drainage. The former condition would tend to divert subsequent flows into adjacent, low-lying areas, thus reducing the sedimentation rate on the lobe surface, providing a stable environment for plant growth. Improved drainage would promote leaching and the development of an illuviated soil profile. The scarcity of coals above paleosols suggests that either vegetation was insufficiently luxuriant for coal genesis, or, perhaps more likely, free drainage and oxidation destroyed much of the vegetable matter before significant accumulation could occur. The grey or green colour of paleosols suggests the presence of reduced iron compounds, the genesis of which was probably related to bacterial activity in the presence of organic matter.

Paleosols developed in siltstones are similarly indicative of low sedimentation rates and probably formed on long-abandoned sectors of the fan, far from active distributary channels.

Calcite nodules are present in siltstones of this facies (eg. section 4, 176 m) but are rare in those parts of the sequence dominated by Facies 1 and 2 (conglomerates and sandstones). Only in the thick siltstone sequences of Section 1 are these nodules common (eg. section 1, 80-85 m, 128-137 m). Calcite nodules are common in soils that are subject to strong, seasonal surface evaporation leading to carbonate supersaturation and subsequent precipitation within the soil profile (Reeves 1970).

The nodules in Facies 5 are comparable to those in Devonian alluvial sediments (Friend and Moddy-Stuart 1970) which were thought to represent a well-drained soil and are generally considered to be an early form of caliche (Gile et al. 1966, Aristarain 1971, Allen 1974, Wilson 1980). The ideal climate for caliche formation is neither arid nor humid, the essential condition being one of clearly separate wet and hot, dry seasons (Reeves 1970). Such a

seasonal distribution of rainfall may be reflected in the Tynemouth Creek Formation in the overall pulsatory or ephemeral style of sedimentation. The relative scarcity of nodules in siltstones interbedded with Facies 1 and 2 may, in large part reflect inhibition by a relatively high sedimentation rate (Leeder 1975) on the more proximal part of the fan.

Facies 6 - Bioclastic Limestones

Bioclastic limestones are a rare but distinctive component of the Tynemouth Creek Formation. Three principal occurrences of limestone are known and two distinct types, A and B are recognized.

Type A, Shelly Limestone - In section 1, two limestones are present at 124 and 128 m. Both examples are about 5 cm thick, nodular and enclosed in red siltstone. These two limestones have a micritic matrix and are dominated by a fauna of ostracodes, the valves of which are often articulated and may have a geopetal fill, together with common *Spirorbis* tubes and rare gastropods. Burrows containing faecal pellets replaced by sparry calcite are also seen (Fig. 31).

In section 3, between 65-67 m, several 2 - 5 cm thick yellowish-weathering dark, ?organic-rich shelly limestones are present towards the top of a relatively thick sequence of distal fan siltstones and sandstones (Facies 5). The fauna is dominated by small ostracodes which have a distinctive ribbed shell ornament, a few small turreted gastropods are also present.

Type B, Algal Limestone - In section 2, at 99 m a nodular, sandy limestone up to 15 cm thick directly overlies a sandstone of Facies 2. This limestone is apparently unique in the Tynemouth Creek Formation and consists of laminated algal plates which may show an oncolitic structure. These are distributed through a sandy matrix which also contains rare, ostracode and gastropod fragments (Fig. 32).

RIGHT

Fig. 22 - Thinly-interbedded siltstone and sandstone of Facies 4. Sandstones are sharp and slightly erosive-based and grade up into siltstone. They are interpreted as levee sediments and overlie massive channel sandstones of Facies 2, seen in lower right.

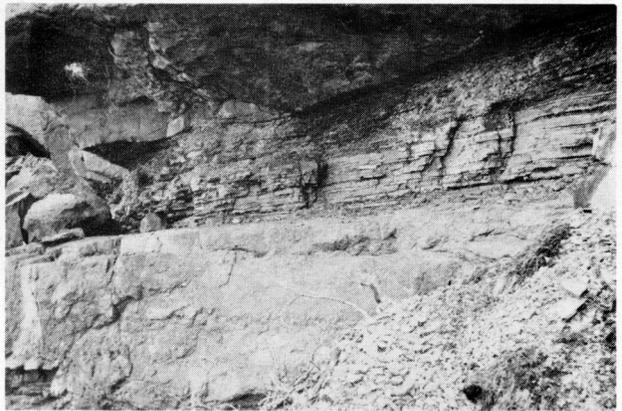


LEFT

Fig. 23 - Thin-bedded sediments of Facies 4, containing *in situ* *Calamites* (arrowed), sharply overlain by tabular sandstone of sheetflood origin. *Calamites* project up into the sheetflood sandstone and were rapidly buried by the flood-borne sediment.

RIGHT

Fig. 24 - Facies 4 interbedded with streamflood conglomerates. In this example, the thin-bedded sediments are interpreted as the fill of an abandoned channel.



LEFT

Fig. 25 - Erosive-based lens of Facies 4, erosively overlain by conglomerates of Facies 1 and interpreted as an abandoned channel-fill.

RIGHT

Fig. 26 - Slumped block of Facies 4 enclosed within sandstones of Facies 2. Note sharp, curved base to slumped block (arrow). Facies 4 interpreted as levee sediments which subsequently slumped into the channel.

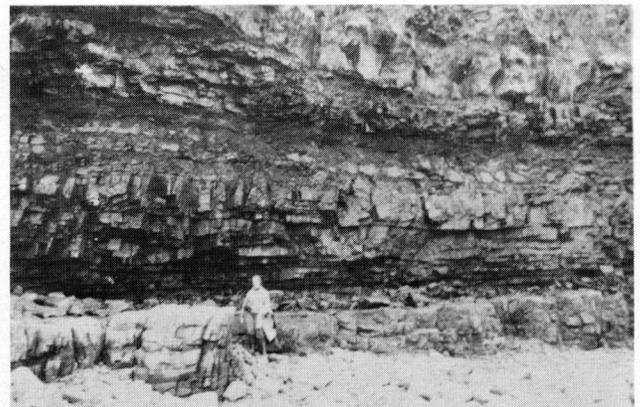


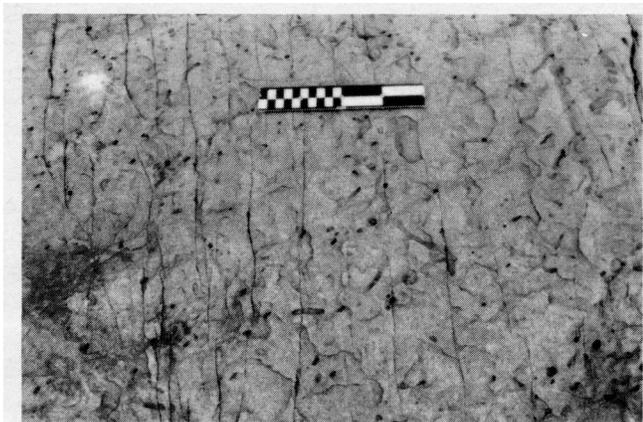
LEFT

Fig. 27 - Facies 5, interchannel sediments showing high lateral continuity of sheet sandstones, interbedded with red siltstones.

RIGHT

Fig. 28 - Thickening-upward sequence in Facies 5. Sequence begins at a very thin coal (at level of figures waist) overlain by progressively thicker-bedded fine and medium sandstones.





LEFT

Fig. 29 - View of top surface of Facies 2 sandstone showing numerous root tubes within a bleached, bioturbated palaeosol.

RIGHT

Fig. 30 - Thick red siltstone with well-developed, green-stained root tubes, erosively overlain by a channel sandstone of Facies 2.

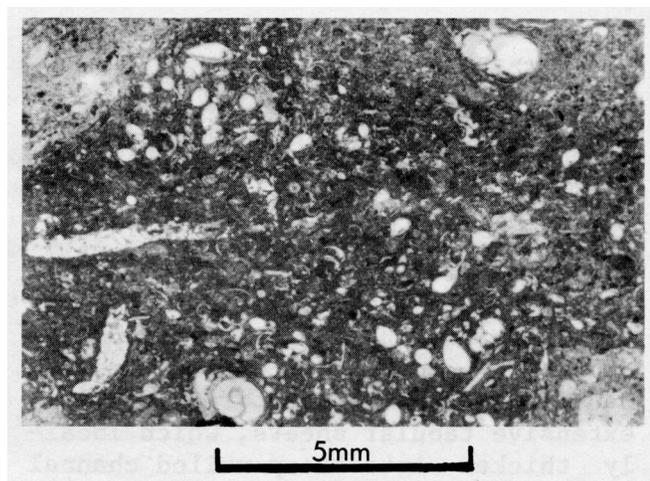
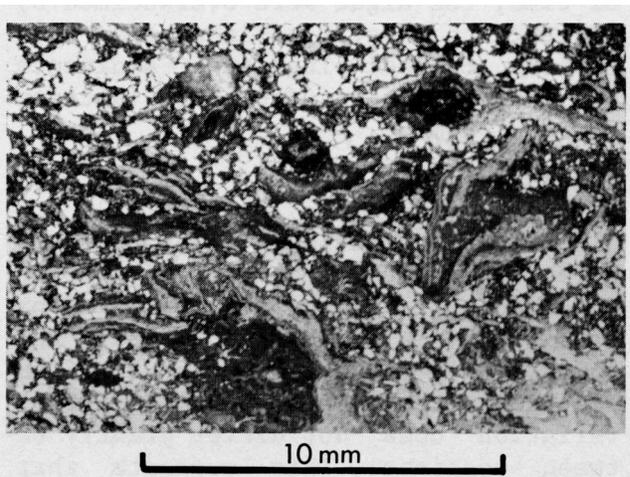


Fig. 31 - Bioclastic limestone of Facies 6 (Section 1, 123 m) composed of numerous articulated ostracodes, small gastropods and bivalves. Note pellet-filled burrows.

Fig. 32 - Algal limestone of Facies 6 (Section 2, 99 m). Note laminated calcareous plates constructed by Phylloid algae in a matrix of angular sand grains.



Interpretation - Limestones comparable to Type A have been described from Devonian and Carboniferous alluvial sequences (Friend and Moody-Stuart 1970, Heward 1978). The former described marlstones with a micritic matrix, thought to be of charophyte origin, containing myriad ostracode valves. These marlstones were interpreted as the deposits of flood plain lakes that were starved of clastic sediment. Both examples of Type A limestones occur in thick units of interchannel distan fan sediments (Facies 5) and were deposited in shallow freshwater lakes existing in areas that, for several tens of years lacked an appreciable clastic input, during which subsidence depressed the surface below the water table, permitting colonization by an algal-grazing fauna.

The laminated algal plates of Type B limestone may be ascribed to a species of Phylloid algae, comparable examples being known from the Permian (Flügel 1977, pl. 1) and Carboniferous (Wray 1977, fig. 157). The single example of Type B in the Tynemouth Creek Formation appears to have developed in an abandoned but water-filled channel which, after abandonment, received no clastic input and colonization by calcareous algae took place. The disappearance of ostracodes and gastropods in the upper part of the limestone suggests an increasingly hostile environment and perhaps reflects stagnant, anoxic conditions. After a period of time, the algae were overwhelmed by a return to clastic sedimentation when typical channel-plug/levee sediments of Facies 4 were deposited (section 2, 100-101 m).

Palaeocurrents

Wherever possible, palaeocurrents were measured throughout the Tynemouth Creek Formation, and their directions are shown in Fig. 33. Although the formation is exposed over about 16 km of coast, the range of palaeocurrent variation does not differ greatly between sections. This suggests that

the Tynemouth Creek Formation represents a sector of a large fan, having its apex some distance to the south-east of the study area. The palaeocurrent pattern is closely comparable to that measured in other ancient alluvial fan deposits (cf. Williams 1966; Howard 1966; Nilsen 1968, 1969; Collinson 1972; Morton 1979; Wilson 1980).

Summary of Conclusions

The Tynemouth Creek Formation of southern New Brunswick is an alluvial sequence of Lower Pennsylvanian (probably Westphalian B) age. It locally overlies basalts of uncertain (?Precambrian, ?Devonian) age. Local patches of Precambrian rocks are exposed inland suggesting a basal landscape unconformity. In the main, however, the formation is fault-bounded. The Tynemouth Creek Formation has a minimum thickness of about 800 m, and is probably considerably thicker. The formation was deposited in an alluvial fan piedmont setting and shows an overall upward-coarsening.

Six principal sedimentary facies are recognized. Coarse polymict stream-flood conglomerates (Facies 1) predominate at the top of the sequence and represent the most proximal, near-source deposits preserved in the area. The immaturity and size of the clasts suggests a source only a few kilometres distant. Braided river deposits (Facies 2) comprise coarse to medium pebbly sandstone which form laterally-extensive tabular sheets, which locally thicken into steep-walled channel sandbodies up to 8 m thick. Tabular sandstones were deposited in shallow unstable channels that continually migrated over the fan surface, generating thin, tabular sandbodies. Channelized sandstones which are more common in the upper part of the fan sequence, record localized incision by (?major) channels, perhaps related to tectonic rejuvenation of streams on the upper part of the fan.

In the lowest part of the formation, coarse, erosive-based sandstones (Facies

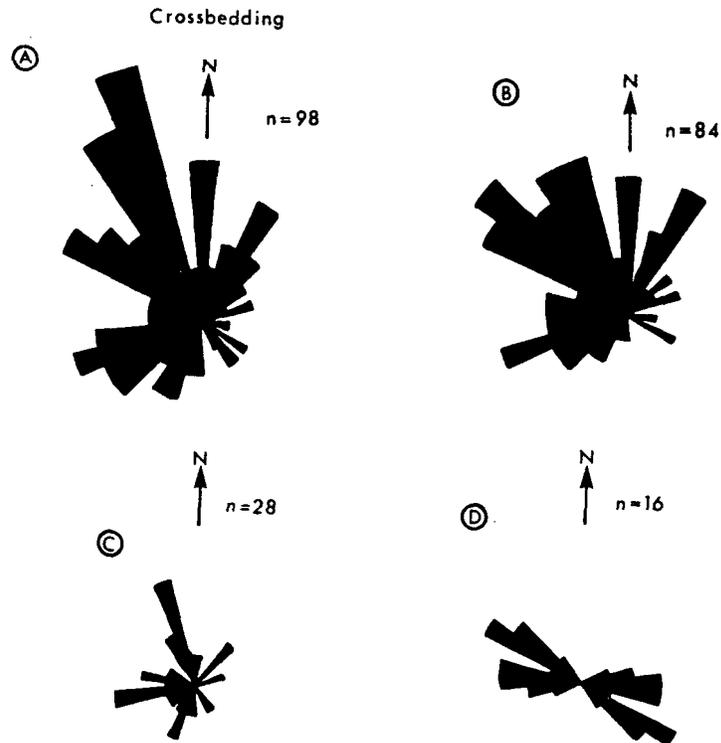


Fig. 33 - Palaeocurrent rose diagram for Tynemouth Creek Formation. Fig. A shows all cross-bedding directions. B shows Sections 2 and 3, all readings. C shows Section 4, all readings. D shows all bi-directional readings (grooves, channels, etc.). Note unimodal distribution with vector mean directed towards the north-west.

ies 3), 15-30 m thick alternate with interchannel siltstones. These thick-bedded, relatively massive sandstones are quite distinct from braided-river sediments of Facies 2 and are interpreted as point-bar deposits of major meandering rivers. Abandoned channel, levee and crevasse splay deposits are associated with these thick sandstones and lend support to a meandering river interpretation. These major rivers are thought to have flowed eastward on a low-lying alluvial plain lying to the north of a basin-margin alluvial fan.

Braided river and streamflood deposits are often associated with relatively thin units of thinly-bedded sandstone and siltstone (Facies 4) which usually contain *in situ* *Calamites* stems. These deposits represent proximal overbank/levee and abandoned channel environments, all of which were favourable sites for the growth of dense stands of *Calamites*.

In interchannel and distal fan areas, red siltstones and tabular fine sandstones (Facies 5) were deposited. Siltstones may have been deposited from floodwaters or as wind-blown dust while tabular sandstones were the result of sheet flooding. Thickening-up sequences of siltstone and sandstone are interpreted as prograding fan lobes. Siltstones, particularly those associated with meandering river sandstones contain small calcite nodules which are interpreted as immature caliche and suggest a distinctly seasonal climate. Rooted palaeosols are a common feature of interchannel sediments. Many developed on the top of braided river sandstones after channel abandonment. The slight topographic elevation of the channel area inhibited further sedimentation promoting vegetation growth and soil development.

Thin bioclastic (ostracode/gastropod/*Spirorbis*) limestones (Facies 6)

are occasionally present in thick siltstone sequences and represent alluvial-plain lakes that developed in areas starved of clastic sediment. A single algal limestone was identified and probably formed in an abandoned channel of a braided river.

Palaeocurrents have a unimodal, fan-like distribution with a mean flow towards the north-west. This pattern compares closely with that of other ancient alluvial fan sequences.

Regional considerations suggest that the Tynemouth Creek Formation was deposited on a major alluvial fan that built northward from the southern, ?fault-bounded margin of the Cumberland Basin. Rapid subsidence of this basin occurred during early Lower Pennsylvanian times, probably in response to an extensional tectonic regime, perhaps associated with wrench-faulting on the Cobequid Fault. Preliminary studies of pebble provenance indicate a possible source region in the western Cobequid Highlands (H. Donohoe, pers. com.).

The upward coarsening of the Tynemouth Creek Formation is interpreted as evidence of source-area uplift through progressively accelerating basin-margin faulting (cf. Steel and Wilson 1975), resulting in a progradation of the fan causing deposition of progressively coarser, upper-fan gravels over finer-grained, lower-fan sediments.

In general, sedimentation on the fan seems to have been episodic with stream-floods, sheetfloods and braided rivers transporting and depositing sediment only during relatively short-lived periods of flood runoff. Braided rivers, perhaps sourced from springs may have carried water at low stage for longer periods but effected little sediment transport.

The sedimentary evidence as a whole (sediment transport processes, calcrites, redbeds) suggests a seasonal climate of alternating hot, dry and rainy periods (Gile et al. 1966, Walker 1967, Reeves 1970, Woodrow et al. 1973).

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