PALEOENVIRONMENT OF TRIASSIC DINOSAURS AND OTHER TETRAPODS AT CARRS BROOK, NOVA SCOTIA

BY:NATALIE O'TOOLE

Abstract

A section of Triassic strata is exposed at Carrs Brook, on the northern margin of the Minas Subbasin, Colchester County, Nova Scotia. A detailed map of the Carrs Brook section was made using a plane table survey. The 200 - 300 m long portion of the Triassic section consists of three facies. Facies 1 consists of coarse, red sandstone with and without mudstone intraclasts. Facies 2 consists of grey conglomerate and sandstone with mudstone intraclasts. Facies 3 consists of fine, red sandstone with and without mudstone intraclasts. The sedimentary features found in these facies include: erosional channel bases, large-scale trough cross-beds, small-scale cross-beds, iron-manganese concretions, calcite concretions, wavy bedding, convolute lamination.

The paleoenvironment consisted of a braided river system in a semi-arid environment. The grey conglomerate and sandstone formed in the river channels, while the fine red sandstone formed eolian dunes which were blown into the river system. The coarse, red sandstone first formed part of the river system, and was then turned into an eolian deposit by the wind. The evidence for this is the lack of matrix in the thin section analysis of the fine, red sandstone facies.

Fossilized vertebrate and plant material was found only in the grey conglomerate and sandstone of Facies 2. Sparse, fragmented bone material of several groups of dinosaurs and other tetrapods were found. There is no evidence in the Carrs Brook section that large herds were overwhelmed by flows. It seems more probable that the tetrapods came to the river to use it as a waterhole and died, after which their bones were washed down the river as fragmented pieces.

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Chapter 1: Introduction

1.0 Purpose of the study:

The purpose of the thesis is to measure and describe a 200 to 300m long cliff section at Carrs Brook, Nova Scotia. A detailed stratigraphic section has not previously been made of these strata. Of primary interest is the interpretation of the paleoenvironmental setting of the Triassic dinosaurs at Carrs Brook. This information will aid in the construction of accurate dinosaur displays at the museum.

There has been previous work done on the entire cliff section at Carrs Brook on approximately 65 meters of strata (Skilliter, 1996). The present thesis only encompasses approximately 20 meters of strata at Carrs Brook. Skilliter divided the cliff section into eight different sandstone, shale, and mudstone facies, including: SGt, SG, SGm, St, Stm, Sa, Sh, and M.

Facies SGt consists of trough cross-bedded units of sandstone that contain gravel. The majority of the cross beds have a trough geometry. Planar and trough cross-beds are found in one unit of the facies. Trough cross-bedded sandstone of red, orange, and grey colouring with minor conglomerate to trough cross-bedded gravel are units within this facies. The facies contains fining- and coarsening- upward units. The unit thickness ranges from 0.35 to 3.43 meters (Skilliter, 1996).

Facies SG consists of medium to very coarse grained, massive sandstone which contains rounded quartz pebbles. The unit varies in colour from red, yellowish-grey, to grey. The thickness of the units ranges from 0.11 to 2.56 meters. This facies contains abundant carbonate cement (Skilliter, 1996).

Facies SGm consists of unstratified sandstone, which contains rounded quartz pebbles

Facies SGm consists of unstratified sandstone, which contains rounded quartz pebbles and abundant mudchips. Units of this facies range from red and reddish-grey to orange, and vary from very fine-grained to coarse-grained sandstone. The thickness of the units ranges from 0.15 to 0.80 meters. As well, olive-green reduction spheres in the sandstone are found throughout this facies. Carbonate cement also occurs (Skilliter, 1996).

Facies St is dominated by trough cross beds. The colour varies from grey, orange, red, to yellowish-grey, and olive green reduction spheres occur in some units. The grain size is fine to coarse. The unit thickness ranges from 0.05 to 5.7 meters. The units contain rare parallel laminations. Layers of carbonate cement also occur (Skilliter, 1996).

Facies Stm consists of cross-bedded sandstone with mudchips. Colour varies from red to orange. The sandstones are fine to coarse-grained sand. Most units are parallel laminations, and some of the mudchips are surrounded by olive-green reduction patches. Some units contain round carbonate nodules. The thickness of the units varies from 0.22 to 3.2 meters (Skilliter, 1996).

Planar, cross-bedded sandstone units describe Facies Sa. The sandstone is red to grey in colour, and is medium to coarse-grained. The units range in thickness from 0.41 to 1.40 meters. The units contain centimetre-sized rounded mudclasts. One unit contains large pyrolusite nodules. The top of this unit contains centimetre-sized round carbonate nodules. This facies also has an abundance of carbonate cement (Skilliter, 1996).

Facies Sh contains parallel-laminated sandstone, ranging in colour from red to reddish-brown, to orange. The units consist of fine to coarse-grained sandstone, and range in thickness from 0.10 to 1.57 meters. Some units contain climbing ripples, while others contain abundant red, centimetre-sized mudchips which are surrounded by olive-green reduction patches (Skilliter, 1996).

Facies M consists of minor units of massive red to brown mudstone, ranging in thickness from 0.05 to 0.23 meters. Within the red mudstone, there are layers of olive-green mudstone (Skilliter, 1996).

1.1 **Fundy Group - Wolfville Formation**

Clastic deposits comprising red claystone, siltstone, sandstone and conglomerate form the bulk of Triassic sedimentary rocks of the Maritime Provinces. The sedimentary rocks display abrupt lateral changes in stratification, composition, texture, and thickness of strata. Coarse-grained sedimentary rocks dominate near the basin margin, while finer-grained clastic rocks are younger and dominate in the central part of the basin (Klein, 1962). The thesis deals with part of the basin margin region of the Fundy Basin at Carrs Brook, Nova Scotia.

The Fundy Basin strata, which are part of the Newark Supergroup, underlie the Minas Basin, Annapolis Valley, and Bay of Fundy, and extend into the Gulf of Maine. They can be partitioned into five formations. The basin is one of a series of half grabens that formed along the eastern margin of North America during the Triassic/Jurassic rifting of Pangea. It lies mainly beneath the Bay of Fundy and south of the Cobequid-Chedabucto Fault System in Nova Scotia. The Fundy Basin covers an area of approximately 16,500 square kilometres (Wade et al., 1996). There were two episodes of deformation in the Mesozoic Fundy rift basin. The first extensional deformation occurred during the Middle Triassic to Early Jurassic, with low-angle boundary faults that had vertical displacements exceeding 10 km. Paleozoic compressional structures, such as strike-slip faults with normal and sinistral strike-slip components which were east trending, were reactivated, and formed the northern boundary faults of the Fundy basin. During the Early Jurassic, the second deformational episode occurred (Withjack et al., 1995).

The Fundy Basin (refer to Figure 1.1 and 1.2 (Withjack et al., 1995)) was located near the paleoequator. Due to the basin's position, the influence of the paleoclimate was very important. The main interpretation is that of a hot and semi-arid climate with seasonal heavy rainfall and a high fluvial discharge (Hubert and Mertz, 1984; Hubert and Forlenza, 1988; Wade et al., 1996). These authors suggested that the climate was semi-arid based on the eolian deposits, calcretes, paleosols, and playa lakes.

The Fundy Basin is characterized by the abundance of sedimentary features characteristic of arid depositional environments, including evaporites, and eolian dunes. In strata deposited in the deepest lakes in the Fundy Basin, there are no organic rich shales exposed, and the cumulative thickness of the exposed strata deposited in the lakes is only approximately 1 km. However, beneath the Bay of Fundy, the thickness of the strata below the present sea floor is greater than 4 km. The Fundy Basin does not closely resemble the rest of the basins that contain the Newark Supergroup in Eastern North America, in that it has no organic-rich shales exposed, and the style of cyclic deposition is different. Instead, it more closely resembles the pattern of the Argana Basin of Morocco (Olsen et al., 1989).

The Wolfville Formation in the Fundy Basin contains coarse- to- medium-grained stratified clastic rocks. The conglomerate layers within the outcrops along the northern shore of the Minas Basin consist of thick-bedded, poorly stratified, sharpstone conglomerates. Clasts were derived from the lower Paleozoic metamorphic rocks, and from the granite and sandstone from the Pennsylvanian. Clasts range in size from 2 - 35 cm in length. The Wolfville Formation contains two conglomerate facies. These are: the Hants Facies, composed of roundstone conglomerates; and the Gerrish Facies, composed of sharpstone conglomerates (Olsen et al., 1989). Many other sandstone facies also occur in the Wolfville Formation. The section of cliff at Carrs Brook consists of conglomerate included in the Hants Facies. The sandstones are coarse-to- medium grained, are reddish/brown, yellowish/brown, grey/red, and greenish/grey in colour, and are poorly sorted. They are thick and medium-bedded and contain cross-bedding. Claystone which is reddish-brown and grey/red occurs in the Hants Facies and is medium-bedded, and conchoidally fractured.

The Coldbrook Group of New Brunswick, the Meguma Group, the Kentville Formation, the Torbrook Formation, the South Mountain Granite, the Horton and Windsor Groups, and the Mabou Group are all unconformably overlain by the Wolfville Formation (Wade et al, 1996). The Wolfville Formation itself is overlain by the Blomidon Formation in Colchester County (Klein, 1962).

1.2Carr's Brook Section of Fundy Basin

The Carrs Brook rocks, which are of interest to this thesis, are unconformably overlain by older Carnian (Late Triassic) strata and are fluvial and eolian in nature. The strata at Carrs Brook are Early to early Middle Triassic and are included in the Wolfville Formation (Wade et al., 1996). The strata at Carrs Brook consist of an alternation between red eolian sandstone, red fluvial sandstone, red mudstone, and brown, calcite-cemented conglomerate with lithic clasts. The conglomerate layers contain bones and thick shelled clams (Wade et al., 1996). The bones found are from the Early to early Middle Triassic time period, and the beds are the oldest exposed strata in the Newark Supergroup. The Carrs Brook section in the Triassic formed part of an arid environment is suggested by the eolian sandstone. The sandstone is eolian because there is evidence of dunes, and terrestrial red beds. The cross-beds in the sandstone are fine-grained and were formed by wind ripples. However, the aquatic fossils lead scientists to believe that there was a perennial water environment. This may be due to a cyclically-changing climate (Olsen, 1989).

1.3Dinosaurs of the Wolfville Formation & Fundy Group

Scattered dinosaur and other tetrapod bones are found in the Wolfville Formation of the Fundy Group. Herbivorous reptiles of the *Procolophonida*e family are observed along with omnivorous *pseudosuchians* of the *Aetosauridae* family, herbivorous *rhynchocephalian*s of the family *Rhynchosauridae*, and the carnivorous *pseudosuchians* and *coelosaurian* dinosaurs. Missing from the strata are the larger fish-eating *phytosaurs* and *metoposaurid* amphibians present in later Triassic sedimentary formations (Klein, 1962). Also present are *sphenodontids*, a lizard-like group, *trithelodonts,* reptiles related to mammals, and *prosauropods* - long-necked dinosaurs with small heads whose bodies are up to four metres long (Klein, 1962).

1.4Methodology

A preliminary survey of the area was conducted to view the general area and to decide upon a 200-300 m long section of the Triassic cliffs, at Carrs Brook, Economy, N.S. to be studied. This section was selected because it was a prime dinosaur and other tetrapod bone site according to Fundy Museum staff. Then a detailed map was made of the cliff section under investigation, using a plane table survey method. Two survey stations were sited on the wave-cut platform. A series of precisely positioned points were marked on the map, corresponding to small headlands, and key outcrop points. After outcrops and cliff locations were marked on the map, the next step was to draw in the outline of the cliff and the upper and lower scarps along the beach. The accuracy of the survey was to several centimeters. There were several problems with mapping: the lateral variation of the strata was a problem; the cliff irregularities posed problems; and the dipping of the beds posed problems as well.

Next, each bedding layer was observed, and all the sedimentary features of each bed was recorded. Each bed was photographed, and a sample of each was taken. There were 22 beds in total. Each bed was drawn in its correct location on the map.

A stratigraphic column was drawn to include each bed, and then the beds were divided into three facies types. The plane table map was then digitized and produced using AutoCad. A visit was made to the Fundy Museum to view some Carrs Brook fossils in their collection and compare rock types containing fossils with the facies identified in the study area.

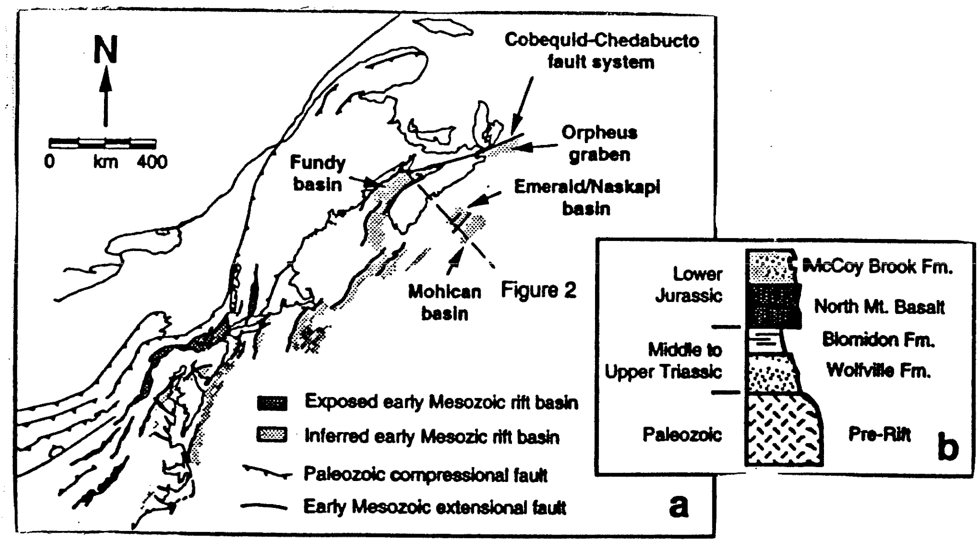


Fig.1.1 Location of the Fundy Basin in Nova Scotia

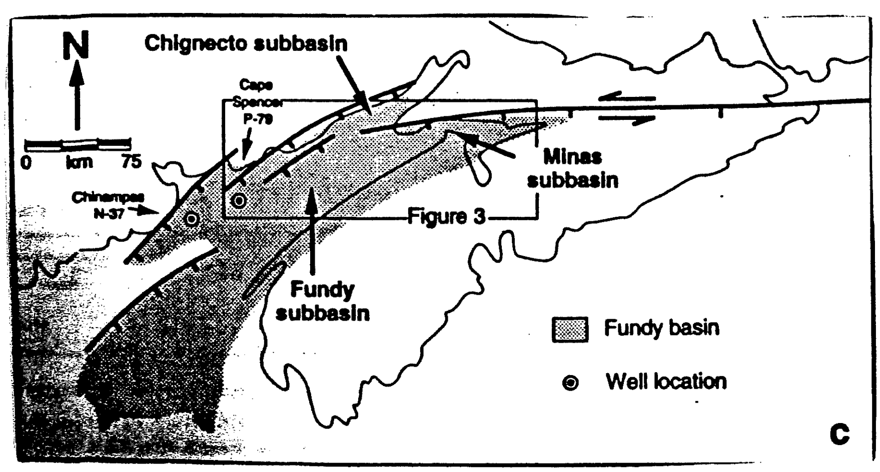


Fig.1.2 Location of the Fundy Basin and its Structural Components

Chapter 2: Sedimentary Beds of the Carrs Brook Section

Fig. 2.1 is a facies column that shows each bed in the cliff section, the facies it belongs to, and the sedimentary features found in each bed. Fig. 2.1.b shows the exact location of Carrs Brook in relation to Economy and Lower Economy. Paleocurrents are represented in Fig. 2.2.a, b, and c. Skilliter's facies are not used in this analysis because they were designed for a more general overview of the entire Carrs Brook section, whereas the facies in this thesis represent a more detailed analysis of a small area.

2.1.1Facies 1

Facies 1 consists of coarse-grained, red sandstone which can be divided into two subfacies: coarse, red sandstone; and coarse, red sandstone with mudstone intraclasts (Table 2.1., Fig. 2.3a, b).

Facies 1A consists of planar bedded, medium to coarse-grained, red sandstone. The maximum thickness of any occurrence is 2m, and the basal contacts vary from gradational and undulating to sharp and planar. The sedimentary features include large-scale, trough cross beds with thicknesses of approximately 1m, iron/ manganese concretions, and calcite concretions.

Facies 1B consists of planar bedded to unbedded, and wavy bedded, coarse-grained, red sandstone. The unit thickness is up to 1.9m, and the basal contacts are abrupt and undulating to planar, and in some areas gradual and undulating. There is also an erosional channel base below one occurrence. Sedimentary features include large-scale trough cross beds, small-scale cross beds, convolute lamination, and mudstone intraclasts typically 2cm in diameter with a maximum diameter of 10cm.

2.1.2 Facies 2

Facies 2 consists of grey conglomerate and sandstone (Table 2.1., Fig. 2.4a, b). The strata are planar bedded to unbedded, wavy, and locally lenticular. The grain size is coarse sand, grey in color. The unit thickness is up to 5.2m, and the basal contacts are abrupt and undulating to planar. The facies has an erosional channel base. Sedimentary features include large-scale, mainly trough cross beds approximately 1m in average thickness: rhizoconcretions about 2cm in long axis; mudstone intraclasts averaging 2cm in diameter with a maximum diameter of 7cm. The facies also contains dark, manganese concretions, and green patches perhaps composed of reduced Fe. Vertebrate bone fragments were found in this facies.

2.1.3Facies 3

Facies 3 consists of two subfacies: fine-grained, red sandstone; and fine-grained, red sandstone with mudstone clasts (Table 2.1., Fig. 2.5a, b).

Facies 3A consists of planar bedded to unbedded, and wavy bedded, fine, red sandstone. The unit thickness is up to 7.2m, and the basal contacts are sharp with planar to undulating surfaces. The sedimentary features include large-scale trough cross beds, small-scale cross beds, and iron/manganese concretions.

Facies 3B consists of planar bedded to unbedded, and wavy bedded, fine-grained, red sandstone. The unit thickness is up to 1.7m, and the basal contacts are either abrupt with planar to undulating surfaces. The sedimentary features include cemented zones, large-scale trough cross beds, abundant mudstone clasts, and muscovite flakes.

2.2Facies Associations

The grey conglomerate and sandstone (facies 2), and red, coarse sandstone (facies1) form the water-laid portion of the river channel fill in the Triassic-aged cliff section. The water-laid deposits were probably carried when the river was flooding or at its highest velocity or carrying capacity, and then deposited as the flow waned. This would explain why the water-laid deposits are of a coarse grain size. The red, fine sandstone (facies 3) is interpreted to form the eolian or wind-blown portion of the channel fills and adjacent floodplains, based on the absence of matrix (see Chapter 3). This portion in-fills the river channels and buried adjacent floodplains, and was deposited during times of stagnancy or low velocity in the river. When flow ceased entirely, river sands were remobilised into wind-blown dunes.

The many sedimentary features in Facies 2 must be explained.The strongly erosional channel bases below some units represents scouring below river channel fills, and erosional conditions. The scouring occurred before the sediment was deposited and reflects river base erosion. The wavy bedding was caused by small ripples, slightly undulating layering, or water escape causing some deformation. The large-scale cross- beds represent 3D dunes on the bottom, accumulating under the lower flow regime. They may indicate a steady flow for a period of time, and the dune system represents a unidirectional flow. The convolute laminae may have been caused by the current going over the top of the dunes, and deforming the layers of sediment below. There was in this case dewatering, a slump, or possibly an earthquake and the layers on the bottom were deformed at shallow depths. The mudstone clasts were formed when mud layers on bank tops and in channels were broken down into smaller pieces as the river cut into the bank.

The calcite concretions were formed under hot, dry conditions. They consist of small crystals that probably formed at or above the water table, while the cements in the sandstone (see Chapter 3) formed below the water table, probably during shallow burial. Fine crystals are less than 0.2mm in diameter, while large crystals are 0.2mm and greater in diameter. The iron/manganese concretions are common in modern soil-forming environments, and the green patches are probably a result of Fe in its reduced state. The ground water table was low, and plant roots were probably growing in the area, although they were not observed in the strata. The plants eventually died, the carbon in them decayed, and the oxygen was used up in that place where the plant died. This would have caused iron in the adjacent sediment to transform from the ferric state to the ferrous state.

This section interprets the environment of Facies 1 and 3. The fine, red sandstone is interpreted as eolian or wind-blown sand because it contains no matrix (see petrographic analysis in Chapter 3). The wind-blown dunes formed during the dry periods, with sand probably taken from the river beds. These sands were blown over the grey conglomerate and sandy channel deposits. The coarse, red sandstone is interpreted as a water-laid deposit because it contains a matrix (see Chapter 3), suggesting that it had not been subjected to winnowing of fines after deposition. The rivers brought down both the coarse and fine sand; the fine sand was blown into dunes, which were then blown into the river beds. In the next flood, the eolian sand by nature of its location, would have been mixed with the coarse, red sand, to some degree.

The environment of Facies 1 will now be interpreted. The river environment represents a unidirectional flow with a lower flow regime, as indicated by the relatively large-scale cross-beds which formed as dunes. This also indicates that there was a relatively steady flow in the river for most of the flood season.The Fe/Mn concretions indicate that there were plants growing near or in the river system. The calcite concretions suggest that the area where the river was located was semi-arid. The wavy bedding indicates that there were ripples on the river bed, and the erosional channel bases represent channel scour. The river must have been flowing fairly fast during its flood period, as suggested by convolute laminae, which may represent current drag on deposited sediment. Mudstone clasts probably accumulated on the bottom as the river cut into the bank and undermined local floodplain muds.

Facies 2 consists of the sediment transported by the flow within the river channels. There are lenses of sandstone in the grey conglomerate and sandstone facies indicating variable flow conditions. There was channel scour as indicated by the erosional channel bases. The large-scale cross-beds indicate that there were large dunes, and a steady, lower flow regime. The mudstone intraclasts indicate bank erosion. The fact that large fragments of vertebrate bones are found in these channel deposits (see Chapter 4) suggests that the water was flowing fast during the flood season in order to transport these bones downstream. My interpretations do not agree entirely with those of Skilliter who states that mudclasts could have formed when the backup stages of large floods were unable to exit through narrow basin outlets. However, I believe that the mudclasts formed in a fluvial environment with a flow drying up, and the mud that accumulated got broken down into smaller pieces as the river cut into the bank. Skilliter also suggests that the red sandstones were formed by eolian activity followed by fluvial deposition. I suggest that some of the deposits (the coarse, red sandstone) was formed by fluvial deposition.

In retrospect, it was not easy to determine whether the final deposition of Facies 1 was eolian or water-laid. I suggest that because Facies 1 has a matrix, the final deposition was in the water, with mixing with the eolian sand because the grains of Facies 1 themselves include an eolian component.

For an outcrop map of the Carrs Brook section see Enclosure 1. This map shows each bed in the 200-300m cliff section, its strike and dip, and what facies it belongs to. The facies are colour coded, where red represents red sandstone and gray represents conglomerate and gray sandstone. Small cliff-base features are shown on the map. For an accurate map showing the exact location of the 200-300m cliff line at Carrs Brook, see Enclosure 2.

2.3Facies Column

The facies column (Fig. 2.1) shows each bed in the cliff section, the facies it belongs to, and all of the sedimentary features found in each bed. It also shows the thickness of each bed and facies. Fig 2.1.b shows the exact location of Carrs Brook in relation to Economy and Lower Economy, and how to access the location of the study area.

2.4Paleoflow

Paleocurrents are represented in Figure 2.2a, b, and c, and are readings taken from the channel deposits, and the eolian deposits, more specifically, the trough cross-beds in the cliff. There were two and three measurements taken for each facies.The paleocurrents in Facies 1 flow generally to the northeast with a minor southerly mode (Fig. 2.2a). The paleocurrent direction in Facies 2 is generally to the northeast and east (Fig. 2.2b). The paleocurrent direction in Facies 3 is to the northeast and southeast (Fig. 2.2c). In general, the water or wind was flowing to a northeasterly and southeasterly direction. Hubert and Mertz (1984) found that in general, the paleodirection of the wind was toward the northwest, and the paleoflow of the rivers was to the south, southeast, and northeast, in the general Cobequid area, and to the northeast closer to the Carrs Brook area. My readings indicated mainly the direction of water flow. Nine measurements of trough cross-beds were taken from the water-laid facies 1 and 2.

2.5 Paleoenvironment

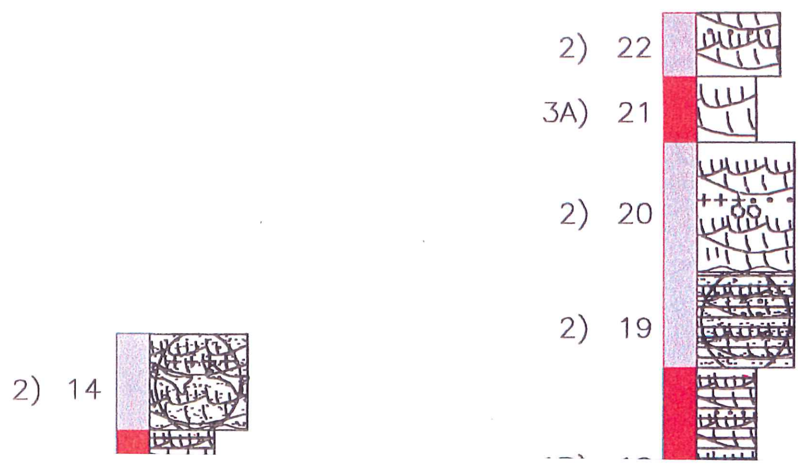
Paleoenvironment of Facies 3

The fine red sandstone of the Late Triassic cliffs of the Wolfville Formation is interpreted as eolian (Hubert and Mertz, 1984). The low-angle cross beds apparent in the red sandstone were formed mostly in the lower part of the foresets, where they became tangential to the ground surface. They were part of the dunes and not the interdune deposits, as is evidenced by the rarity in some of the sandstones of mud clasts. The dunes formed barchans and barchanoid ridges, suggested by the pattern of cross-beds, and the predominant wind direction was to the northwest (Hubert and Mertz, 1984). Skilliter's (1996) paleoflow information indicates that the wind direction was to the northeast. This finding agrees with paleoflow directions measured in this thesis. I suggest that the paleocurrents of water-laid sediment at Carrs Brook were to the northeast and southeast. When there was flooding, the low volume floods resulted in a short lived sheet flow which carried the dune material down the river. The dune material containing the mud clasts accumulated over the channel banks. During high stages of the river, shallow sheet flows covered these areas. Most of the cross-bed sets are trough shaped, suggesting that trains of sinuous crested dunes were a common bedform.

Paleoenvironment of Facies 1 and 2

Hubert and Forlenza (1988) studied the Wolfville Formation braided rivers on the south side of the Fundy Rift, opposite to the Carrs Brook area. During the Late Triassic, ephemeral rivers led down from highlands on both sides of the valley, forming large alluvial fans along the escarpment of the Cobequid fault (Hubert and Forlenza, 1988). These braided rivers flowed out onto the valley floor, and some caliche paleosols developed over a wide area due to the semiarid climate. The rivers had a bedload of gravel/sand, and the channels within the rivers shifted due to lateral cutting and avulsion. Trough cross-beds are more numerous than planar cross beds, implying that most of the gravel and sand accumulated on sinuous-crested dunes. Because channel depths were at least twice cross-bed set thickness, some of the river channels were 1-3m deep. In some cycles, cosets of cross-bedded sandstone overlie the cosets of cross-bedded conglomerate, reflecting the burial of gravel bars by dunes as the deeper parts of the channel filled and shallowed (Hubert and Forlenza, 1988). The river system at Carrs Brook can be interpreted as braided because of the ratio of sandstone to mudstone, and the thin, discontinuous nature of the beds containing mud clasts which imply a low suspended load. Ripple cross lamination was not seen (which is present in most meandering rivers). The river was wide and shallow, and there is a large continuity of the cosets of cross-bedded sandstone. At Carrs Brook, according to data gathered for this thesis, the river channels were small and numerous (Enclosure 1), were shallow, and were flowing in a southeasterly and northeasterly direction. Therefore, some of my data coincides with Hubert's data for the Wolfville Formation. Some of the planar sets of cross-beds are topped by smaller cross-bed sets which represent dunes which moved on the upper surfaces of linguoid bars. Most of these sandstone wedges are cut by erosional surfaces, scoured during falling river stages (Hubert and Forlenza, 1988).

Hubert and Forlenza (1988) inferred that the dispersal patterns of flow near fault lines implied the presence of alluvial fans. The fluvial systems that built the formation at Carrs Brook can be determined using paleoflow data. Paleoflow on the alluvial fan was to the southeast and south, and the braided river system flowed to the southeast. Rivers flowed down the highlands on both sides of the valley, out onto large alluvial fans. Out on the valley floor, the rivers flowed in a longitudinal pattern to the east.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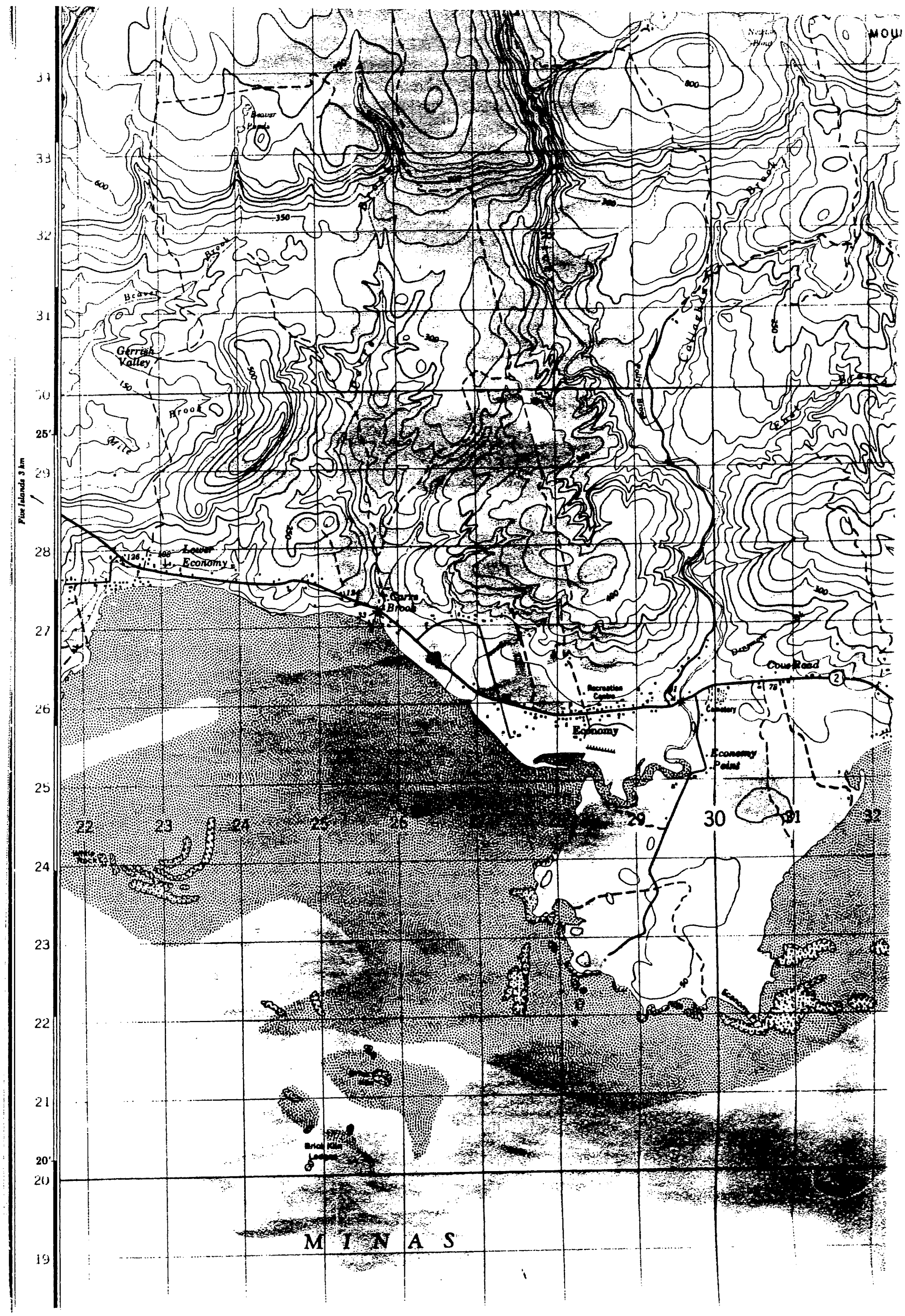

Fig.2.1.b Location of Carrs Brook in Relation to Economy and Lower Economy

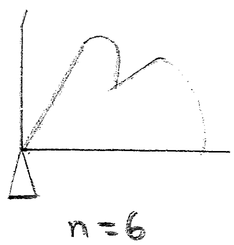

Fig. 2.2a
Paleoflow direction for trough cross-beds in Facies 1

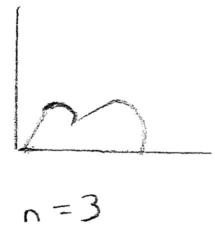

Fig. 2.2b
Paleoflow direction for trough cross-beds in Facies 2

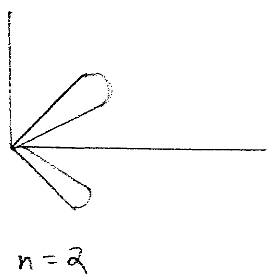

Fig. 2.2c
Paleoflow direction for trough cross-beds in Facies 3

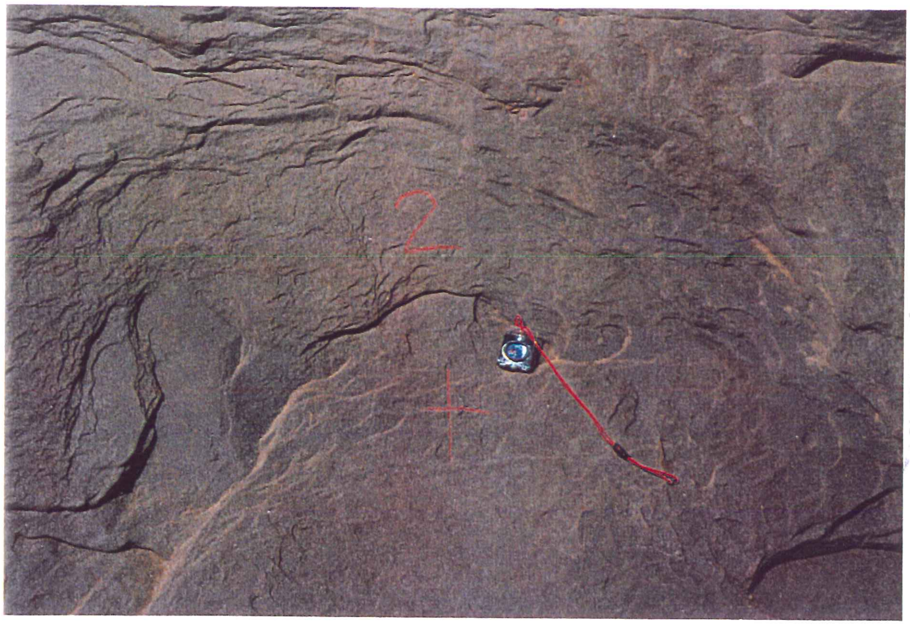

Fig.2.3.a Photograph of Facies 1 Covering an Area of 1m*1m

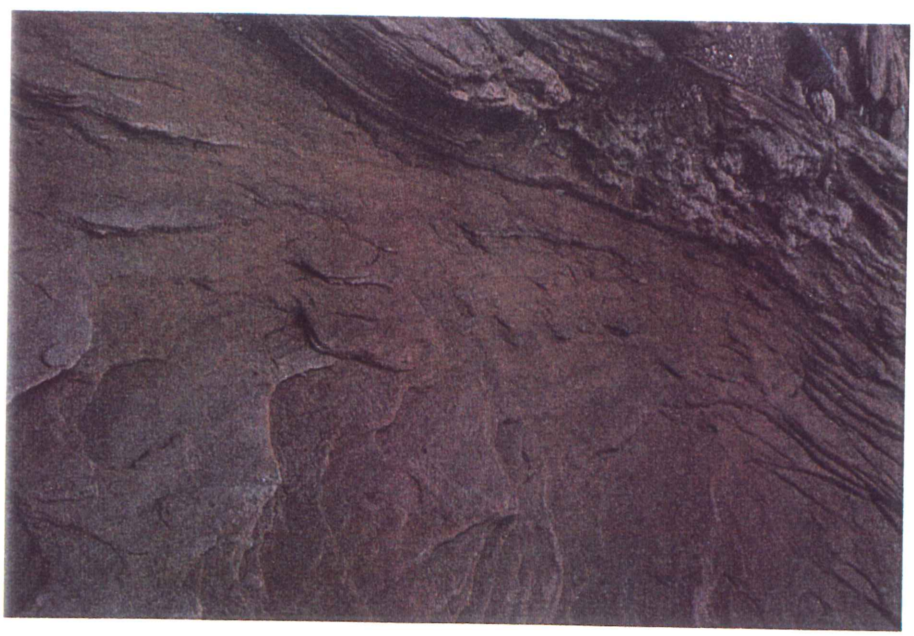

Fig.2.3.b Photograph of Facies 1 Covering an Area of 1m*1m

Fig.2.4.a Photograph of Facies 2 Covering an Area of 1m*1m

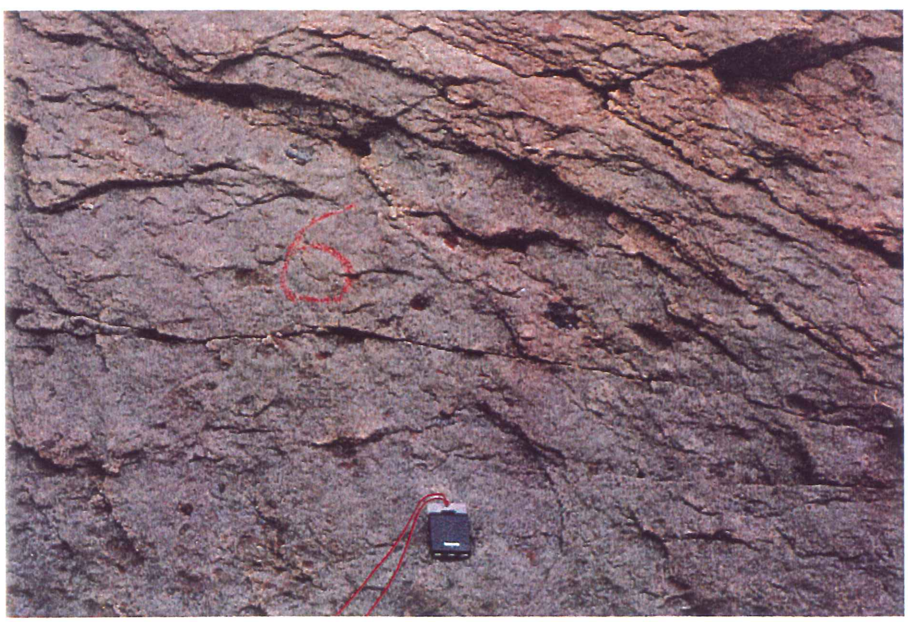

Fig.2.4.b Photograph of Facies 2 Covering an Area of 1m*1m

Fig.2.5.a Photograph of Facies 3 Covering an Area of 1m*1m

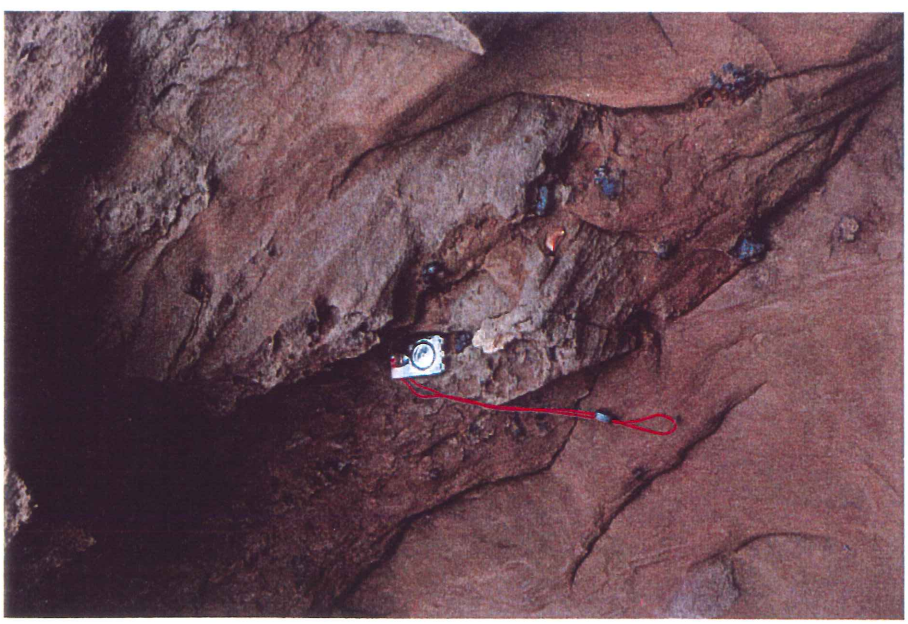

Fig.2.5.b Photograph of Facies 3 Covering an Area of 1m*1m

Facies	Bedding	Grain Size	Color
1A)Coarse red sandstone	planar	medium to coarse sand	red
1B)Coarse red sandstone with mudstone intraclasts	planar bedded to unbedded	coarse sand	red
2)Grey conglomerate and sandstone	planar bedded to unbedded; slightly wavy bedding	coarse sand	grey
3A)Fine, red sandstone with mudstone intraclasts	planar bedded to unbedded; slightly wavy bedding	fine sand	red
3B)Fine red sandstone	planar bedded to unbedded; wavy bedding	fine sand	red

Facies	Unit Thickness	Basal Contacts	Sedimentary Structures
1A)Coarse red sandstone	0.85m	gradational and undulating, to sharp and planar	large-scale trough cross-beds, manganese nodules, calcite concretions
1B)Coarse red sandstone with mudstone intraclasts	1.9m	Abrupt and undulating to planar; erosional channel base in some areas, gradual and undulating locally	large-scale trough cross-bedding, small-scale cross beds, mudstone intraclasts approximately 2 cm in diameter; convolute lamination
2)Grey conglomerate and sandstone	5.2m	Abrupt and undulating to planar, erosional channel base locally	large-scale planar to trough cross beds, calcareous, elliptical concretions, mudstone intraclasts; manganese nodules, chlorite patches
3A)Fine, red sandstone with mudstone intraclasts	1.7m	Abrupt and planar to undulating, gradual and undulating in places	cemented zones; trough cross-beds, mudstone intraclasts approximately 2cm in diameter, muscovite flakes
3B)Fine, red sandstone	7.2m	Sharp and planar to undulating	large-scale trough cross-beds, manganese nodules, small-scale, planar cross beds

Facies	Fossils
1A)Coarse red sandstone	none
1B)Coarse red sandstone with mudstone intraclasts	none
2)Grey conglomerate and sandstone	vertebrate bone fragment
3A)Fine red sandstone with mudstone intraclasts	none
3B)Fine red sandstone	none

Table 2.1 Shows the Bedding, Grain Size, Color, Unit Thickness, Basal Contacts, Sedimentary Structures, and Fossil Content of each Facies

Chapter 3: Petrographic Analysis of Sandstones and Conglomerates

3.0Methodology and Purpose

Ten thin sections were examined using a petrographic microscope, and the percentages of minerals, lithic fragments, matrix, and cements were estimated by eye. The percentages for major framework grains, quartz, feldspar, and lithic fragments sum to 100% and do not include matrix or cement. Firstly, the minerals and lithic fragments may indicate the direction that the river is flowing from, which aids in determining the paleoflow. As well, the presence or absence of a matrix, the roundness and sphericity of the grains, and the degree of sorting can support either a fluvial origin (as in the grey conglomerate and sandstone) or an eolian origin (as in the red sandstone). Finally, observing the minerals under thin section aids in determining the burial history and diagenesis of the conglomerate and sandstones.

3.1Sedimentary Analysis

The textures of the conglomerate and sandstone were examined, and an interesting observation was made. The coarse, red sandstone (Facies 1) has a large proportion of clay- and silt-sized matrix, while the fine sandstone (Facies 3) has no matrix. The fine, red sandstone could be eolian. The fact that the coarse, red sandstone has a matrix could indicate that the coarse sand was a water-laid deposit. As well, after observation of the grains under the microscope, it was determined that the sandstones were well-sorted with rounded and highly spherical grains. This may indicate that the water-laid Facies 1 contains grains with a previous eolian history.

The coarse, red sandstone (Facies 1) is a hematite-cemented lithic subarkose (Figure 3.1), while the fine, red sandstone (Facies 3) is a calcite-cemented subarkose (Figure 3.1). The grey conglomerate (Facies 2) is a pebbly, calcite-cemented lithic conglomerate (McBride, 1963).

3.2 Petrography

3.2.1.Facies 1

Facies 1 (Fig.3.2) consists of coarse-grained, red sandstone. The grains are of a moderate sphericity in a 2-D thin section, more rounded than angular, and are relatively well-sorted. The contacts are mainly long with the grains occurring very close together, and the sand is relatively mature, as it contains a great percentage of quartz. The sand contains a great deal of monocrystalline quartz, alkali feldspar, and plagioclase. It contains few lithic fragments, but contains some rhyolite clasts, and some ferruginized grains. The sand is cemented by a hematite cement, and contains a tightly packed matrix. For a list of the minerals and lithic fragments contained in the sand, refer to Table 3.1.

3.2.2Facies 2

Facies 2 (Fig. 3.3) consists of coarse, grey conglomerate and sandstone (Table 3.1). The grains are more circular than elongate, more rounded than angular, and are moderately well-sorted. The grain contacts are floating point in nature, with the grains barely touching one another in the plane of a 2D thin section, and the sand is quite mature, as it contains a great percentage of quartz. The conglomerate and sand contains a high percentage of mostly monocrystalline and some polycrystalline quartz, and a high percentage of alkali feldspar. The sandstone and conglomerate contain a high percentage of lithic fragments, especially siltstone, rhyolite, and granitic fragments. For a listing of all the minerals and lithic fragments contained in Facies 2 and their percentages (Table 3.1).

The cement consists of a small amount of hematite cement, and a large amount of calcite cement. The hematite cement forms a circular ring around each of the grains, and may have originated as a pellicle of ferrugenous material around the sand grains. The calcite cement fills in the spaces between the grains. The matrix in this facies may have been winnowed away during deposition by the action of water. The grey conglomerate and sandstone formed the channel fills of the Triassic rivers. The river winnowed away the matrix from the gravel and sand during the seasonal flooding, and the wind may additionally have winnowed away the matrix during dry times when there was no water flowing through the river channels.

3.2.3Facies 3

Facies 3 (Fig.3.4) consists of fine, red sandstone. Refer to Table 3.1.The grains are more spherical than elongate in a 2D thin section, more rounded than angular, and are moderately well-sorted. The grain contacts are floating point in nature, with the grains either apparently completely separated or barely touching one another, and the sand is quite mature, as it contains a high percentage of quartz. The sand contains a great percentage of monocrystalline quartz, chert, and alkali feldspar. The sand contains barely any lithic fragments, except for a tiny amount of rhyolite. The sand is cemented by a small amount of hematite cement, and a large amount of calcite cement. The hematite cement forms a circular ring around each grain, while the calcite cement fills in the spaces between the grains. The matrix has probably been winnowed away by the action of wind. There probably was a matrix in Facies 3 in the beginning because the sand that formed the eolian dunes was taken from the river beds. Facies 3 consists of sand that was carried downstream by the river, and when the river dried up, was blown by the wind into dunes. It is conceivable that wind action would remove the matrix from this fine grained sand.

3.3 Provenance

There are four places where the minerals in the Triassic-aged cliffs could have come from. They could have originated from the Cobequid Hills which consist of granite, gabbroic and old volcanic rocks, metasedimentary and other metamorphic rocks (Donohoe and Wallace, 1982). They could have originated from the Carboniferous section of the cliff at Carrs Brook (Donohoe and Wallace, 1982) which lies close to the Triassic-aged sediments dealt with in the thesis, from the Meguma metaquartzite (Waldron, 1992), or from the granitic rocks of the South Mountain Batholith. Monocrystalline quartz does not give a good indication of where the minerals and lithic fragments came from, but polycrystalline quartz originates from metamorphic rocks. The quartz in the three facies could have its origin in the Meguma Group, or in the Cobequid Highlands (Donohoe and Wallace, 1982). Chert is found in sedimentary rocks, so it could possibly have originated in the Carboniferous rocks near the Triassic cliffs at Carrs Brook, if any is present there, or in the Cobequid Highlands (Donohoe and Wallace, 1982). Alkali feldspar is found in granite, and may have originated from the granitic South Mountain Batholith. Microcline also comes from plutonic igneous origins and may have been eroded from the Cobequid Hills (Donohoe and Wallace, 1982). Muscovite comes from metamorphic and igneous rocks and may have originated in the Meguma, the Cobequid Mountains, or the South Mountain Batholith (Donohoe and Wallace, 1982). Olivine and pyroxene are typically plutonic igneous minerals and may have had their origins in the Cobequid Hills (Donohoe and Wallace, 1982). Apatite, opaques, zircon, and rutile are mostly minor materials in most rocks for which it is quite difficult to determine their origins. For example, zircon can come from igneous, metamorphic, or sedimentary origins.

As for the lithic fragments, siltstone is sedimentary in origin, and thus may have come from the Carboniferous section of the cliffs at Carrs Brook (Donohoe and Wallace, 1982). Mud clasts originated in the Triassic sediment (Donohoe and Wallace, 1982), and while working with ferruginized grains, it is impossible to determine their origin.The rhyolite almost certainly originates from the Cobequid Highlands (Donohoe and Wallace, 1982), while the granitic fragments may have come from the South Mountain batholith, or Cobequid Highlands (Donohoe and Wallace). Schists and phyllites are metamorphic rocks and may have originated from the Meguma or from the Cobequid Hills (Donohoe and Wallace, 1982)..

To conclude, the main possible source of minerals was probably from the Cobequid Highlands because they are to the north of the Carrs Brook section, and are quite close to Carrs Brook. The paleodirections for the water-laid deposits in my thesis were generally to the east. They were measured over a small area, and thus it is difficult to draw any conclusions about the source of the minerals from this small amount of data. However, the paleodirections of the rivers determined by Hubert and Mertz (1984) were generally to the south and east, and were assessed over a much broader area. This dominant source accords well with the paleoflow data in this thesis. Since the rivers were flowing to the east, and the Cobequid Hills are to the north, it is possible to suggest that the Cobequid Hills were a source of minerals for the Carrs Brook area, with the rivers transporting the minerals in an easterly and southerly direction.

3.4 Diagenesis

The grains, after being eroded from their various sources, were transported by the river and wind. These minerals suffered progressive burial in the basin. Eventually the minerals were cemented together by new minerals that precipitated through the pore spaces as groundwater flowed through them. First, hematite cement surrounded each grain in the grey conglomerate and sandstone, and in the fine, red sandstone. In the coarse, red sandstone, the hematite cement bound the grains together, and no other cement precipitated around the grains. Some of the hematite may have originated as ferruginous material that coated the grains at the time of deposition or during very shallow burial, as in many modern wind-blown dunes. In the grey conglomerate and sandstone, and in the fine, red sandstone, calcite cement subsequently bound the grains together.

Fig.3.1 M

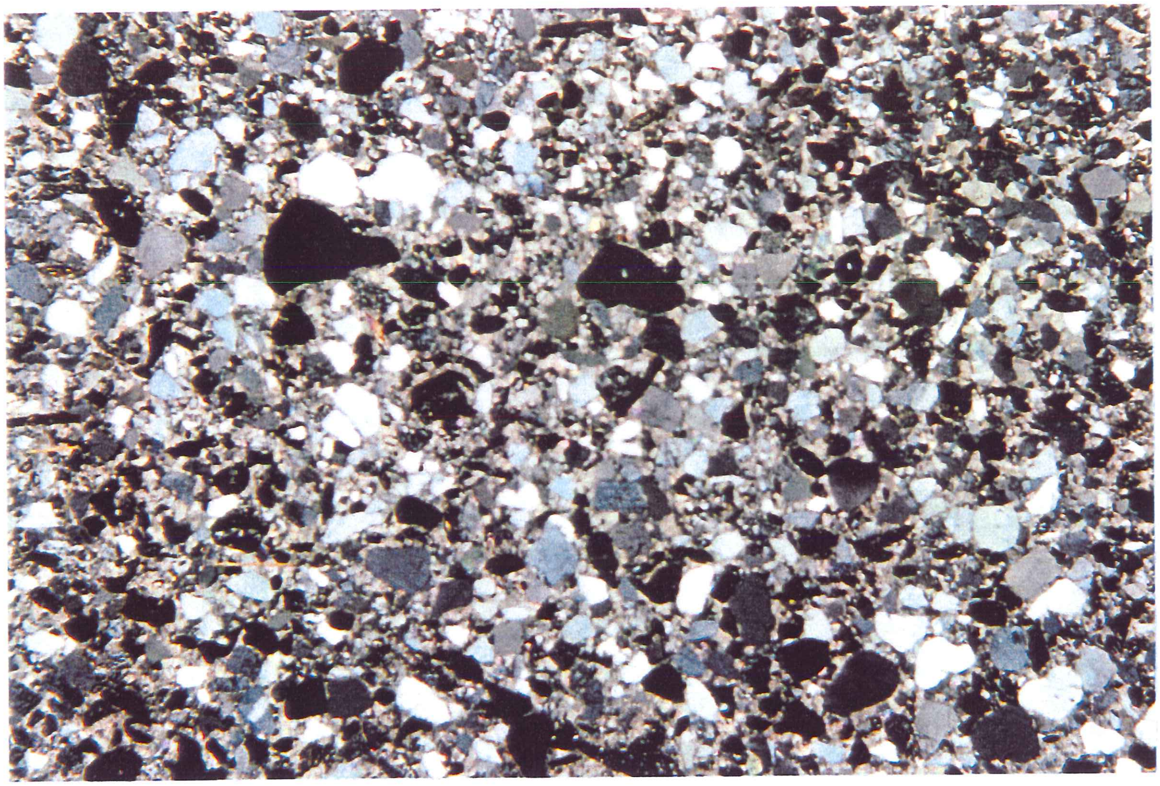

Fig.3.2 Photograph of Thin Section of Facies 1 with a Scale of 2cm *2cm

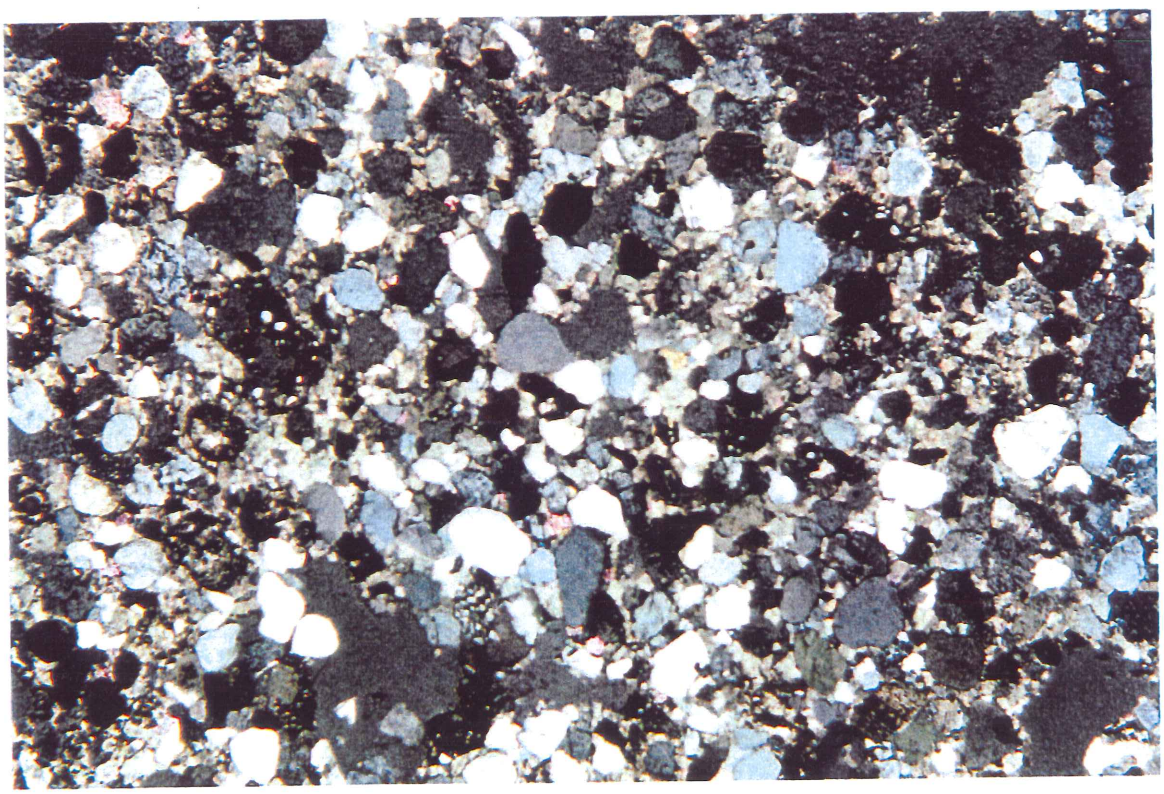

Fig.3.3 Photograph of Thin Section of Facies 2 with a Scale of 2cm*2cm

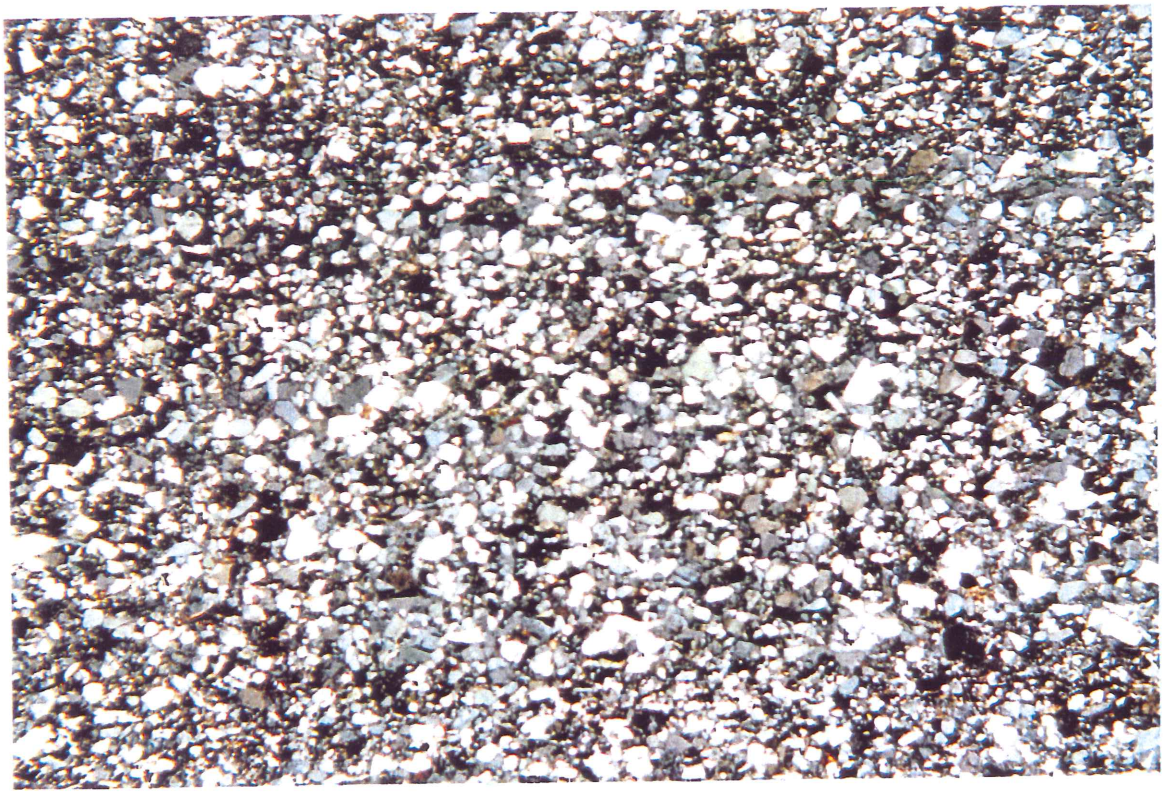

Fig.3.4 Photograph of Thin Section of Facies 3 with a Scale of 2cm *2cm

Sample #	Framework Grains	Accessory Minerals	Lithic Grains	Cement	Matrix
CAB1 Facies 1	quartz-55% monocrystalline-40% polycrystalline-10% chert-5% alkali feldspar-10% plagioclase-10%	olivine-5% zircon-10% opaques-4%	rhyolite-2% ferruginized grains-2% granitic fragments-2%	hematite-30%	20%
CAB2 Facies 2	quartz-55% Monocrystalline-30% polycrystalline-20% chert-5% alkali feldspar-7% plagioclase-5%	microcline-5% muscovite-5% olivine-5% opaques-1% rutile-2%	siltstone-4% rhyolite-2% ferruginized grains-2% granitic fragments-5% schist/phyllite-2%	hematite-15% calcite-25%	none
CAB3 Facies 3	quartz-60% monocrystalline-40% polycrystalline-5% chert-15% alkali feldspar-10% plagioclase-10%	microcline-4% olivine-4% opaques-1% rutile-5%	rhyolite-4% granitic fragments-2%	hematite-10% calcite-25%	none
CAB4 Facies 2	quartz-50% monocrystalline-40% Polycrystalline-5% Chert-5% alkali feldspar-6% plagioclase-2%	microcline-2% muscovite-7% olivine-2% opaques-2% rutile-4%	siltstone-5% mudclasts-5% rhyolite-5% ferruginized grains-5% granitic fragments-4% schist/phyllite-1%	hematite-10% calcite-25%	none
CAB5 Facies 2	quartz-50% monocrystalline-50% Polycrystalline-5% chert-5% alkali feldspar-5% plagioclase-6%	microcline-5% muscovite-5% olivine-1% opaques-1% rutile-3%	siltstone-6% mudclasts-1% root casts-1% ferruginized grains-2% granitic fragments-1% schist/phyllite-1%	hematite-10% calcite-25%	none
CAB6 Facies 1	quartz-54% polycrystalline-48% chert-6% alkali feldspar-10% plagioclase-10%	muscovite-2% olivine-5% zircon-4% opaques-1%	rhyolite-8% ferruginized grains-4% granitic fragments-5%	hematite-20%	20%
CAB7 Facies 1	quartz-50% monocrystalline-25% polycrystalline-20% chert-5% alkali feldspar-8% plagioclase-10%	muscovite-5% olivine-5% zircon-7% opaques-3%	rhyolite-4% ferruginized grains-3% granitic fragments-5%	hematite-25%	20%

CAB8 Facies 2	quartz-60% monocrystalline-50% polycrystalline-5% chert-5% alkali feldspar-5% plagioclase-5%	microcline-5% muscovite-7%	siltstone-3% mudclasts-6% rhyolite-1% root casts-5% granitic fragments-3%	hematite-5% calcite-20%	none
CAB9 Facies 2	quartz-50% monocrystalline-30% polycrystalline-15% chert-5% alkali feldspar-7% plagioclase-10%	microcline-2% muscovite-5% olivine-4% opaques-1%	siltstone-8% mudclasts-2% rhyolite-5% root casts-2% ferruginized grains-2% granitic fragments-2%	hematite-10% calcite-20%	none
CAB10 Facies 2	quartz-60% monocrystalline-50% polycrystalline-5% chert-5% alkali feldspar-7% plagioclase-2%	microcline-1% olivine-5% opaques-2% apatite-2%	siltstone-6% rhyolite-3% ferruginized grains-6% granitic fragments-2% schist/phyllite-4%	hematite-10% calcite-25%	none

Table 3.1 List of all Minerals and Lithic Fragments for each Thin Section Representing each Facies

Chapter 4: Vertebrate and Plant Material

4.1 Fundy Dinosaurs

The Fundy dinosaurs are the oldest in Canada, and those dating from the Triassic are among the oldest known anywhere. The Fundy Group represents a period in which there was a proliferation of a group called the archosaurs. They replaced the hierarchy of mammal-like reptiles, and became the dominant land animals. They include extinct dinosaurs, pterosaurs, and the ancestors of crocodiles. *Tanystropheus* was a primitive archosaur-like creature which had a neck twice as long as its body. The body could reach up to 7 meters long. It had short limbs and used its neck for catching fish. It was aquatic in nature, and its vertebrae were one foot in length. These dinosaurs were found at Carrs Brook (Thurston, 1994). Another group found in the Fundy area from the Triassic was the *rhyncosaur* group. The rhyncosaurs had long, overhanging beaks used to crop vegetation, and were pig-like in shape. Archosaurs resembling heavily built, long-legged crocodiles are found in the Triassic sediments of the Fundy Basin, these include *phytosaurs, aetosaurs*, and *rauisuchids*. The phytosaurs were aquatic in nature, and had long, narrow snouts for catching their prey, which was fish. Their backs were covered with bony plates, and their nostrils were located on a mound above their heads. Aetosaurs were terrestrial, heavily armoured dinosaurs that ate with their pig-like snouts. *Rauisuchids,* although not technically dinosaurs, were upright and had a head shape similar to that of *Tyrannosaurus rex.* They were meat-eating, and their teeth were 6 cm long. However, *rauisuchid phytosairs* and *aetosaurs* all went extinct by the end of the Triassic. The Age of Dinosaurs had dawned by the Late Triassic. This is evident from the fossils and footprints present in the Triassic sediments, in the Fundy Group (Thurston, 1994).

4.2 Bone Material in Section:

In the 200 - 300 m cliff section under investigation at Carrs Brook, Nova Scotia, bone material was found in one of the beds by Fundy Museum staff, shortly before my investigation began. The bone was a palatine specimen from a Metoposaur which belongs to the superfamily Metoposauridae, the group Temnospondlyi, and the subclass Labyrinthodontia of Amphibia and was specimen number FGM999GF65. As well, a few bone fragments were found by the author in the 200 - 300 m cliff section in the coarse grey conglomerate and sandstone facies. All of the bone fragments of Triassic dinosaurs, reptiles, amphibians, and plant fragments found by the Fundy Museum were found in the coarse, grey conglomerate and sandstone facies (2). The plant material consists of leaf fragments and fossilized tree trunk pieces found by the Fundy Museum staff at Carrs Brook.

4.3 Death of the Dinosaurs:

The fact that the bone and plant material was found in the grey conglomerate and sandstone associated with the mudstone intraclasts has some implications with respect to how the dinosaurs died and how their bones were preserved. The bone fragments found by the Fundy Museum were spaced widely apart and were very fragmented. There were various types of tetrapod and dinosaur remains found. These observations suggest that perhaps the creatures came to the river and for some reason died, and their bones were carried downstream and deposited when the flow was too weak to carry the bones any longer. The bones are composed of dense material and would most likely sink to the bottom of the river to form components of the grey conglomerate and sandstone.

The Fundy Museum found material at Carrs Brook of different Triassic flora and fauna.

They found for example, fossilized tree material (Fig. 4.1), a vertebrate pelvic bone (Fig. 4.2), a vertebrate rib bone (Fig. 4.3), a vertebrate tooth (Fig. 4.4), and fossilized leaf debris (Fig. 4.5). The Fundy Museum could not elaborate on which specific reptiles these bones came from, but instead provided examples of the types of bone fragments and floral debris found.

4.4 Triassic Ecosystems:

The plant material can help to determine the ecosystems in which the Triassic dinosaurs and tetrapods at Carrs Brook lived. Behrensmeyer, 1987, has done taphonomic work on vertebrate bones in the Siwalik Sequence in the Chinji and Dhok Pathan Formations in Pakistan. The rocks investigated by Behrensmeyer were Miocene in age, and the vertebrates were mostly Miocene-aged mammals. The fossils in part of Behrensmeyer's study were associated with mudclast conglomerate, as were the fossils in the Carrs Brook area. In Behrensmeyer's area of study, vertebrate bones were found in secondary channels, particularly in the large-scale abandoned channels. In Carrs Brook, the vertebrate material was found in subsidiary channels forming braided streams. These channels extended down from the mountains into the floodplain. There are two factors that together promote bone preservation in floodplain channels (Behrensmeyer, 1987). Two critical factors are topographic lows and rapid infilling of the channel troughs. Ground and surface water are concentrated in these braided channels, which also provide habitats for plant growth, animal activity and predation (Behrensmeyer, 1987). These "waterholes" would attract vertebrates. Behrensmeyer states that faunas from this context represent localized time averaged samples of the original vertebrate communities inhabiting areas near the floodplain channels.

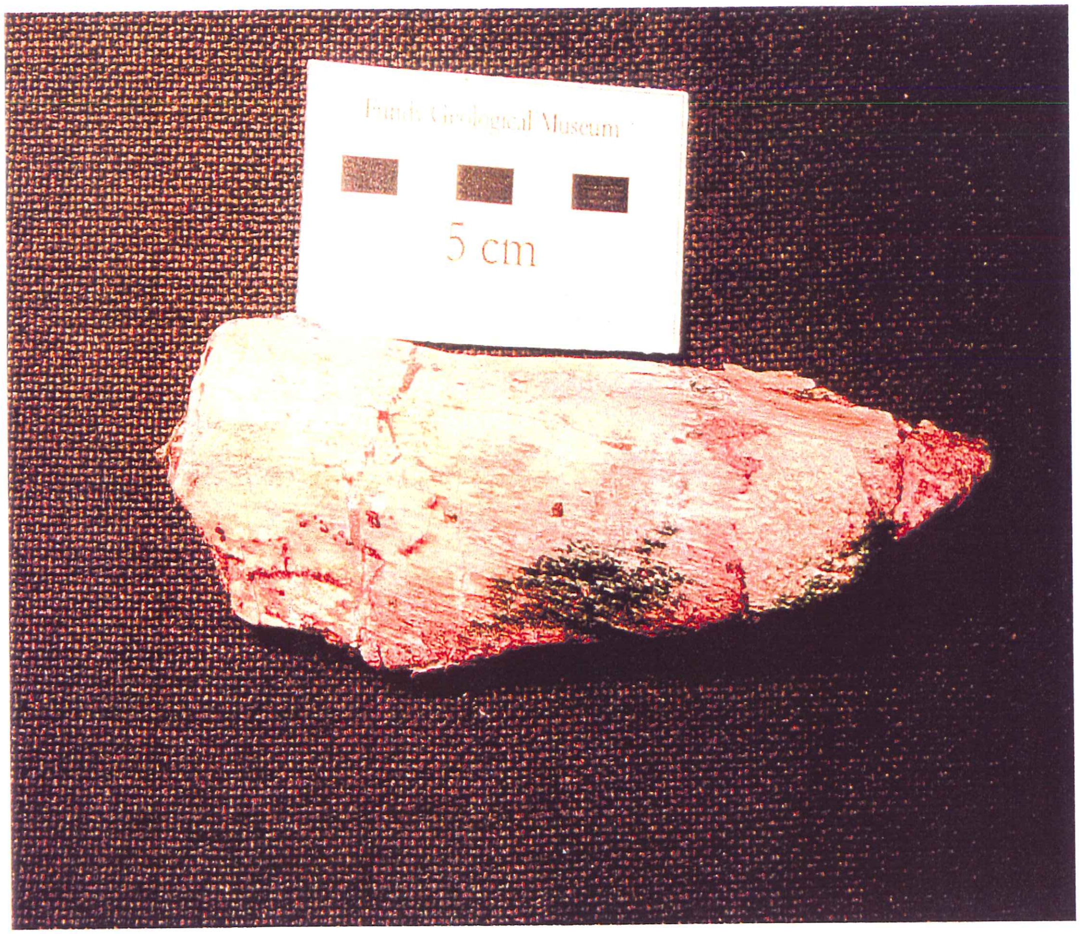

Fig. 4.1 Fossilized Tree Trunk Material Found at
Carrs Brook, Nova Scotia

Fig. 4.2 Vertebrate Pelvic Bone of Unknown Species
Found at Carrs Brook, Nova Scotia

Fig. 4.3 Vertebrate Rib Bone Found at Carrs Brook, Nova Scotia

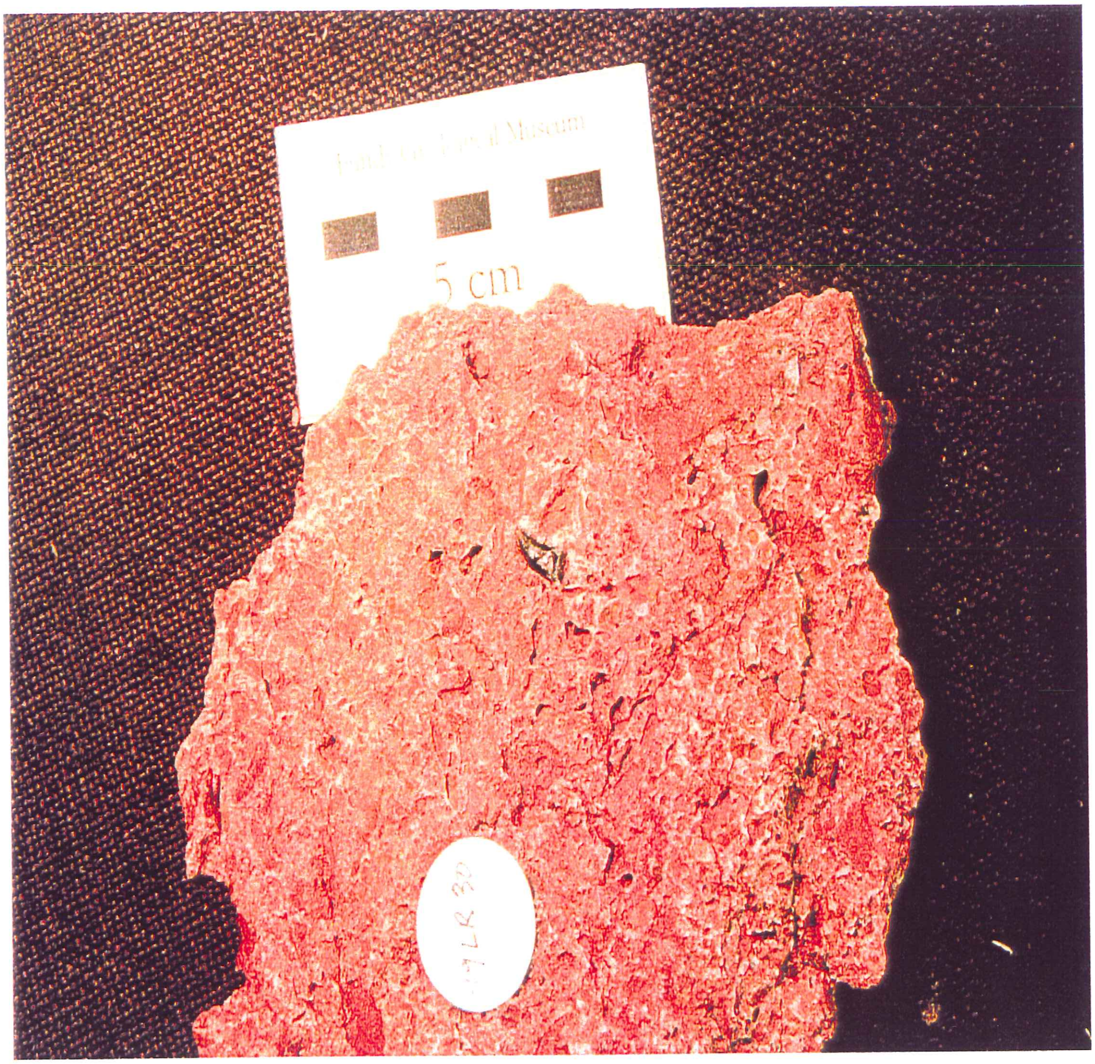

Fig. 4.4 Vertebrate Tooth of Unknown Species
Found at Carrs Brook, Nova Scotia

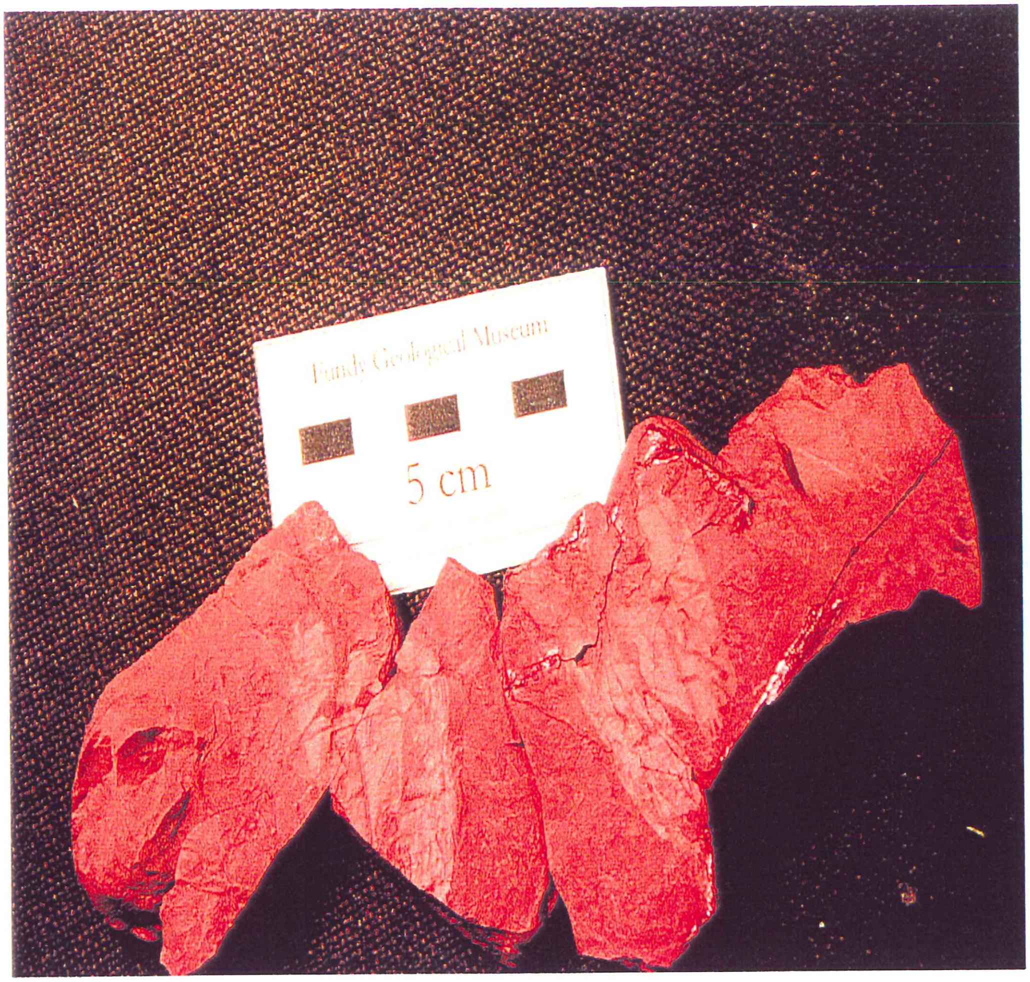

Fig. 4.5 Fossilized Leaf Material Found at
Carrs Brook, Nova Scotia

Chapter 5: Conclusions:

In the 200 - 300 m long Triassic cliff section under study at Carrs Brook, Nova Scotia, three facies types were found: a coarse, red sandstone facies; a fine, red sandstone facies; and a coarse, grey conglomerate and sandstone facies. Many sedimentary features were found in these facies, including erosional channel bases, large-scale, trough cross-bedding, small scale cross-beds, manganese concretions, calcite concentrations, wavy bedding, convolute lamination, and mudstone intraclasts.

The paleoenvironment consisted of a braided river system flowing down from a mountain onto a floodplain in a semi-arid environment. The grey conglomerate and sandstone, and the coarse red sandstone formed within the river channel, while the fine red sandstone may have formed eolian dunes which were blown out from the river system by wind action in the desert. The river flooded periodically, and mudclasts were deposited in the sand and conglomerate. Mud accumulated in the overbanks and has been eroded by the river channel and incorporated into the channel lag.

Most of the minerals found in the fine and coarse red sandstones, and the grey conglomerates and sandstone might have come from the Cobequid Hills, the South Mountain Batholith, the Meguma Group or the Carboniferous cliff section at Carrs Brook.

The vertebrate bone and plant material found at Carrs Brook was associated with the grey conglomerate and sandstone facies. This, combined with the fact that only pieces of material of numerous taxa rather than whole skeletons were found, indicate that the animals went to the river, to use it as a "waterhole", and for some reason died. The bones were then transported down the river, perhaps after scavengers had picked the bones apart. This mode of bone deposition is favoured over a model that suggests that herds of vertebrates died in a flash flood, with their bones being washed down the river by the flood. Had this been the case, whole, fossilized skeletons, and large amounts of material from one or a few taxa might have been found in the Carrs Brook section.

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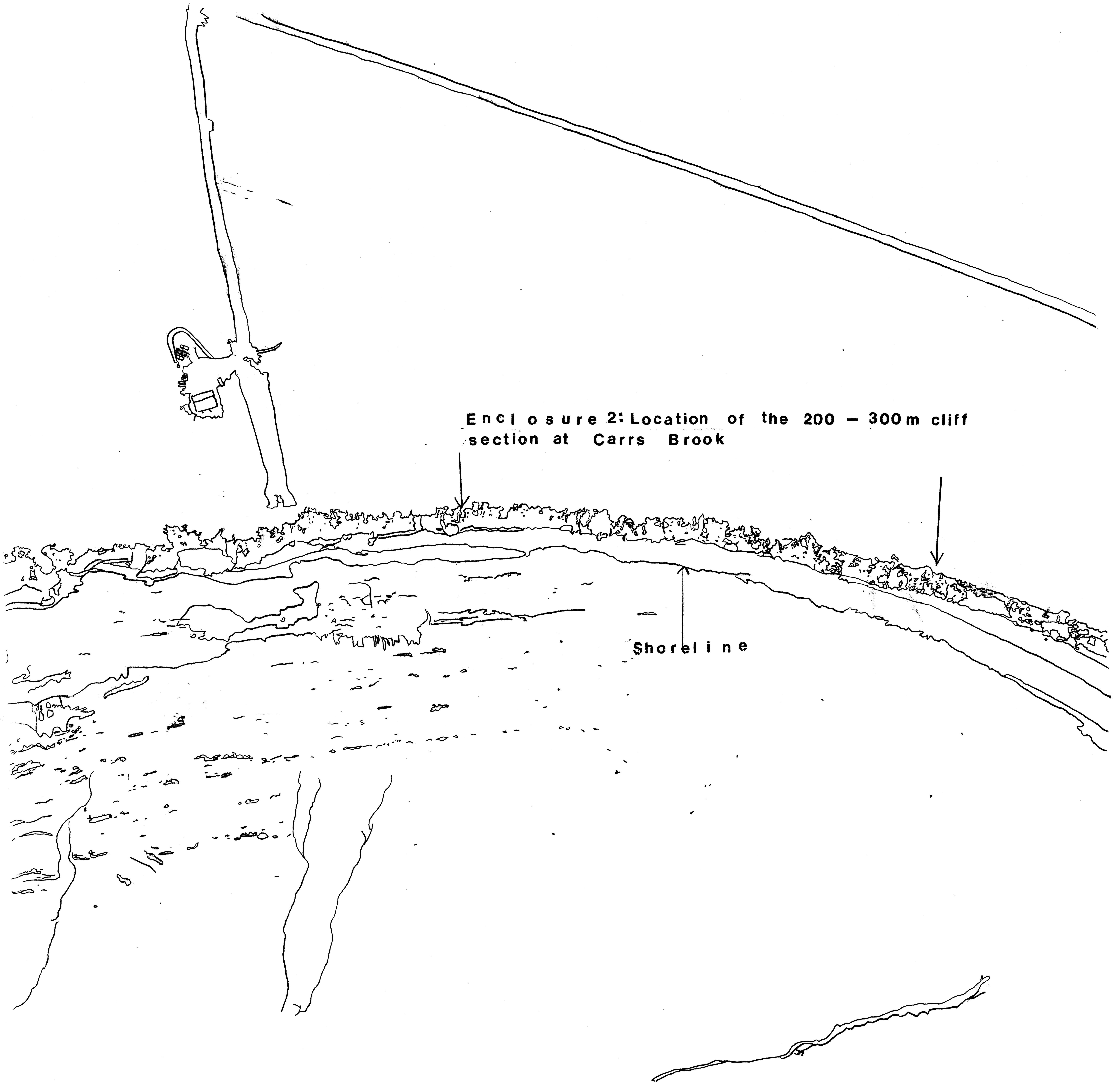
Enclosure 1 Outcrop Map of the Carrs Brook Section



Enclosure 2: Location of the 200 – 300m cliff section at Carrs Brook