Cretaceous Deposits of the Windsor Area, Nova Scotia: Another Glimpse of the Chaswood Formation

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Abstract

Found mainly within the Carboniferous basins of Nova Scotia, onshore Cretaceous deposits provide a glimpse into the environment, structural and stratigraphic setting of the Atlantic Cretaceous. Previously unknown deposits of probable Cretaceous age have been discovered at Avondale, Mantua (Fundy Gypsum Bailey Quarry), and Wentworth Road (Fundy Gypsum Wentworth Dark Quarry). Five new sites have been uncovered, one at Avondale (1.5x4m), four in Bailey Quarry (from 3m to 6x15m), and one in Wentworth Dark Quarry (1x3m). Additionally, a drill core, between the Bailey Quarry and Millers Creek Quarry (Mantua) penetrated >40 m of probable Cretaceous material in a narrow karstic "trench". Although small, these occurrences (attributed to the Chaswood Formation) have considerable significance in linking the Cretaceous catchment area with thick, hydrocarbon-prone deltaic and marine deposits of the Scotian Shelf.

The deposits consist of sand, lignite, clay and quartz-rich gravel, resting unconformably on gypsum of the Windsor Group. The Cretaceous materials mainly occupy fractures, sinkholes and depressions within the gypsum, with especially clear relationships to gypsum karst at Avondale where sands have penetrated fractures in the gypsum for several meters. The sand and gravel are fluvial in origin, and some thick clay with lignite may record associated lakes. Palynological studies at two localities confirm an age of Aptian-Albian. Samples of charcoal from Bailey Quarry site BQ 4 near Mantua represent ginkgo, conifer and angiosperm wood, supporting a Mesozoic age, possibly Aptian-Maastrichtian.

Large gypsum crystals, confirmed using XRD, locally cement the quartz-rich gravel and sand. Other constituents include patches of clay and iron oxide matrix, some feldspars (K-feldspar, mainly microcline, plagioclase), and small amounts of muscovite, biotite and heavy minerals (rutile, ilmenite, staurolite, and zircon in order of abundance). The feldspars are strongly altered, suggesting extensive weathering of the source area, and the sands are classified as quartz-arenite to subarkose. The Meguma and the South Mountain Batholith are the likely sources for much of the material. Recycling from Carboniferous clastic strata is also likely.

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Chapter 1: Introduction

The earliest geological maps of Nova Scotia show known Cretaceous deposits (Dickie, 1986). Clay, used as one of the first industrial minerals, is associated with these deposits and has been used for pottery in eastern Canada, for centuries (Dickie 1986). Sands and more recently quartz-rich sands, used in glass making, and high quality clays, used for fine pottery and paper, have been of interest (Atlantic Geoscience Society, 2001; Stea and Pullan, 2001). Few onshore deposits of Cretaceous material are available for study, and most of these are poorly exposed, so it is difficult to present a comprehensive account of the Cretaceous history of Nova Scotia. The onshore strata of these Cretaceous units correlate with offshore strata that are now being exploited for oil and gas (Dickie 1986). This correlation underlines the importance of studying onshore deposits so that a better understanding of offshore units, which researchers are unable to access readily, may be gained. The study location is close to the Windsor area and is shown on Figure 1.1.

During a Dalhousie undergraduate field excursion at Avondale, Nova Scotia in 2001, poorly cemented quartzose sands and gravel were discovered resting unconformably on Carboniferous strata. These strata resemble in stratigraphic setting and composition Cretaceous deposits that had been described previously in southern Nova Scotia. They were the focus of the initial thesis study. Subsequent discussion with M. Holleman at the Fundy Gypsum Company nearby indicated that several other probable Cretaceous localities were present in the quarries in the area. These sites were visited and added to the study. In all, five individual sites are now confirmed or strongly inferred to

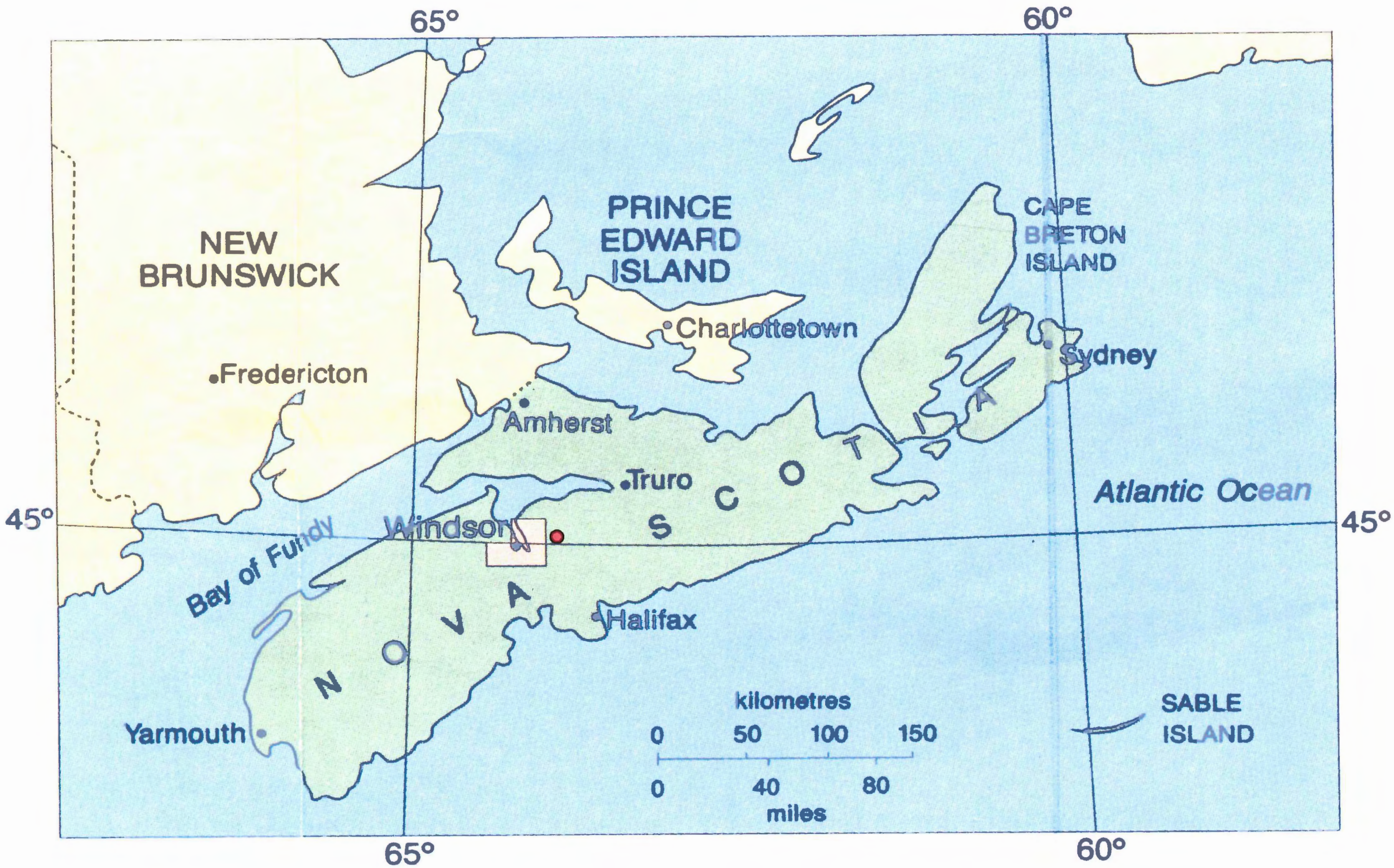


Figure 1.1: Field area surrounding Windsor, Nova Scotia (from Moore and Ferguson, 1985; Geological map of the Windsor area, Nova Scotia). Red dot indicates McKay Settlement found just to the right of the field area.

be Cretaceous. As only eleven Cretaceous occurrences were previously known onshore in Atlantic Canada, the present study adds considerably to our knowledge of this poorly understood period in the history of the region.

The first locality of interest in this report is near Avondale, Hants Co., Nova Scotia (Fig. 1.2). Along the east bank of the Avon River, gypsum and limestone of the Mississippian Windsor Group make up the cliff face. In these units there is a small, cemented block of what is thought to be Cretaceous material. The material consists mostly of quartz-rich gravel, with small amounts of sand, clay and organics.

A second group of localities is in the Fundy Gypsum Bailey Quarry, near Mantua, close to Avondale (Fig. 1.3). The quarry contains four areas of probable Cretaceous exposures overlying the B-zone of the Windsor Group, spread throughout the quarry. One of these areas (BQ2) is associated with the Chamber Siltstone, and the Belmont and Fisher Limestones at a fold axis. The probable Cretaceous material in the quarry consists of silica sand with thin layers of clay and quartz-rich gravels that are cemented locally. Some areas have had strong weathering and wash outs that have mixed the material at these sites. These areas hold higher amounts of organics, clays, and silica sands than the first locality on the Avon River. Additionally a core extracted between the Bailey and Millers Creek Quarries of Fundy Gypsum (Core 685: Fig. 1.3) consisted of almost 50 m of probable Cretaceous material.

The third locality is in the Fundy Gypsum Wentworth Dark Quarry (Fig. 1.4). Here a possible channel area is exposed where likely Cretaceous sand was deposited. This sand has an abundance of lignitic material and is overlain by a thick layer of clay. The area is not well exposed and the clay is being extracted for use as fill in construction.

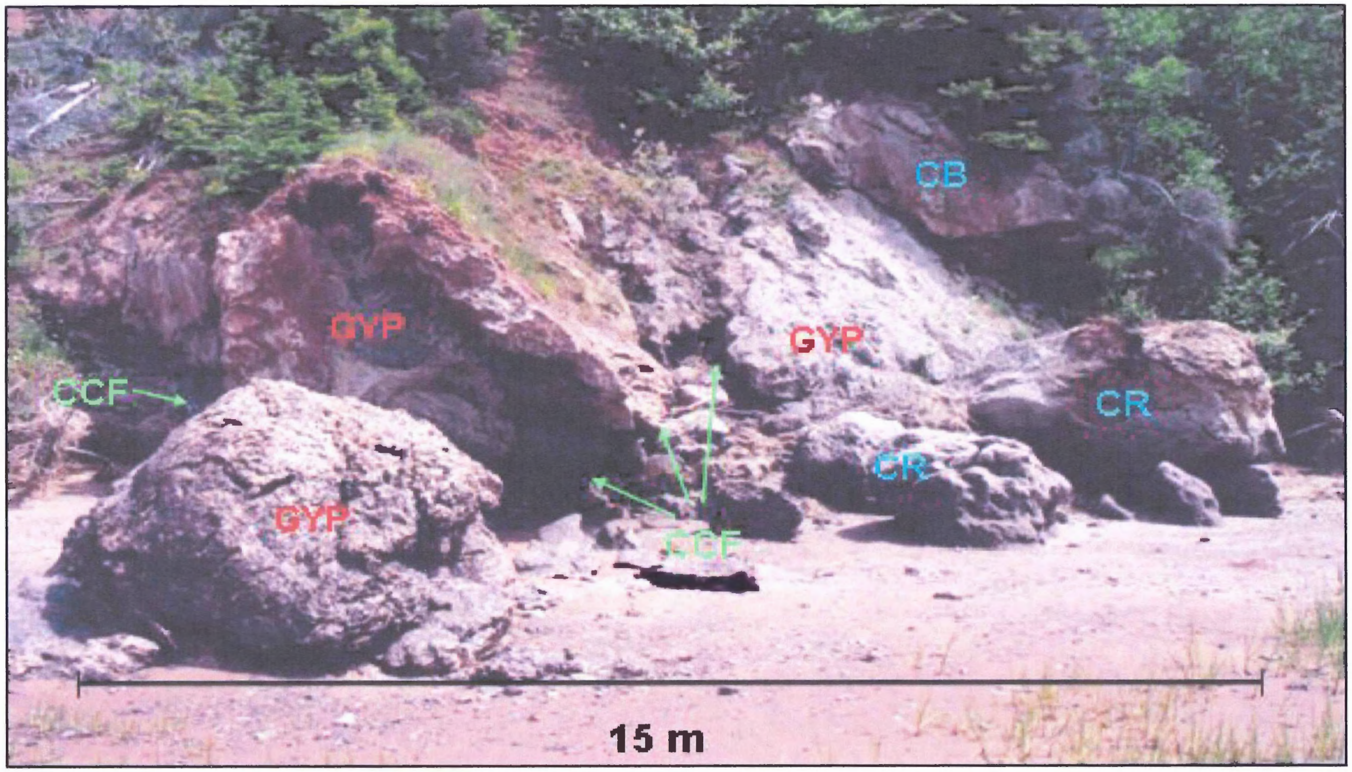


Figure 1.2: Field locality at Avondale, Hants County, Nova Scotia along the Avon River. GYP, Windsor Group Gypsum; CB, Cretaceous block; CR, Cretaceous rubble; CCF, Cretaceous crack fills.

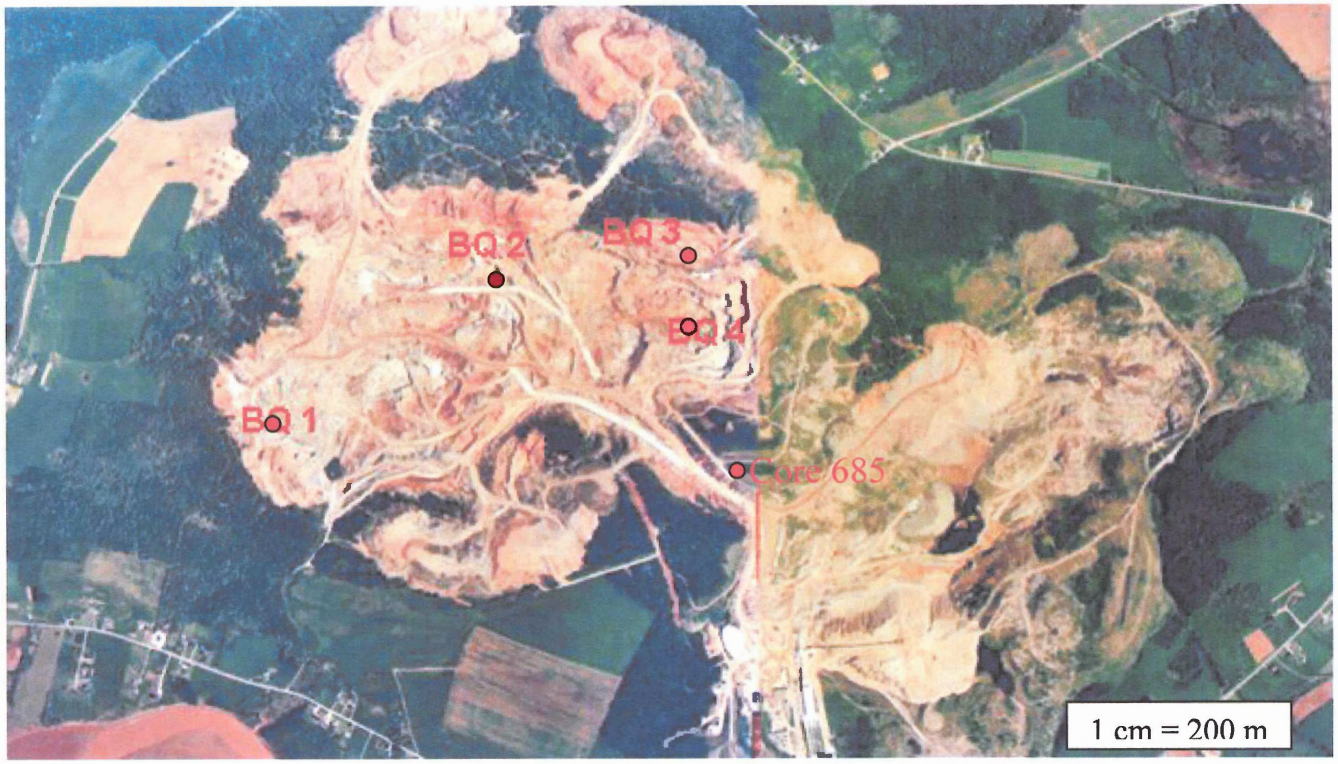


Figure 1.3: Field area Bailey Quarry, Fundy Gypsum Company, near Avondale in Mantua, Hants County, Nova Scotia. BQ 1-4, field localities shown, as well as core 685 (Airphotos; 2964 & 2962, 92-06-17).

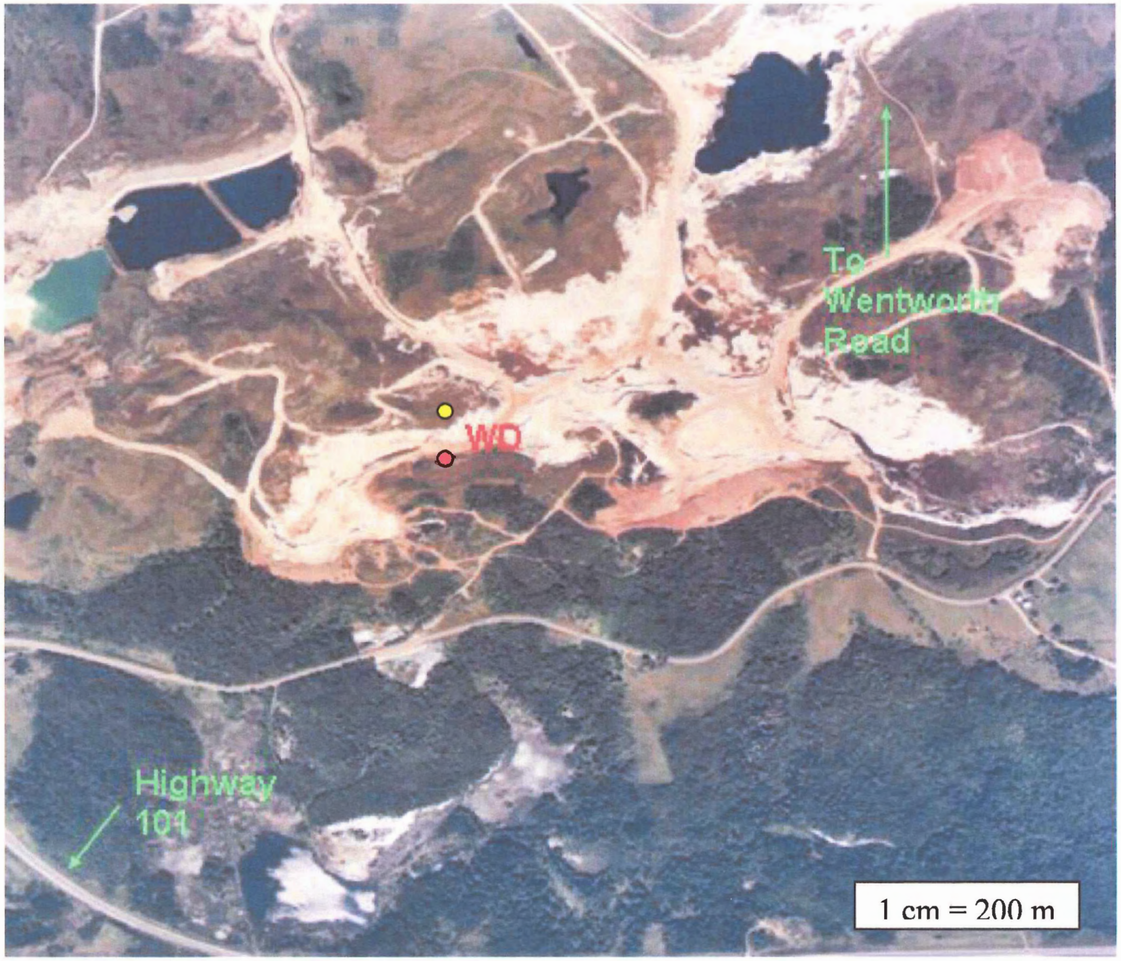


Figure 1.4: Field area Wentworth Dark Quarry, Fundy Gypsum Company, Wentworth Road, Windsor, Hants County, Nova Scotia. WD field locality shown, yellow dot indicates organic layer locality (Airphoto; 7541, 92-08-22).

This report examines the field relations, structure, stratigraphy, environment of deposition, petrography, provenance, and age of the field localities. The correlation of these units to other known Cretaceous deposits onshore, and to offshore units, is also examined. Figure 1.5 shows the locations of the field areas of this study and those previously recorded onshore. The findings in this study help to explain the source of these deposits, and provide new information on these types of occurrences.

Cretaceous dates have been confirmed at localities BQ 4 (charcoal analysis and palynology) and BQ 1 (palynology). There are no confirmed dates for the other localities but stratigraphic and sedimentological similarities between BQ 4, BQ 2, and Avondale, and BQ 1 and WD, suggest that all localities are of Cretaceous age. Therefore in the text all sites are referred to as "Cretaceous", although confirmation is needed for some sites.

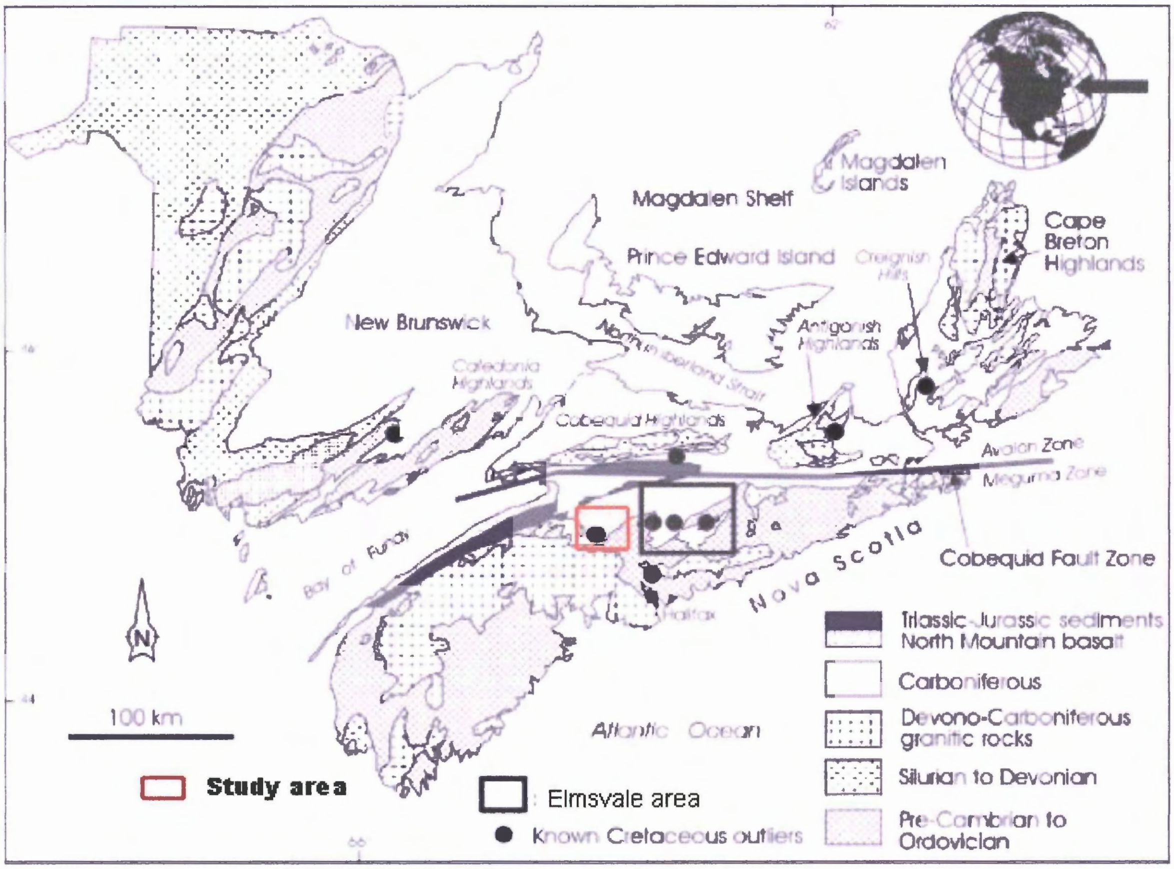


Figure 1.5: Cretaceous outliers and mapped Cretaceous basins of Nova Scotia and New Brunswick. Red indicates this report's study area. Black dot in study area represents the McKay Settlement locality (Modified from Stea and Pullan, 2001).

Chapter 2: Geological Background

2.1: The Cretaceous Period and Deposits

Warm climates and high sea levels dominated the Cretaceous Period, which occurred in the Mesozoic Era from 142 million years ago (Ma) to 65 Ma (Table 2.1). During the Cretaceous the supercontinent, Pangea was almost complete in its breakup. During the late Cretaceous the climate was tropical to subtropical, shown by the extensive chalk deposits, made up of coccoliths (microscopic shell fragments), which are found on the Scotian Shelf (Atlantic Geoscience Society, 2001).

Table 2.1: Cretaceous time scale (Gradstein et al., 1995).

Era	Period		Stage	Date (Ma)
Mesozoic	Cretaceous	Late	Maastrichtian	65.0
				103
			Campanian	
				83.5
			Santonian	
				85.8
			Coniacian	
				89.0
			Turonian	
				93.5
			Cenomanian	
				98.9
		Early	Albian	
				112.2
			Aptian	
				121.0
			Barremian	
				127.0
			Hauterivian	
				132.0
			Valanginian	
				136.0
			Ryazanian	
				142.0
			Berriasian	

Preserved remnants of poorly consolidated, quartz-rich sand, kaolinitic clay, and lignite are found under thick layers of glacial drift in the Carboniferous and Triassic basins of Nova Scotia (Stevenson, 1959; Lin, 1971; Fowler, 1972; Dickie, 1986; Stea and Pullan, 2001). The age for some of these deposits was first established by Stevenson (1959) to be Early Cretaceous. Early Cretaceous outliers in the Maritimes are shown in Figure 1.5. About 100 million years ago the last stage in the separation of Newfoundland and Labrador from northern Europe occurred. This event affected the Maritimes with an increase in earthquake activity and an uplift of land in the region (Atlantic Geoscience Society, 2001).

2.2: Onshore Cretaceous in Nova Scotia

The first known Cretaceous deposits were mined for valuable material such as kaolin, aggregate, and glass-sand for use as industrial minerals (Fowler, 1972; Dickie, 1986; Stea and Pullan, 2001). Extensive clay deposits were recorded by Stevenson (1959) during his mapping of the Shubenacadie and Kennetcook areas. In 1967 the Nova Scotia Department of Mines began a mapping and drilling program in the Musquodoboit Valley (Fowler, 1972), a major fault-bounded basin (Dickie, 1986). In that same year the silica sands and clay deposits at Paint Brook and Elmsvale were discovered (Gobeil, 2002).

The Shubenacadie outlier is found in Hants and Colchester counties. This and other onshore Cretaceous strata have recently been attributed to the Chaswood Formation by Stea and Pullan (2001). This area was previously thought to be underlain by Pleistocene deposits but in 1970 it was determined, from cuttings that contained spores, to contain Early Cretaceous strata (Lin, 1971). The Chaswood Formation in these areas consists of three informal units: the lower, middle, and upper members, which are dominantly terrestrial clastic sediments. These members are described below, based on information provided by Stea and Pullan (2001), Gobeil (2002) and Eisnor (2002) to show what types of material are found within known Cretaceous strata.

***Lower member**:* total thickness: 60 m; consists of silica sand and mud. The clay is thought to be kaolinite rich with a light grey to white colour. The silica sand is more abundant than the mud. These sand layers are associated with small amounts of gravel, which are mostly basal lags of channel bodies. Near the base of the lower member are mud-dominated, organic-rich units.

***Middle member**:* total thickness: ~5m; consists of black lignite-bearing clay layers that alternate with dark grey clay, silty clay, and lignite layers, which range to 1.5 m in thickness. The lignite-bearing clay and lignite layers contain pyrite in rounded and dendritic growths. Within this member are silica sands, which are cemented by calcium carbonate and are associated with clays that are rich in organics. Both boundaries of this unit are sharp to gradational.

***Upper member**:* total thickness: 40 m; dominated by sands, this member also contains mud and gravel. Upward fining cycles of white to light grey sand to gravel are 0.5 to 10 m thick. A 0.5-2 m layer of light grey, red, yellow, and purplish mottled silty clay caps the upper member, which may be indicative of paleosol formation. The upper member sand units have a greater amount of clay than the sands of the lower member. The upper member also shows facies changes across the deposit from sand-dominated to mud-dominated.

Other known onshore Atlantic Canada deposits of Cretaceous material are summarized in Table 2.2 and shown in Figure 1.5. In the Musquodoboit and Shubenacadie Valleys, where Stea and Pullan (2001) studied the Cretaceous strata of the Chaswood Formation, the deposits were confined to narrow and steep-sided fault-bounded basins, whereas the Cretaceous strata in the Gays River Lead-Zinc Mine are found within a sinkhole or 'trench' (Davies *et al.*, 1984). These two types of deposit are the most common forms of Cretaceous occurrences onshore in Nova Scotia.

The best exposures of Lower Cretaceous silica sand and clay deposits are at the West Indian Road Pit/Brazil Lake in Hants County. This area holds the members that are described above and is currently being exploited by the Shaw Resources Company (Gobeil, 2002).

The McKay Settlement occurrence is found in Hants County in an abandoned gypsum quarry, close to the study area (Fig. 1.1). A deposit of silica sand and quartz-rich gravel of unknown thickness was uncovered on the south face of the quarry. This occurrence is thought to have been deposited in a sinkhole or on an unconformable surface and is underlain by gypsum, limestone and red and green shale of the Windsor Group. The Windsor Group is fault-bounded to the southeast against the basement slates and quartzites of the Meguma Group (Dickie, 1986). This occurrence of Cretaceous material is the closest to the area focused on in this report. Located approximately 15-20 km to the southeast of the Bailey Quarry and the Avondale occurrences, the McKay Settlement deposit is found overlying the same bedrock (Windsor Group) material as the Cretaceous material found in these locations.

Table 2.2: Summary of Onshore Cretaceous deposits in Nova Scotia.

Location	Occurrence	Sediment Type	Thickness (m)	Age	Author
Belmont, Colchester County, NS	Fault-bounded within Carboniferous Basin	silica sand	Undetermined	Early Cretaceous	Dickie, 1986
Brierly Brook, Antigonish County, NS	Undetermined	kaolinite clay; minimal amounts of lignite; brownish coarse-medium grained quartzose sand	3 m	Early Cretaceous	Stea *et al,* 1994; Stea & Fowler, 1981
Gays River, NS	Karst depression in Carboniferous material	semi-consolidated gravels, sands, silts, clays, minor coaly material	Unknown	Aptian-early Albian	Davies *et al,* 1984
McKay Settlement, Hants County, NS	Sinkhole or infilling along unconformity, Fault-bounded within Carboniferous Basin	white silica sand; quartz-rich gravel	Unknown	Unknown	Dickie, 1986
Musquodoboit Valley, NS	Fault-bounded within Carboniferous Basin	silica sand; pottery clay	150-170 m	Early Cretaceous	Lin, 1971; Hacquebard, 1984; Dickie, 1986
River Denys Basin, Diogenes Brook, Inverness County, NS	Fault-bounded within Carboniferous basin	silica sand; white clay	125 m	Valanginian at base to early Aptian at the top of deposit	Guernsey, 1926; Carnochan, 1931; Hacquebard, 1984; Dickie, 1986
Shubenacadie and Elmsvale, NS	Steep sided exposures within Carboniferous Basin	black organic silty clay; kaolinite clay; lignite; quartz-rich sand ;	170 m	Barremian to Aptian older not ruled out	Stevenson, 1959; Dickie, 1986; Finck *et al,* 1994; Stea & Pullan, 2001
Stewiacke Cross Roads, Colchester County, NS	Fault bounded within Carboniferous basin	silica sand; multicolored clay	Not extensive	Early Cretaceous	Dickie, 1986
West Indian Road Pit, Brazil Lake, Hants County, NS	Large gypsum sinkhole	sandy gravel; sandy mud; well sorted quartz-rich sand; kaolinite clay	105 m	Early Cretaceous	Stea & Fowler, 1981; Gobeil, 2002
Vinegar Hill, Cassidy Lake, south of Sussex, NB	Down-faulted block south side, Clover Hill Fault	silica sands; clay;	Not extensive	Early Cretaceous, Albian	Falcon-Lang, Fensome, and Venugopal, 2003.

2.2.1 Environment of Deposition (West Indian Road Pit Cretaceous)

The environment of deposition in these previously known areas has a great deal of variability (Gobeil, 2002). The dark organic-rich clays suggest an oxygen-reduced and closed environment, which, along with the lack of marine fossils, suggests a marsh, floodplain or lacustrine environment. The thickness of the clay suggests that this setting persisted for some time. Colour changes within the clay unit show fluctuating levels of oxygen in the environment during deposition or changes in chemical weathering (Gobeil, 2002).

Within the majority of sand sequences that are associated with the Chaswood Formation, upward-fining sequences are a dominant cyclic pattern. These types of sequences are commonly found in fluvial areas where channels migrate and flooding events occur regularly (Gobeil, 2002). Lithofacies successions, paleocurrent measurements and grain size analysis from the study of the West Indian Pit occurrence showed that the most likely environment of the Chaswood Formation in this area is a braided river system (Gobeil, 2002).

2.3: Offshore Cretaceous in Atlantic Canada

Extending 1200 km from the Grand Banks to Georges Bank, the Scotian Basin consists of Mesozoic-Cenozoic units that lie off Nova Scotia's coast, covering an area of about 300 000 km^2. The stratigraphy of the basin was determined using reflection seismic profiles and a set of 120 wells, of which the majority were on the Scotian Shelf and Slope (Wade and MacLean, 1990).

2.3.1 Overview of units

The correlation of these offshore strata to onshore exposures may be carried out through biostratigraphic similarities. Early Cretaceous deposits in the Scotian Basin are designated as the Missisauga and Logan Canyon formations. Palynomorph assemblages suggest that they are marine and non-marine strata (Wade and MacLean, 1990) that correlate with the Chaswood Formation, which contains non-marine palynomorphs of Early Cretaceous age, probably Valanginian to Albian age (Table 2.2).

The Lower Cretaceous Missisauga Formation is dated as Berriasian-Barremian (Williams and Stelck, 1975) and contains thick sandstone units. The formation is up to 1267 m thick with the sandstone units averaging 23 m and up to a maximum of 91 m, separated by thin shale and siltstone beds (Wade and MacLean, 1990). Near the upper part of the Missisauga Formation, a zone of limestone 122 m thick defines a lithostratigraphical and geophysical marker due to its oolitic composition and is named the "O" marker, found in a sequence dated as Hauterivian-Barremian (Williams, 1974).

The Logan Canyon Formation, which overlies the Missisauga Formation, is divided into four members: the Naskapi, Cree, Sable, and Marmora members. With alternations of thick shale and sandstone-shale units, the Logan Canyon Formation has been interpreted by Wade and MacLean (1990) to have been deposited during periods of quartz-clastic deposition in a coastal shelf (shallow marine) environment. The Naskapi Member is of Aptian age, consists of reddish-brown, green-grey, yellow-brown shales, and is found as the lower transgressive unit of the Logan Canyon Formation (Wade and MacLean, 1990). Found interbedded with and on top of the Naskapi Member is the Cree Member, which is Aptian to late Albian in age and consists of interbedded sandstone, medium to dark grey shale, and thin sparse layers of siltstone (Wade and MacLean, 1990). Above the Cree Member lies the Sable Member, dominantly shale with thin sandstone and siltstone beds. This member represents a time of greater transgression in the late Albian (Wade and MacLean, 1990). The Marmora Member, which is overlain by the Dawson Canyon Formation, is similar to the Cree Member, and its upward-thinning and -fining sand beds are Cenomanian in age (Wade and MacLean, 1990).

2.4: The Windsor Group

Cretaceous material found onshore is commonly associated with Carboniferous gypsum of the Windsor Group. This association occurs because of the nature of the Carboniferous material. The susceptibility of gypsum and other Windsor Group deposits to form karst deposits (in fractures), sinkholes and depressions from dissolution allows for the penetration or filling of sand and clay material, of which the Cretaceous deposits are made. Table 2.3 documents the characteristics of the Windsor Group Carboniferous material in the study area. Stratigraphic units of the Windsor Group are mentioned with locality information in Chapter 4.

Table 2.3: Stratigraphy and characteristics of the Carboniferous Windsor Group. (Geological Map of the Windsor Area, Nova Scotia by Moore and Ferguson, 1986).

Formation	Zone	Relative age (series)	Material
Murphy Road Formation	C-E subzone	Asbian	Siltstone, minor gypsum, and sequence of limestone members: Kennetcook, Wallace Point, Meander River, Avon, Brooklyn Station, Herbert River.
Pesaquid Lake Formation	C-E subzone	Asbian	Silstone, and sequence of limestone members: Lebreau, Pesaquid.
Wentworth Station Formation	B subzone	Holkerian	Gypsum, minor siltstone, limestone, dolostone and sequence of carbonate rocks: North 60 Dolostone, Dimock Limestone, Phillips Limestone, St. Croix Limestone.
Miller Creek Formation	B subzone	Arundian-Holkerian	Gypsum, minor siltstone, limestone, dolostone, and sequence of carbonate rocks an a siltstone bed: Sanford Limestone, Big Red siltstone, Chambers Limestone, Belmont Limestone, Belmont Limestone, Mantua Limestone, Fisher Limestone, and McCulloch Dolostone.
White Quarry Formation	A subzone	Arundian	Anhydrite, minor dolostone, salt.
Macumber Formation	A subzone	Arundian	Thin bedded, arenaceous limestone.

Chapter 3: Methods

3.1: Field Methods

3.1.1 Sample Collection and Preparation

Avondale

K.R. Fletcher and Dr. M. Gibling sampled the Avondale locality. Beginning in the summer and ending in the fall of 2003 this area was observed and samples were taken. Because the area is small and was the only new location known at the time, it was looked at in great detail. Samples were taken from the Cretaceous material and thin sections were made and observed (descriptions and figures in Chapter 4 and 5).

Fundy Gypsum Bailey Quarry (BQ)

The Bailey Quarry sites were located with the help of the Fundy Gypsum Quarry geologist, Matt Holleman. M. Holleman was contacted in the hopes that deposits of possible Cretaceous material might have been uncovered during blasting in the quarry. This proved to be the case, and this location was visited and sampled by K.R. Fletcher, Dr. M. Gibling, and Dr. Y. Kettanah under the guidance of M. Holleman. Four sites (BQ 1-4) were distinguished. BQ 1 consists of silica sand that was difficult to observe because it was being extracted for use in construction. A sample was taken, sieved for grain size, and a thin-section was made. BQ 2 was a small amount of cemented quartz-rich material found in a cliff, and the material was sampled, thin sections made and observed in the lab. BQ 3 is a dumpsite from the quarry where waste material is located. Here, cemented material was sampled and observed. The final location in the Bailey Quarry is BQ 4. Here a larger occurrence of Cretaceous sits between gypsum layers, which are in a vertical position. This area was sampled at the bottom, middle and at the top. The materials that were sampled at this location were quartz-rich gravel, clays, and charcoal. The gravels were made into thin-sections, the clays were sent to Bedford Institute of Oceanography (BIO) for palynological analysis by Dr. R. Fensome, and the charcoal was sent to Dr. H. Falcon-Lang for identification and dating. Because the localities were being excavated or were small and covered by surface wash, only generalized strata and sediment information could be obtained at any of these sites.

Wentworth Dark Quarry

K.R. Fletcher, Dr. M. Gibling and Dr. Y. Kettanah sampled this area. The sand sample was observed in the lab and the clay was sent to Dr. R. Fensome at BIO for palynological analysis.

McKay Settlement

This area was previously recorded by Dickie (1986) and was visited to compare known Cretaceous material to the new localities in this study. K.R. Fletcher and Dr. M. Gibling obtained samples that were observed in the lab.

Standard thin sections were made of units and examined for composition, cementation, matrix, transport, and sorting of grains. In total nine (9) thin sections were assessed for the above properties, four from the Avondale locality, two from BQ 1, two from BQ 4, and one from the presumed Cretaceous material from the McKay Settlement locality.

3.2: Laboratory Methods

3.2.1 Grain size distribution

Sand collected from Fundy Gypsum Bailey Quarry (BQ1) was analyzed for grain size distribution. Sieving was used to determine the size distribution of the sand at given phi intervals, the sorting and skewness of the sand.

For sieve analysis, two sand samples from locality BQ1, BQ1S1A and BQ1S1B, were used. Sieves were used at half phi intervals from -1.0 to 4.0 phi. The proportion from the collecting pan at the bottom of the sieve stack represents the >4.0 phi interval. The sands were each sieved for 20 minutes, using a Ro-tap machine, divided into the specified half-phi intervals, weighed and placed in separate jars for storage. Weight distributions are given in Chapter 5. The weight percentages were calculated for each phi class and the cumulative weight percents were derived. These were then plotted as cumulative curves. From the cumulative weight percent graph, percentiles were calculated and the skewness, sorting, mean, median, and mode were obtained. Skewness was plotted against sorting for each sample to explore depositional environment (beach or river deposit).

3.2.2 Petrographic Descriptions

3.2.2.1 X-Ray Diffraction (XRD)

A sample from the Avondale locality was used for XRD analysis. About 5 g of sample was prepared by grinding to a size suitable for the XRD with manual disaggregation. The sample was placed in a dry mount and analyzed using Cu K-alpha radiation. The exact parameters for this procedure can be seen in appendix A. The diffraction trace that was obtained was then used to determine the proportions of the material that was present. From methods outlined in Cook et al. (1975), the percentages were derived by multiplying the diagnostic peak heights for the specific minerals, obtained from the diffraction trace, by the intensity factors appropriate to each mineral (from Cook et al., 1975). These values can be seen in Table 5.5, Chapter 5.

3.2.2.2 Microscope Work: point counts

Point counts were done on the prepared thin sections using a Swift semi-automatic point count tabulator attached to a microscope stage. Adjustments were made so that the stage interval was equal to 3 and the row movement equal to 2 at a magnification of X5 (3.8 mm field of view) so that most of the thin section was covered in scans. Seven of the nine slides where examined, KF-03-2, KF-03-3, KF-03-4, BQ1S1, BQ1S4, BQ4S2 and MS-2. The other two slides were omitted because of close similarities with slides from the same area. A total of 500 points were counted per slide and divided into the following categories: monocrystalline quartz (Qm), polycrystalline quartz (Qp), K-feldspar, plagioclase, cement (gypsum), matrix (Fe-oxide/clay), muscovite, staurolite, tourmaline, opaques, rock fragments, clay aggregates, and pore space. Percentages were calculated for total quartz (Qm + Qp = Qt), total feldspar (F) from K-feldspar and plagioclase, and rock fragments or lithics (L). These percentages were then plotted on triangular diagrams modeled after Folk (1968) and Dickinson (1988). Folk's sandstone classification has seven sandstone types (Fig. 3.1): quartzarenite (Qz >95%), subfeldsarenite (Qz >75 %, feldspar > lithics), sublitharenite (Qz > 75%, lithics > feldspar), feldsarenite, lithic arkose, feldspathic litharenite and litharenite (last four all <75% Qz with varying amounts of feldspar and lithics).

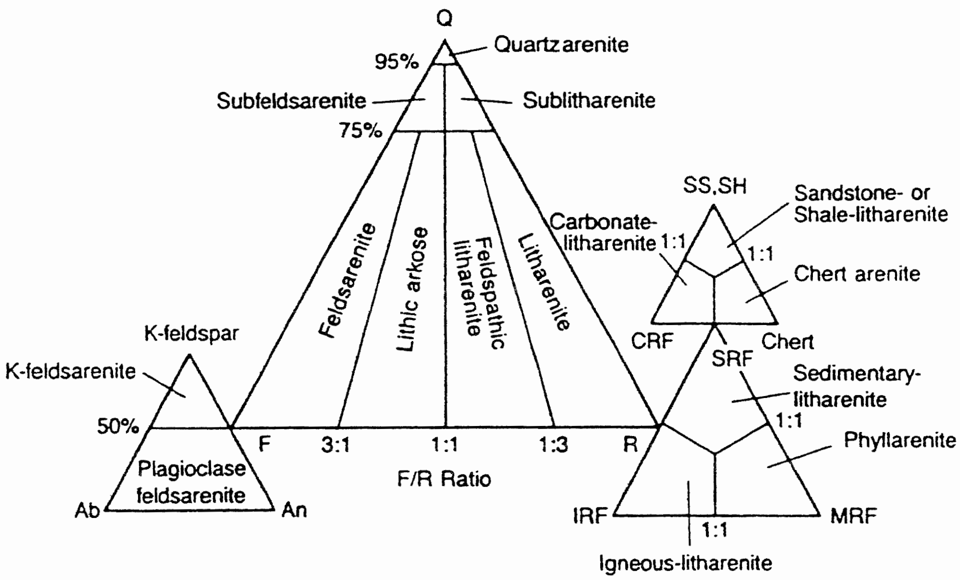


Figure 3.1: Sandstone classification system by Folk, 1968. From Boggs (1987).

Dickinson's classification considers the relationship between detrital modes of sandy detritus and different generic types of provenance terrene (Dickinson, 1988; Fig. 3.2). Dickinson used the provenance interpretation to identify five tectonic-sedimentary groups. Quartzose: sands are dominantly Qm, minor Qp and F (K>P), formed from deeply weathered cratonic landmasses or recycled sediments. Volcaniclastic sands are dominantly Lv (Lv >F), F (P>K), with low Qm, formed from volcanic fields of active magmatic arcs. Arkosic sands are dominantly F (var. K/P) and Qm (low Qt), formed from uplift continental basement or eroded arc plutons. Volcanoplutonic sands are mixed Qt (Qm>Qp), F (P>K), and L (Lv>Ls), formed from variably dissected magmatic arcs. Quartzolithic sands are mixed Qm, Qp, Ls (variable Qt/L and Qm/Lt ratios) with minor F and Lv, formed from uplifted strata of fold-thrust belts (Dickinson, 1988; see Fig.3.2 for grain type symbol meaning). The top two triangles were used in this study for interpretation of sample material. These plots have been developed form the analysis of modern sands derived from stable cratons, continental basement uplifts, recycled orogens and magmatic arcs, and subduction zones.

3.2.3 Age dating

To determine the age for the Cretaceous material found in this study palynology and identification of charcoal was used, with descriptions and procedures described below.

3.2.2.1 Palynology

Palynology is the study of modern or fossil pollen and spores from vascular plants and bryophytes, as well as cysts from protist groups. The pollen, spores and cysts (organic-walled microfossils) are referred to as palynomorphs. When referring to the

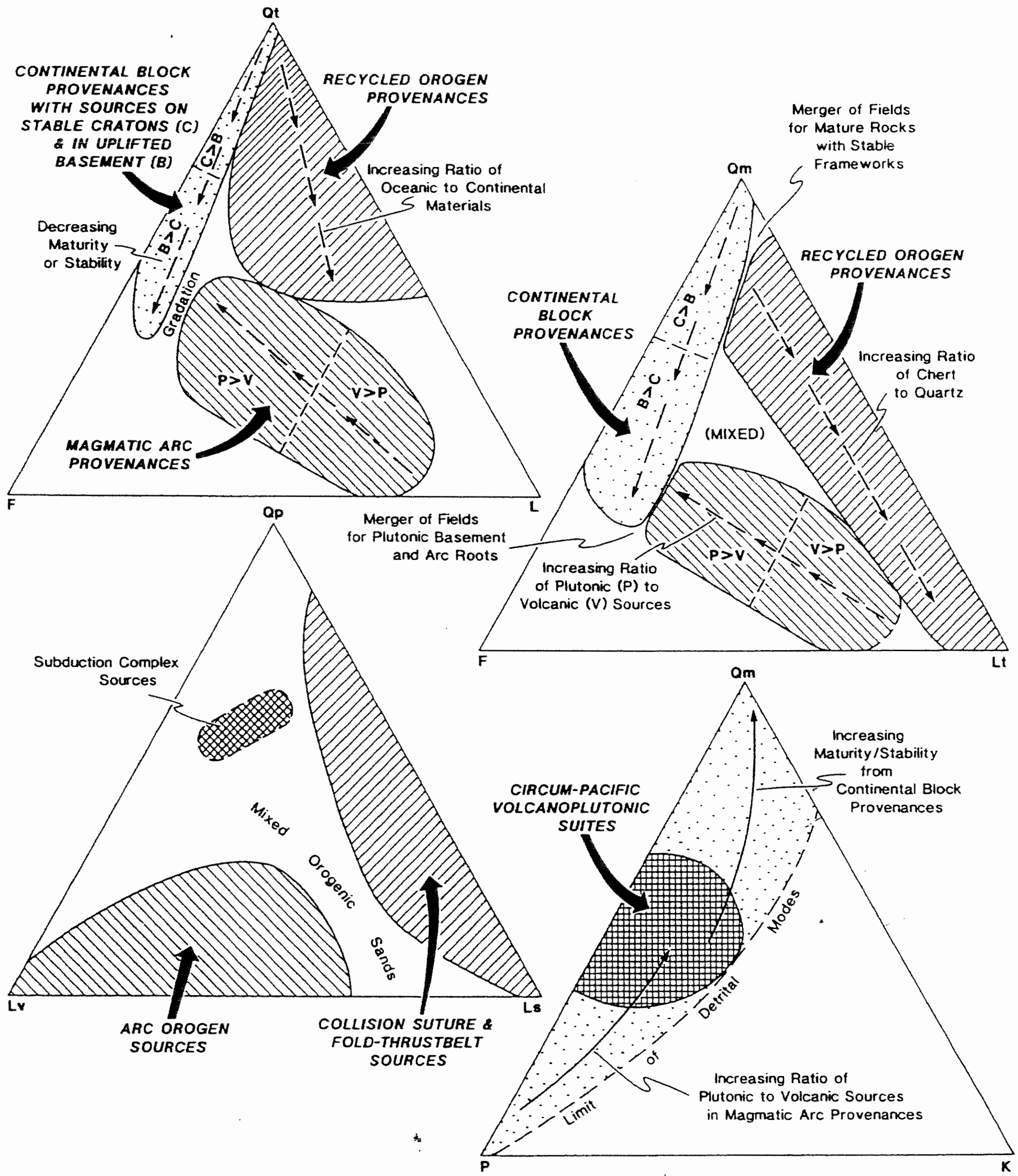


Figure 3.2: Distributions of mean detrital modes of sandstones derived from different provenance terranes plotted on standard ternary diagrams (Dickinson, 1988). Grain type symbols; Qt = total quartz (Qp +Qm); Qm = monocrystalline quartz; Qp = polycrystalline quartz; F = total monocrystalline feldspar (P+K); P = plagioclase; K = K-feldspar; Lt = total polycrystalline lithic fragments (L+Qp); L = unstable lithic fragments (Lv + Ls); Lv = volcanogenic lithic fragments; Ls = sedimentary and metasedimentary lithic fragments.

study of fossil palynomorphs the term paleopalynology may be used (Eisnor, 2002; Jansonius and McGregor, 1996).

There were several localities where clays, suitable for palynomorph analysis were found: Avondale, WD, BQ 1, BQ 2, and BQ 4. Only samples from localities that had a significant amount of clay (BQ1, BQ4, WD) were sent to Dr. Robert Fensome for palynological analysis at the Bedford Institute of Oceanography (BIO). Avondale and BQ 2 had small amounts of clay that were not suitable for use. BQ 1 was being extracted for construction purposes so only a small amount of the clay was obtained.

Palynomorphs are extracted from the rock through a maceration procedure that involves hydrochloric acid (to remove carbonates), hydrofluoric acid (to remove silicates), and sometimes additionally nitric acid (to selectively remove unwanted organic fractions and pyrite). The process usually also involves a heavy liquid (zinc bromide) flotation as well as sieving through micromesh sieves, both procedures further concentrating the palynomorphs. The resulting residue is then usually stained (typically with Bismark Brown) to make the fossils more readily observable. The process used at the Geological Survey of Canada Atlantic is slightly modified from Barss and Williams (1973).

3.2.2.2 Paleobotany

Charcoal pieces sampled from Fundy Gypsum Bailey Quarry were sent to Dr. H. Falcon-Lang for observation. The charcoal was studied to indicate the type and possibly the species of tree that it originated from. The presence of growth rings can be good indicators of climatic conditions so these are looked for when observing the samples. The blocks of charcoal were examined under the scanning electron microscope (SEM) by Dr. H. Falcon-Lang, and identified.

Chapter 4: Field Localities

4.1: Introduction: Field area covered by localities

The Cretaceous material found, in all field locations of this study are associated with Carboniferous evaporites of the Windsor Group. The four field localities (Avondale, Fundy Gypsum Bailey Quarry (BQ), Fundy Gypsum Wentworth Dark Quarry (WD), and McKay Settlement (MS) are within a 72-km^2 area of Hants County around the Avon and St. Croix Rivers (Fig. 4.1 & Fig. 1.1). Cretaceous deposits in this area are not shown on bedrock maps of the area. In BQ, up to 1 km separates the sites from one another, BQ1 and BQ4 being located the furthest apart west to east within the pit. All other field localities have one site that is being studied. The Avondale location is found 2 km N of the St Croix River fork, on the Avon River's eastern bank. The Bailey Quarry is located north of the St. Croix River in Mantua, ~5 km east of the Avondale location. Wentworth Dark Quarry is also part of the Fundy Gypsum Company operation and is located along the Wentworth Road to the south of the St. Croix River. These locations have not previously been documented to contain Cretaceous material. It is the goal of this report to give an accurate description and representation of the material found in these areas. The MS location was recorded by Dickie (1986) but no firm age or thickness were noted.

4.2: Avondale locality

The Avondale location consists of an in-place, cemented block, 3 m wide by 1.5 m high, of quartz-rich gravel with minor sand, clay and organic material (Figs. 1.2, 4.2). The whole field area is 15 m long, along the eastern beach of the Avon River. The gravel is clear white to light brown/grey and is well sorted, with particles from 2 mm to 1 cm with sparse larger clasts of sedimentary and black organic material up to 4 cm in

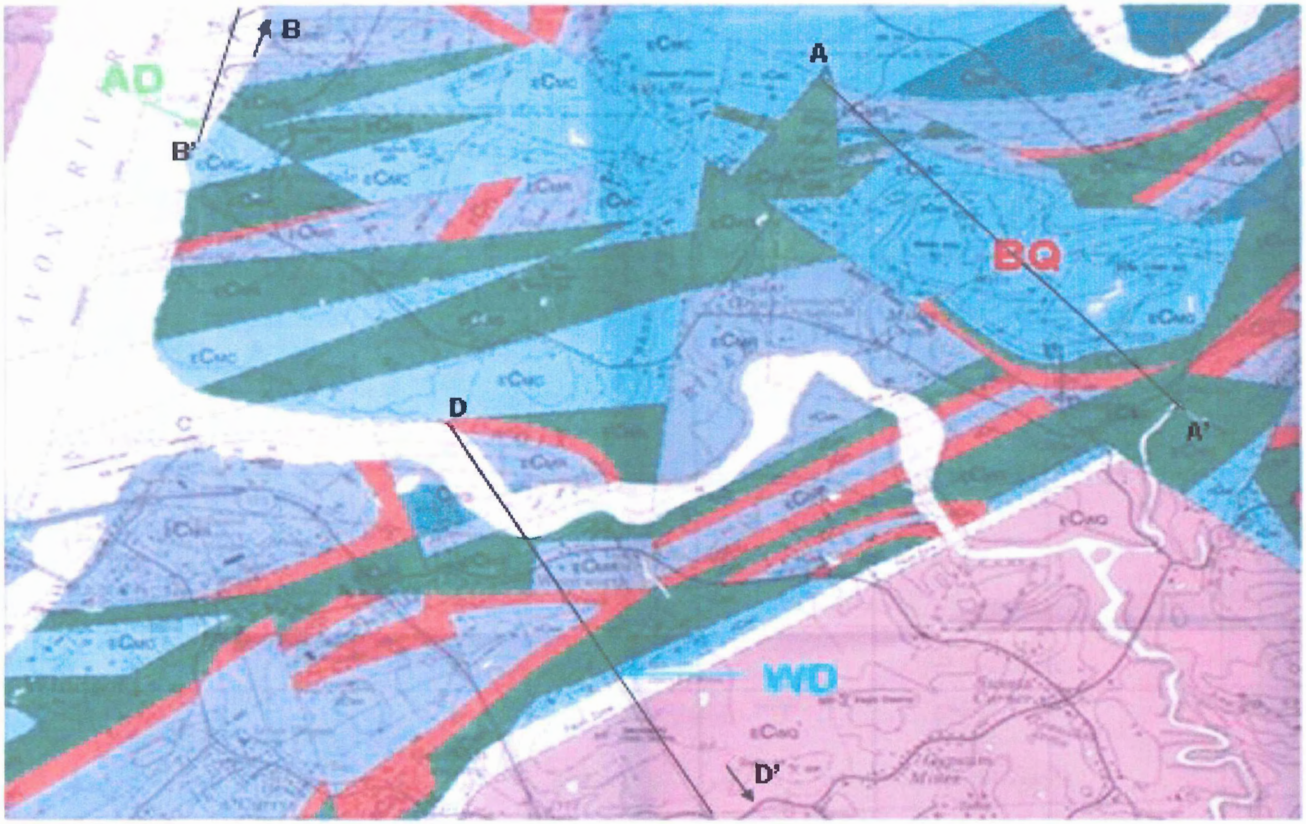


Figure 4.1: Overview of field localities covered in this study. Geological Map of the Windsor Area, Nova Scotia (modified from Moore and Ferguson map 86-2). BQ, Bailey Quarry; AD, Avondale; WD, Wentworth Dark Quarry. Scale 1:25000; 1cm = 0.25 km. Legend on following page.

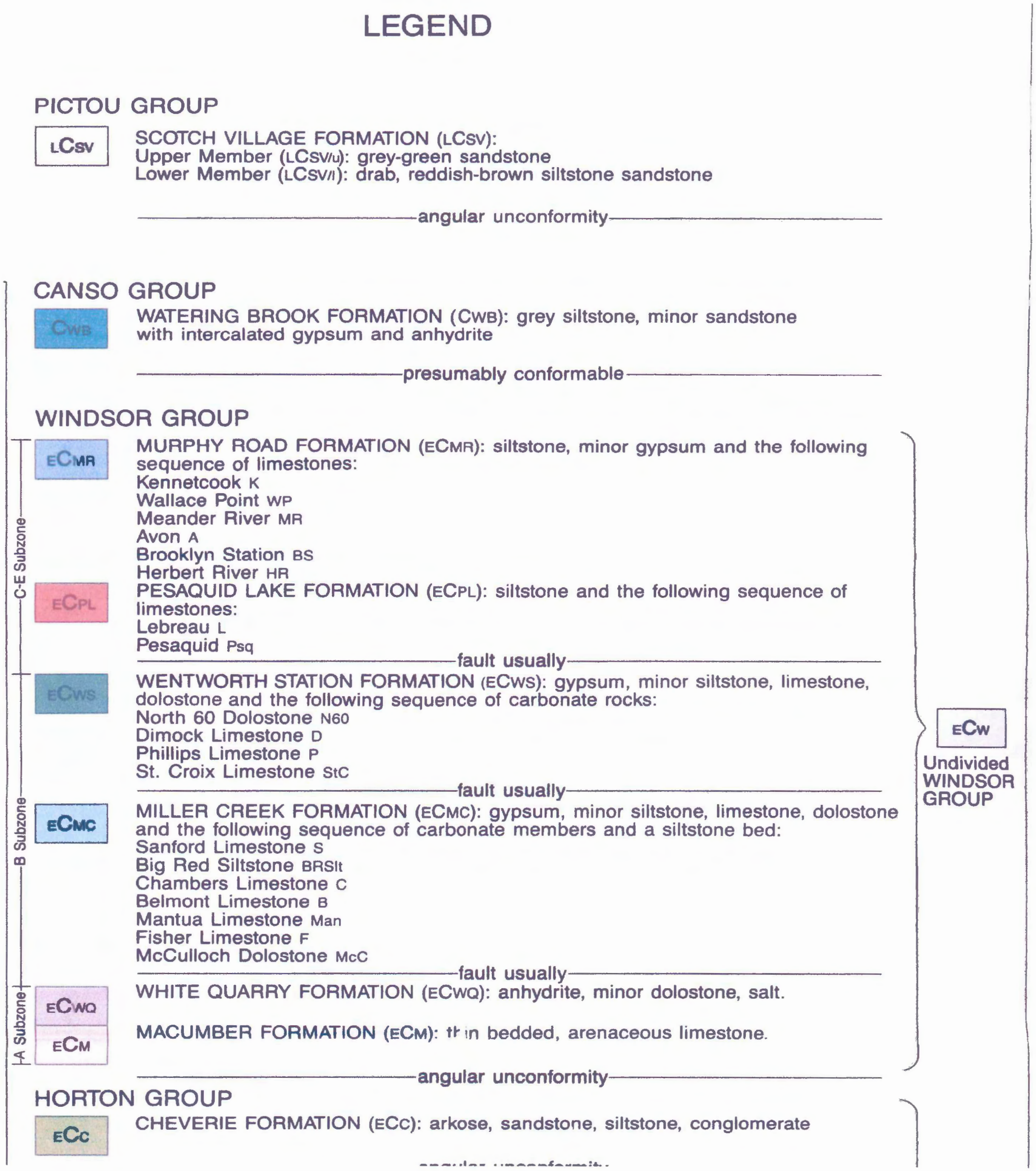


Figure 4.1: Legend

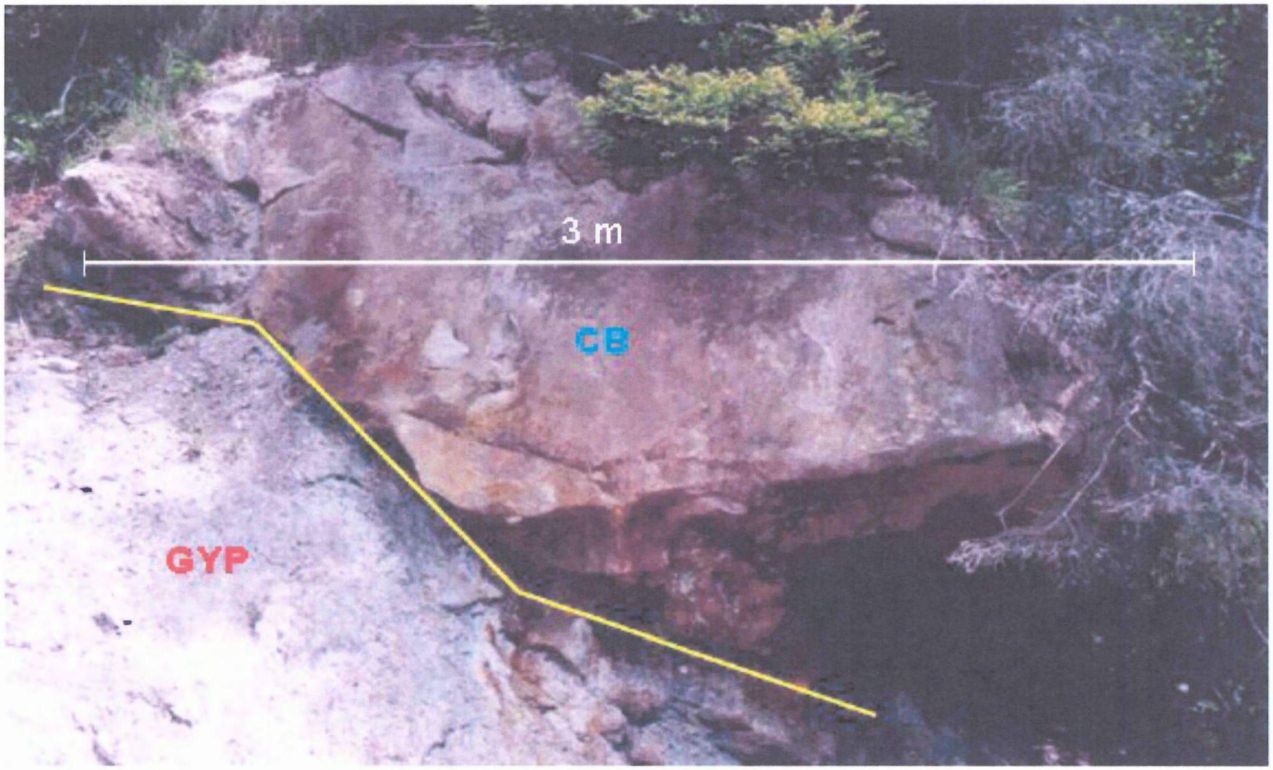


Figure 4.2: In place Cretaceous material (CB), and underlying Windsor Group gypsum (GYP). Yellow line indicates contact.

diameter, and cemented by gypsum. These sedimentary clasts are 1 cm – 3 cm in size and are < 5% of the unit that define layers. The block is underlain by the Miller Creek Formation of the Windsor Group, that consists of gypsum and limestone (Table 2.3). Possible bedding layers can be seen in the gypsum that are near vertical and highly contorted locally below and to the north of the cemented Cretaceous material. The gypsum here is severely weathered and broken, and a small modern day stream of water flows down the gypsum in this area. Fissures in the underlying gypsum have been filled with the same, cemented probable Cretaceous material found in the large block. These crack fills lie up to 7 m to the north and up to 2 m below the cemented block where a fold in the gypsum can be seen, 2 m high by 1.5 m wide. These cracks range from 5 cm to 15 cm wide and up to 1 m in length, where accessible (Fig. 1.2) and may represent karstification. In these cracks the Cretaceous material, cemented with gypsum is darker grey in colour. On the beach below the cemented block of Cretaceous material are large masses that have fallen from the block. These masses contain the same quartz-rich gravel as the block.

The Carboniferous material was deposited by the evaporation of saline water that periodically inundated the area. The arid climate during that time period allowed the evaporation of large amounts of floodwater into the Carboniferous evaporite deposits we see today. A major unconformity developed during the Cretaceous and probably Permian, Triassic, and Jurassic, following deposition of Carboniferous Scotch Village Formation (Fig. 4.1), and lower sea levels caused fresh water systems to dominate the area, giving rise to karst topography with crack fills and sinkhole deposits that are found in this area. Figure 4.3 shows a cross section from the Geological map of the Windsor Area, Nova

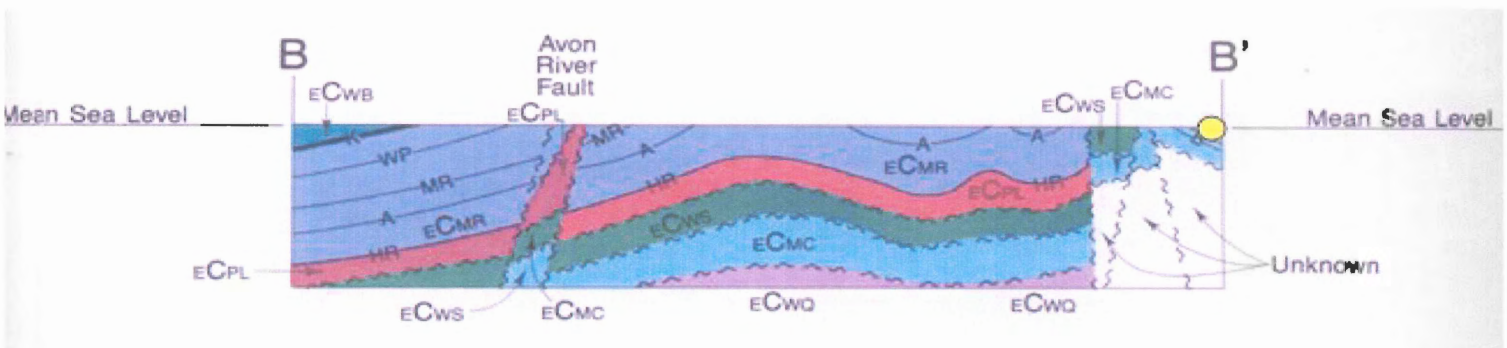


Figure 4.3: Cross section through the Avondale locality (B-B'; shown on Fig. 4.1). Yellow indicates Cretaceous material at Avondale (modified from Moore and Ferguson, 1985). Legend in Fig. 4.1.

Scotia with the addition of the Cretaceous material found at the Avondale location. This shows that the Cretaceous occurrence rests on strongly deformed, eroded and karstified material of the Windsor Group indicating that the unconformity spans ~ 225 million years of time.

4.3: Fundy Gypsum Bailey Quarry (BQ)

Cretaceous material in the Fundy Gypsum Bailey Quarry overlies the Miller Creek Formation, B-zone gypsum of the Windsor Group, which is found at the surface in the quarry (Table 2.3; Fig. 2.1). In the BQ, four locations where visited (Fig. 4.4). One locality is a rubble pile where Cretaceous material that was removed from locations in the quarry was dumped (BQ 3). Although not in place, this locality is noted here because it contains significant scientific material. The entire quarry area covers about 1 km^2 (Fig. 1.3).

4.4: BQ 1 (coordinates: N: 4987140, E: 5534393; taken by NSMTM29)

This location is found in the west side of the quarry (Fig. 1.3) and consists of sand and lenses or layers of clay. With till overlying, from 1 m to over 3 m thick, and gypsum below that was not exposed, the whole exposure of probable Cretaceous sand is approximately 3 to 4 m thick and 20 to 25 m long (Fig. 4.5). The sand is medium grained, with areas of fine-grained sand, that is light brown/cream and white in color and well sorted. Layering is evident, with planar to low-angle laminations on a cm scale (Fig. 4.6 A). The clay is found in thin layers or lenses in the sand (Fig. 4.6 B), dark grey to brown and are a few millimeters to 3 cm thick. This deposit of sand was being extracted for use in construction, so more extensive observations could not be obtained. The direct relation of this unit to the underlying Windsor Group gypsum was not seen in this area.

Figure 4.4: Bailey Quarry, Fundy Gypsum Company, localities shown.

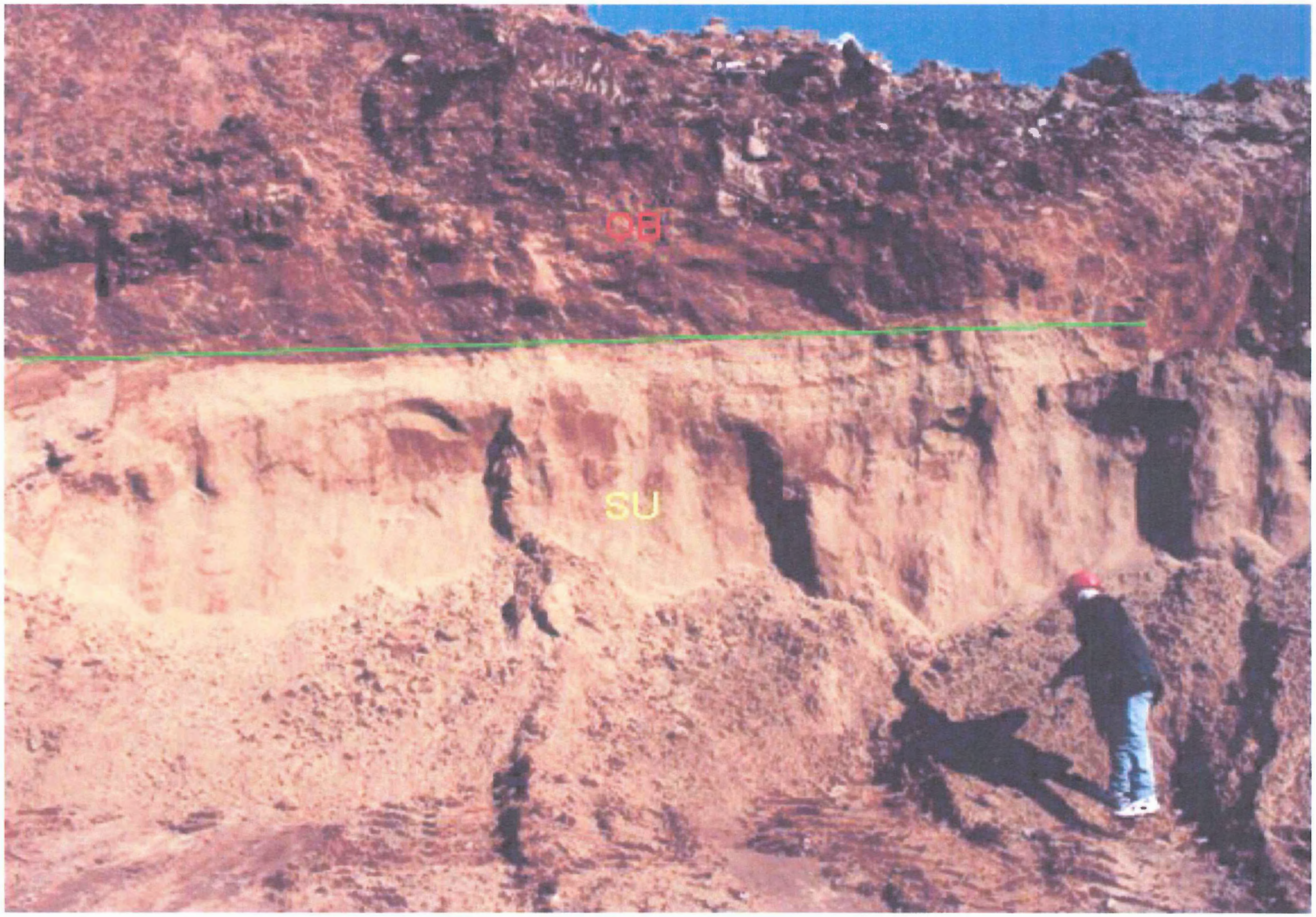


Figure 4.5: BQ 1 locality; SU, sand unit; OB, overburden; green line indicates top of the sand unit.

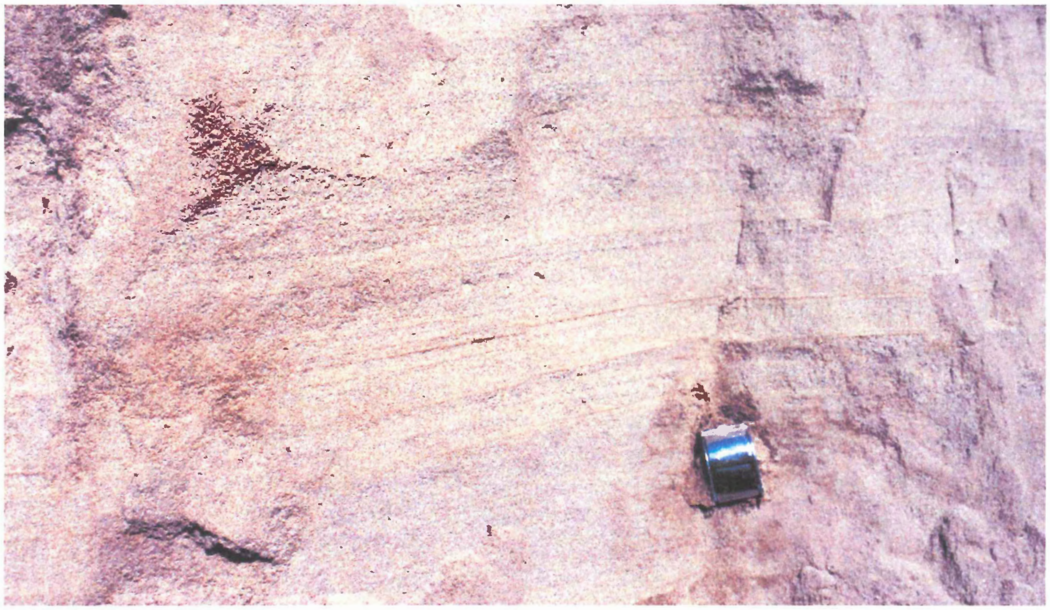


Figure 4.6 A: Sand structures from BQ1 sand unit. Lens = 1.5 cm.

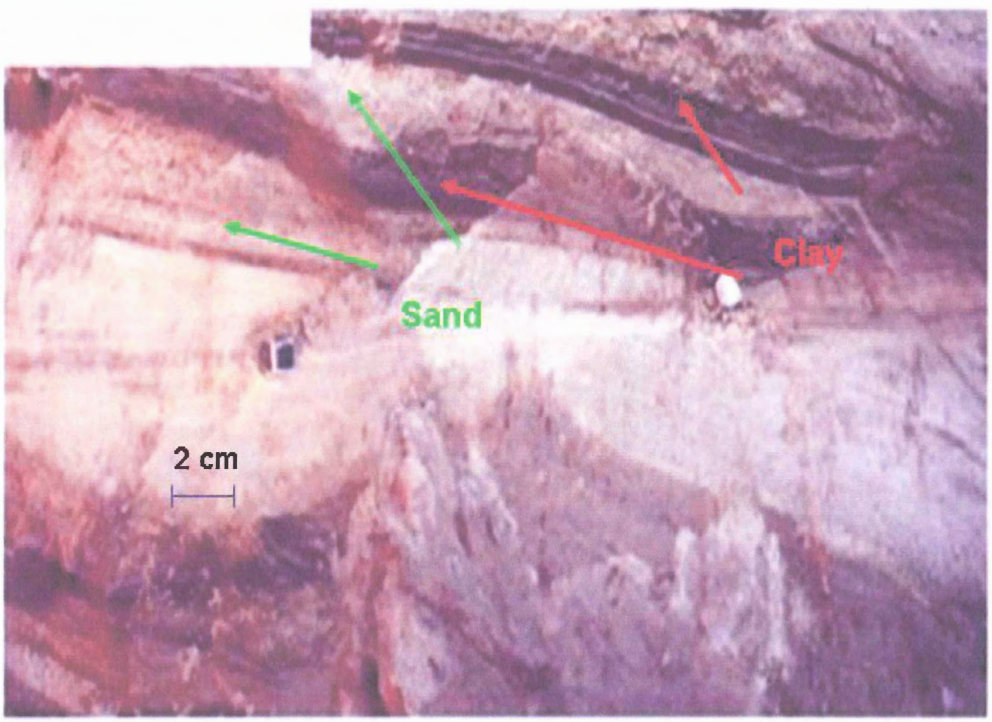


Figure 4.6 B: Sand and clay layers from BQ 1 sand unit.

4.5: BQ 2 (coordinates: N: 4986975, E: 5535343)

This location is found in the northeast portion of the quarry (Fig. 1.3), where a cemented block of Cretaceous material is 1.5 m wide by 1 m high (Fig. 4.7). This deposit may extend further into the surrounding gypsum but could not be traced. On the left of the block there is a faulted area, with white and dark grey banded 'chicken wire' gypsum, the Belmont Limestone, Fisher Limestone, and then the bottom of the B-zone gypsum in which the block sits. This area is a fold axis in the Windsor Group. The B-zone of the Windsor Group consists of intensively folded material that is covered with another layer of gypsum, the C-zone of the Windsor Group. This distortion of the gypsum could be explained by recent rubble that has fallen or a series of complex trench hollows in the gypsum. The cemented block resembles the material found at Avondale. Quartz-rich clear white and grey gravel of 1-6 mm size is cemented by grey gypsum. In this area there was more organic material in the probable Cretaceous. This black charcoal material is abundant, making up 5 % of the outcrop, and fragments range from a few mm in size to 1 cm.

4.6: BQ 3 (coordinates: N: 4986986, E: 5535639)

This location as mentioned above consists of a rubble pile of Cretaceous material that has been moved from other unknown locations in the quarry. This Cretaceous material contains abundant pyrite, fossilized trees (one sampled: 15 cm in diameter and 30 cm long) and charcoal fragments, 2 mm to 3 cm size. The Cretaceous material here is quartz-rich gravel, white to light grey and is well sorted with 2 mm to 6 mm grains. This area is found in the back northern portion of the quarry.

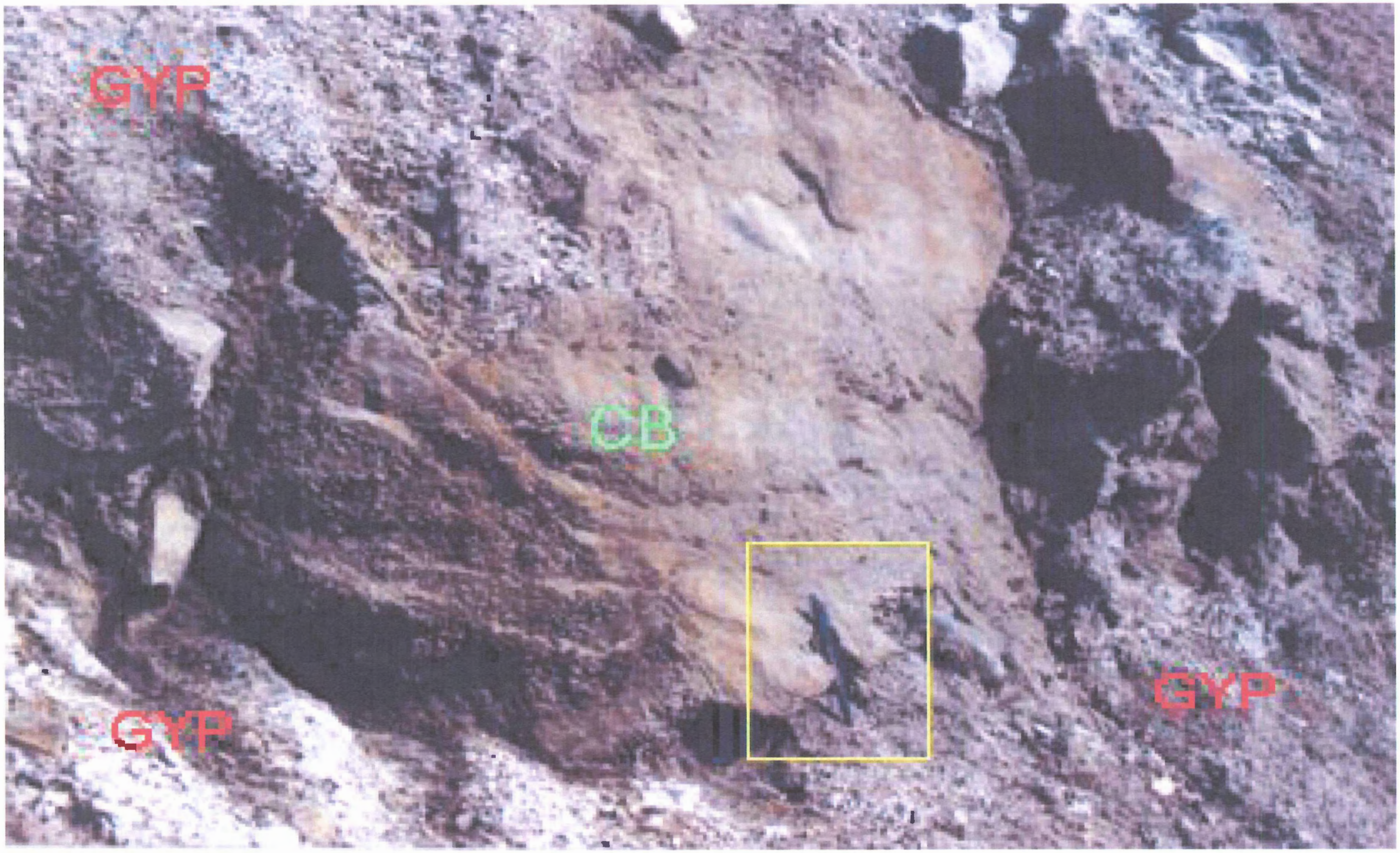


Figure 4.7: BQ 2 locality; CB, Cretaceous block, GYP, gypsum surrounding Cretaceous block, yellow surrounds pen (10 cm) for scale.

4.7: BQ 4 (coordinates: N: 4986701, E: 5535467)

The fourth area is in the east side of Figure 1.3 and is extensively weathered and eroded, with the top material washed down. The exposed Cretaceous strata are 6-7 m thick and 15-18 m wide (Fig. 4.8). Gypsum is found on either side of this outcrop. The western contact with gypsum is sharp and steep, and the gypsum is bordered by limestone that is almost vertical in relation to the sand and gravel. The eastern contact seems similarly steep but is partially covered with rubble. Blocks of gypsum, 0.5-1 m in size, are present in the sandy quartz-rich Cretaceous material near the eastern contact, and the gypsum is more fractured here. The Cretaceous material seems to occupy a large valley in the gypsum. The underlying unit is not seen in relation to the Cretaceous.

The material at this location consists of quartz-rich gravel, 2-7 mm in size, that is clear white and grey, not firmly cemented, and clays that are mostly chocolate brown with some dark grey patches and bands. The clays are slightly more abundant than the sand and become sand and gravel rich upward. Within this material, there is an abundance of charcoal and wood fragments that are associated with large greenish grey to brown pyrite nodules and gypsum. Near the top of the outcrop where material has been washed down there are also areas covered with pieces of charcoal, 1-6 cm in diameter (Fig. 4.9). The thickness of individual units could not be determined because of the extensive weathering at this locality.

4.8: BQ Core 685 (coordinates: N: 4986504.6 and E: 5535543.8)

A core, taken from just outside the northeast portion of the Bailey Quarry, shows an extensive section, more than 40 m, of Cretaceous material. Table 4.1 is the record of the full core logged by Matt Holleman of Fundy Gypsum Company in October 1999.

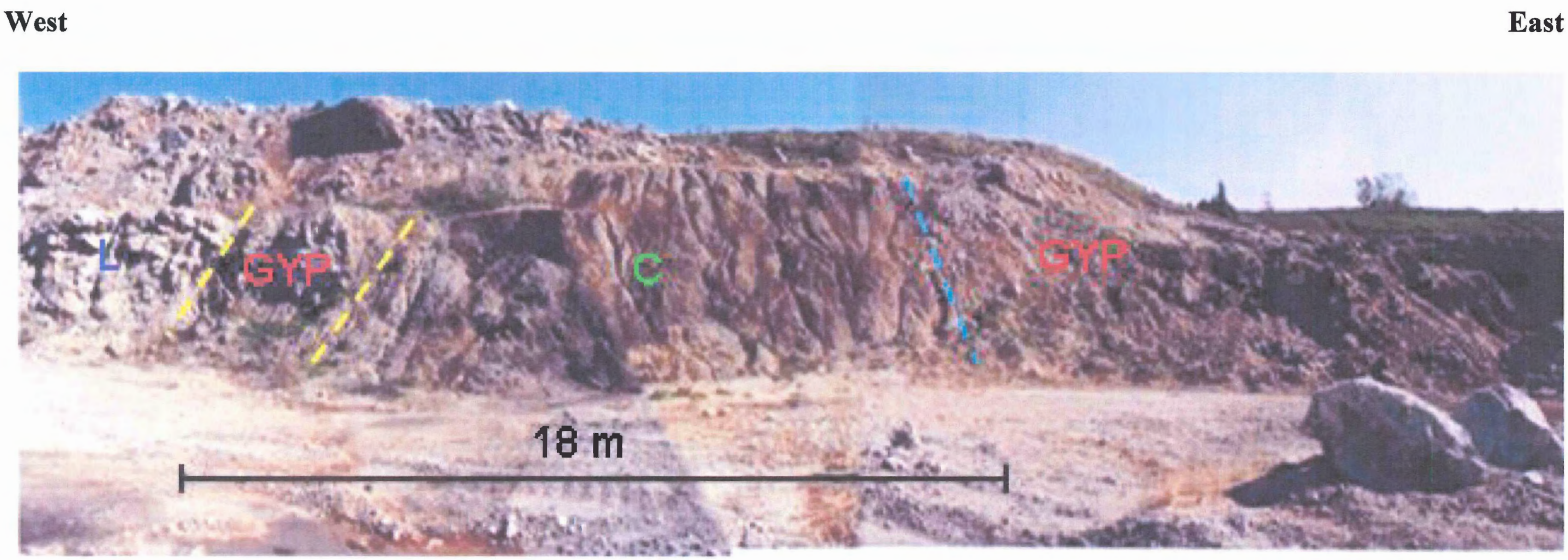
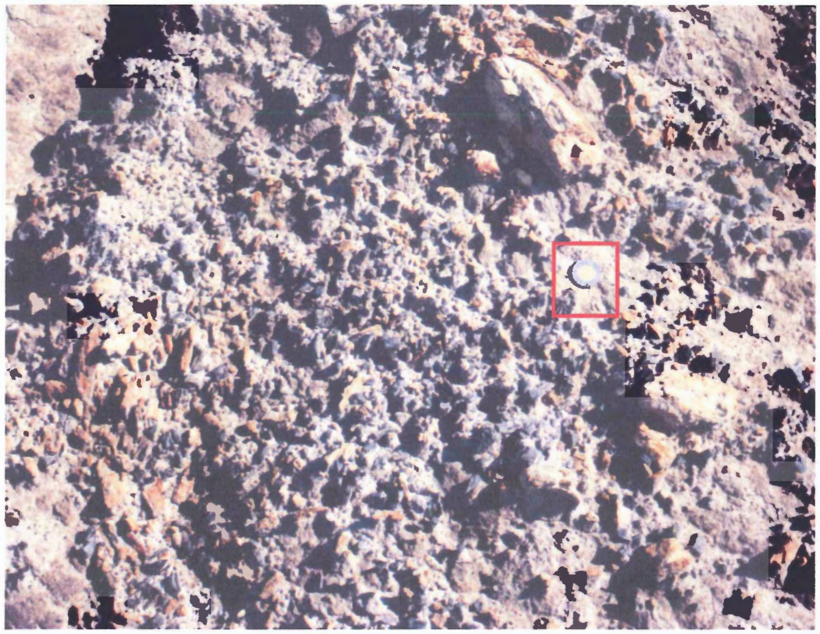


Figure 4.8: BQ 4 locality; C, Cretaceous material, GYP, Windsor Group, L, Limestone. Yellow and blue dashed lines indicate contacts, blue represents gradational.



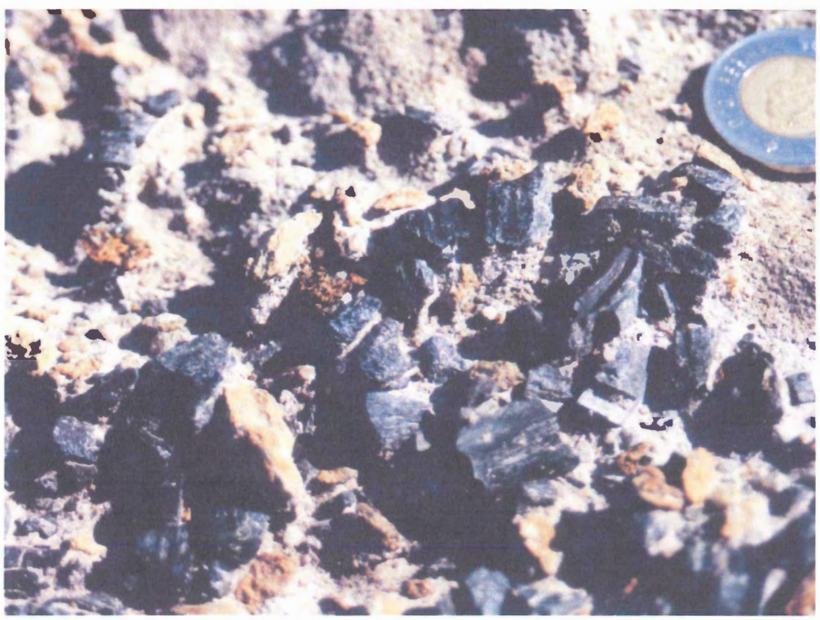


Figure 4.9: Charcoal found, BQ 4 locality, partially washed from outcrop. Two dollar coin is 2.5 cm in diameter.

Core 685 has a total depth of 90 m and was taken between the Bailey Quarry and the Millers Creek Quarry of Fundy Gypsum. Only about 20 feet of the core is available for observation at the Wentworth Road office of Fundy Gypsum (Fig. 4.10).

Figure 4.11 shows a cross section (A-A') through the Fundy Gypsum Bailey Quarry showing locations of Cretaceous units found there. Figure 4.12 A and B show cross sections through the Bailey Quarry as drawn by M. Holleman of Fundy Gypsum The exact location of the core can be seen in Figure 4.12 B. The core lies within an area of near-vertical strata as a deep narrow occurrence of soft sediments.

Table 4.1: Fundy Gypsum Company core drilling log used to show 48.3 m of probable Cretaceous strata at the top of core 685, Bailey Quarry.

Depth (m)	Lithological Description
0-20	Overburden; clay
20-24	Gypsum, medium grey, abundant dark grey sandstone
24-27	Mud, silt, clay with gypsum fragments, cavity fill.
27-29.7	Mud, light olive green, silty clay, weathered limestone.
29.7-36.5	Siltstone, dark to medium grey, sandstone, non-calcareous, white gypsum veins throughout, some 1 m between clayey cavity filling at 34.2, dip near vertical, core complete to crumbly.
36.5-48.3	Gypsum dark grey, abundant dark grey siltstone inclusions and stringers
48.3-90	Siltstone, light grey-brown/dark grey/grey, probably dolomite, some sand inclusions, abundant white gypsum veins and inclusions, bedding generally indistinct, dip near vertical, some sandstone beds, same as 29.7. new unit? Base on St. Croix Limestone? Similar to outcrop in quarry
90	END

4.9: Wentworth Dark Quarry Location (WD) (coordinates: N: 4981830, E: 5532892)

In the Fundy Gypsum Wentworth Dark Quarry (Fig. 1.4), a possible channel body, 1 m thick by 3-6 m wide consists of sands that are associated with lignitic deposits, set in the gypsum. The sand is fine-to coarse-grained, with sparse quartz gravel with 2 mm-6

Figure 4.10: BQ core taken between Bailey Quarry and Millers Creek Quarry, Fundy Gypsum Company. Gypsum cemented Cretaceous material. There are 5 feet per row, 45.5 (top) - 60.5 feet and 82 – 90 feet (bottom) (see table 3 for rock types).

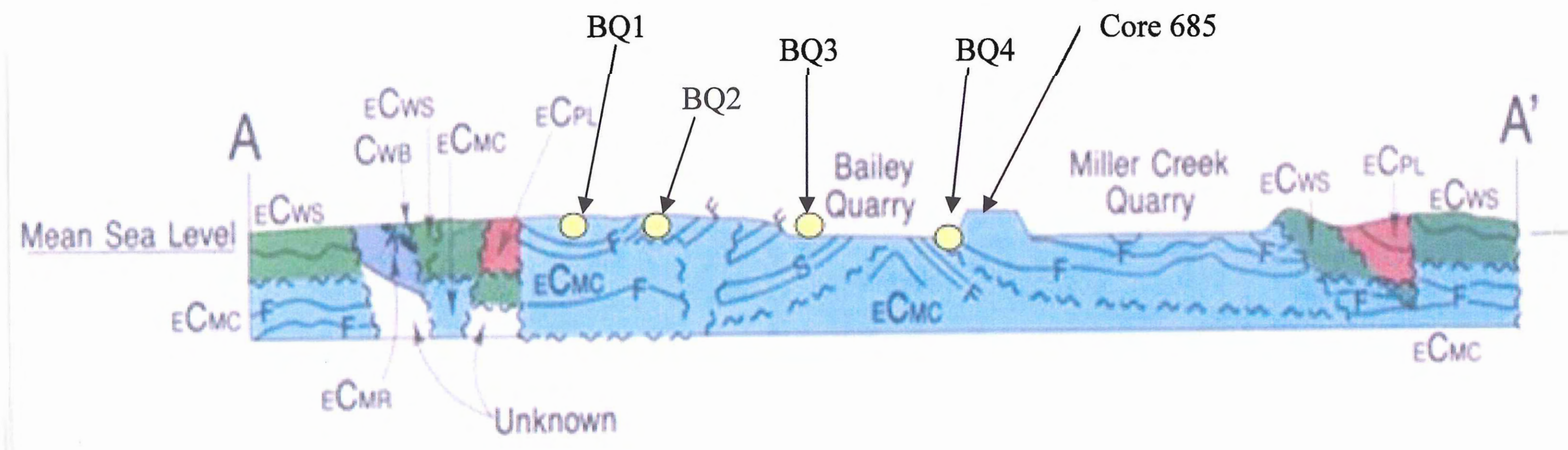


Figure 4.11: Cross section through the Bailey and Millers Creek Quarries, Fundy Gypsum Company. Yellow indicates relative position of Cretaceous units BQ 1-4 in order from A - A' (modified from Moore and Ferguson, 1985). Legend in Fig.4.1.

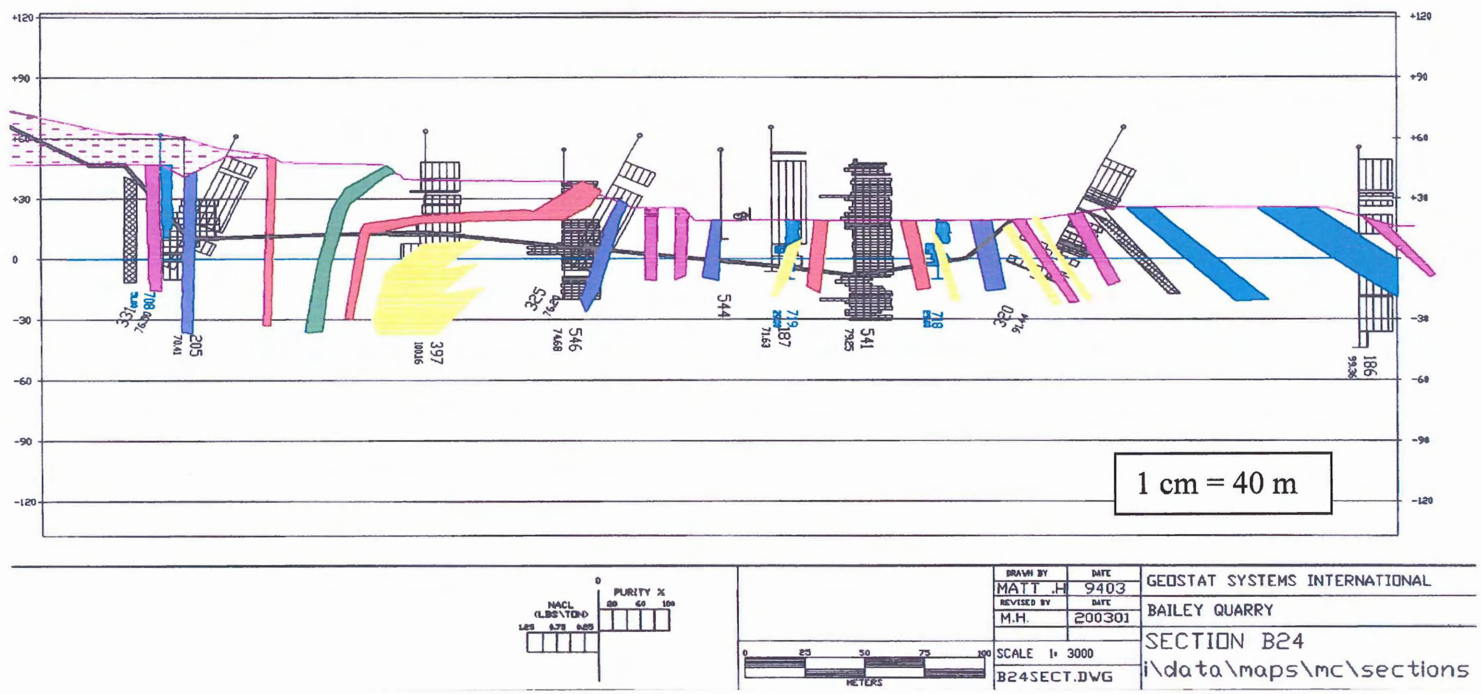


Figure 4.12: A) Cross section through Bailey Quarry (section B24), Fundy Gypsum Company (drawn by M. Holleman). Green = Cretaceous; Yellow = anhydrite; White = gypsum, anhydrite, or unknown; All other colours = limestones; Vertical lines = cored holes, black boxes indicating preserved core.

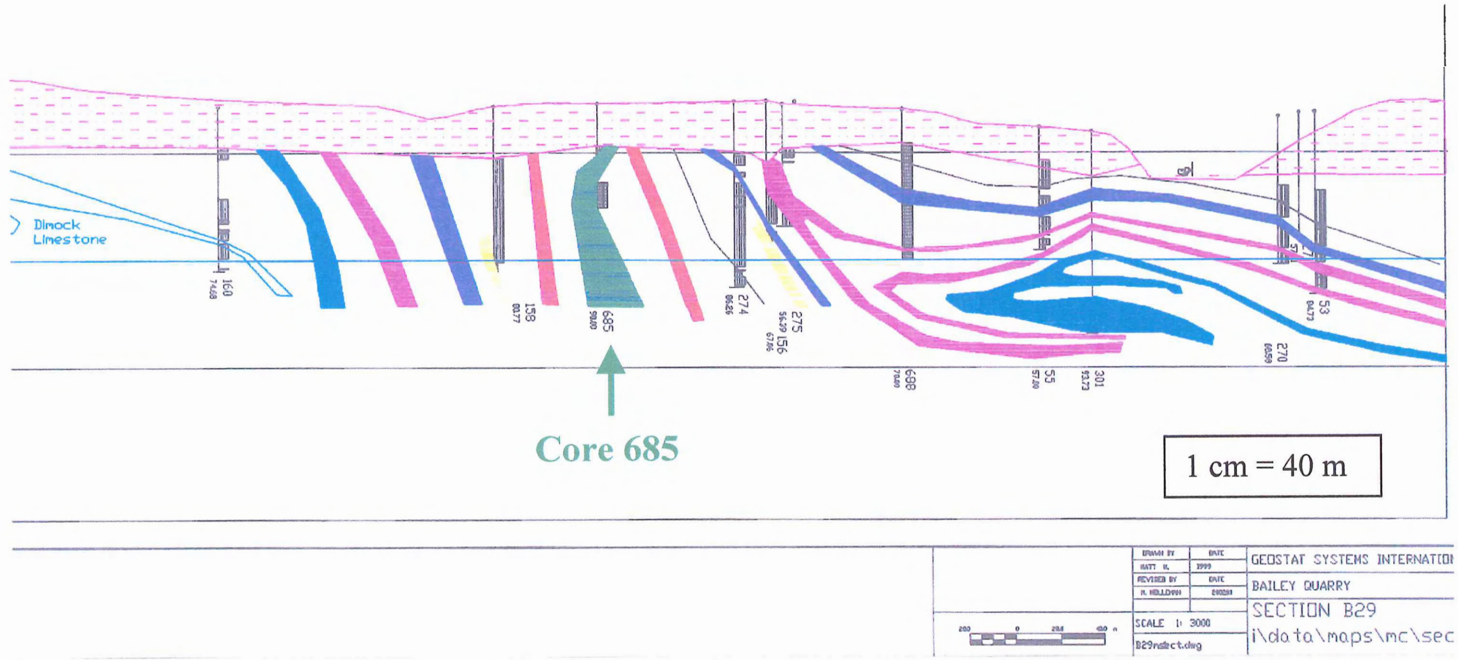


Figure 4.12: B) Cross section through Bailey Quarry (section B29), Fundy Gypsum Company (drawn by M. Holleman). Green = Cretaceous; Yellow = anhydrite; White = gypsum, anhydrite, or unknown; All other colours = limestone; Vertical lines = cored holes, black boxes indicating preserved core.

cm particles and is a light brown/cream color. The lignite is dark brown to black and is easily broken into pieces. The lignite material was quite abundant and was found in patches that ranged in size from centimeters to meters. It is unclear whether these lignite occurrences are a distinct layer or inclusions of material. In a related small outcrop a thin, 10-15 cm thick by 20 m long layer of dark brown to black crumbly organic material is found (Fig. 4.13: coordinates: N: 4981840, E: 5532923). This area is located across the quarry from the sand unit (Fig 1.4); as noted in Chapter 6 the latter outcrop is probably Quaternary in age. Figure 4.14 shows a cross section through the Wentworth Dark Quarry with the Cretaceous material added. This shows that the Cretaceous material, while still overlying the Miller Creek Formation, is near the contact with the White Quarry Formation gypsum.

4.10: McKay Settlement Location (MS)

The McKay Settlement occurrence is described in Chapter 2. On the south-facing side of an abandoned gypsum mine, a deposit of fine silica gravel was uncovered (Dickie, 1986). The material is quartz-rich gravel, 2-7 mm in size that is light brown to yellow in colour, possibly due to weathering. This gravel has been removed from its original place and dumped in piles, but no in-situ outcrop was observed at this location in July 2003.

4.11: Interpretations of Depositional Environment

The Chaswood Formation, across previous outcrops in Nova Scotia, is predominantly composed of terrestrial sediments, dominated by quartz-rich sand and gravel (silica-rich), multicoloured kaolinitic clays, and lignitic clays and lignite (Stea and Pullan, 2001). These previously documented deposits closely resemble those in the study area, apart from the extensive kaolinite clays. Quartz-rich gravelly sands in the study area

Figure 4.13: Organic layer, WD locality.

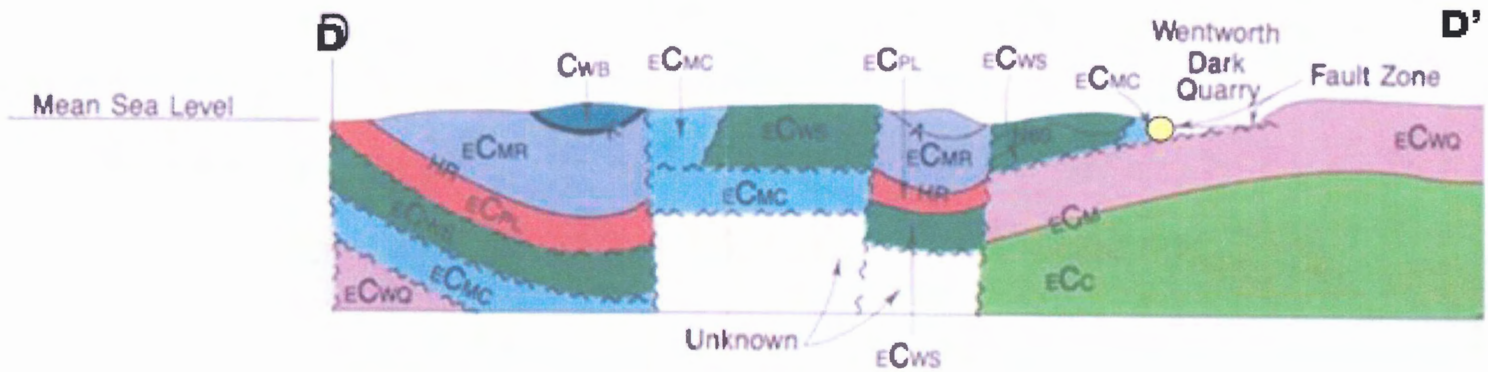


Figure 4.14: Cross section through Wentworth Dark Quarry, Fundy Gypsum Company. Yellow indicates relative position of Cretaceous unit (modified from Moore and Ferguson, 1985). Legend in Fig. 4.1.

are white to grey and, as in the McKay Settlement area, may be stained yellow/orange to purple from Fe-oxide weathering. The grain size varies from the fine-grained sands found in BQ1 and WD to coarse gravels found in Avondale and BQ 2 and 4. The quartz-rich gravels show sub-rounded to angular grains, and sub-angular grains with smaller amounts of sub-rounded and rounded grains dominate the sand. These sediments, although dominated by quartz, show trace amounts of muscovite, clay, and heavy minerals.

Gypsum was present as local cement in gravelly sand units at the West Indian Road Pit with rare feldspars (Stea and Pullan, 2001). The lithology of the material here, as well as the occurrence of the cement, resembles the gravelly sandy units found at Avondale, BQ2, BQ3, and BQ4.

Avondale, BQ2, and BQ4 have similar quartz-rich gravelly sand with no indication of graded sequences. These units resemble the upper and lower members of the Chaswood formation, where gravelly portions are presented locally, mainly confined to basal lags (Stea and Pullan, 2001). Chaswood localities show thick fining upward cycles, which are not apparent in this study. In BQ4 there was also the presence of grey silty clay, finer dark brown clay units and charcoal. The middle member also has organic-rich clay and abundant charcoal (Stea and Pullan, 2001). The upper member has packages of sands that are more enriched in clay compared to the lower member and has lignite associated with them (Stea and Pullan, 2001). These sand-dominated units most closely resemble the BQ1 and WD localities in this study where finer grained sands and clay are associated with lignite material.

Identification of the Chaswood upper and lower members at other localities as the deposition of fluvial systems is indicated by fining-upward sequences, coarse clastic material, and unidirectional flow features, with little evidence for deltaic sedimentation such as coarsening-upward facies and progradational clinoform sand bodies (Stea and Pullan, 2001). The gamma logs that depict sharp upper and lower boundaries of most of the channelized sand units suggest that abrupt channel switching occurred (avulsion) rather than the systematic migration characteristic of a highly sinuous system (Stea and Pullan, 2001). The mechanism by which the sands and gravels were deposited was efficient (based on grain size) and this supports the interpretation of a river or channel system where channels change rapidly, trapping fine to medium-grained deposits. These observations suggest deposition in a braided-fluvial system. Braiding of fluvial systems is typically found in the upper reaches of the system as the river comes out of the source area, so these areas usually have abundant coarser sediments (sand and gravel), and rapid discharge fluctuations, which lead to rapid channel shifting and local erosion of banks (Prothero and Schwab, 1996). The sands and gravels may represent variously channel-base sands, bars, and sand flats. The Avondale, BQ4, BQ2, and MS localities may correlate with the upper reaches of the braided fluvial system where they are dominated by quartz-rich gravel units that may form longitudinal bars. Islands or floodplains may also form above the sand flats in the river system, which are dominated by fluvial sands and can range from 50 m to 2 km long (Cant, 1978). These sand flats consist of planar cross-beds and parallel laminations (Cant, 1978), which may correspond to those found in BQ1 locality (Fig. 4.6 A), attributing the sand unit to sand flats within a braided river system.

The middle member, 5 m thick and dominated by organic-rich fine-grained sediments and lignite was interpreted as an estuarine or lacustrine system (Gobeil, 2002).

Abundant charcoal is also found in the member, which indicates forest fires, possibly with rapid sedimentation as a result of fire-caused soil erosion (Stea and Pullan, 2001). Given these aspects, localities WD and BQ4 with thick clay and lignite occurrences may be considered part of this lacustrine system. The localities Avondale and BQ2, with small pieces of clay and charcoal may represent small areas of river channels.

The gypsum cement of some material in this study is also seen in the middle member at West Indian Road. In the middle member the cause of the cementation is not known but short-term marine inundation has not been ruled out (Stea and Pullan, 2001). The gypsum cementation in this study area is very localized and is especially notable where sands and gravels are deeply inset into Windsor gypsum, which may indicate local dissolution and precipitation of sulphates.

The localities in this study resemble the characteristics of the Chaswood Formation studied elsewhere, and the depositional environments also appear broadly similar. However it is not possible to place the individual localities firmly into a member classification and earlier defined members are probably local.

Chapter 5: Sedimentary Material

5.1: Grain size analysis

Sand samples BQ1S1A and BQ1S1B were taken from the northern and southern portions of the sand unit in BQ1, respectively. The results of the analysis are listed in Table 5.1. Starting amount for these samples were 70.50 g (BQ1S1A) and 70.05 g (BQ1S1B). The table shows that the majority of sand is in the 1.5 to 4.0 phi range with 96 % (BQ1S1A) and 95.5 % (BQ1S1B), with only 2.1 % (BQ1S1A) to 1.6 % (BQ1S1B) between –1.0 and 1.5 phi, and 1.9 % (BQ1S1A) and 2.8 % (BQ1S1B) finer than 4.0 phi. The two samples show a similar weight distribution with small differences in the proportions larger than 4.0 phi and smaller than 1.5 phi: in BQ1S1A there is more sand coarser than 1.5 phi and less finer than 4.0 phi. There may also be changes within the fractions due to slight discrepancies between total starting amounts and sieve totals, 0.350 g (BQ1S1A), and 0.020 g (BQ1S1B).

The weights were plotted against the size fractions to produce line graphs so that the distribution of grain size could be seen more readily (Figs. 5.1 & 5.2). The graphs show that, at about 2.0 phi a sharp increase in slope (sand size fraction amounts) begins, with a gradual increase in the –1.0 to 2.0 phi range, a leveling off at 3.0 phi and a sharp decrease in the 3.0 and >4.0 phi. These plots show a very well sorted fraction between 1.5 and 3.0 phi with a strong decrease in concentration between 3.0 and 3.5 phi and a peak in concentration at 3.0 phi with an average weight of 27.441 g between the two samples.

Table 5.1: Size (phi), weight (grams), weight percent, and cumulative weight percent for sand samples BQ1S1A & BQ1S1B.

Sample	**BQ1S1A**	**BQ1S1A**	**BQ1S1A**	**BQ1S1B**	**BQ1S1B**	**BQ1S1B**
Size (phi)	**Weight (g)**	**Weight Percent**	**Cum. Weight %**	**Weight (g)**	**Weight Percent**	**Cum. Weight %**
-1.0	0.110	0.157	0.157	0.010	0.014	0.014
-0.5	0.106	0.151	0.308	0.086	0.123	0.137
0.0	0.100	0.142	0.450	0.128	0.183	0.320
0.5	0.258	0.367	0.817	0.216	0.308	0.628
1.0	0.845	1.205	2.022	0.725	1.035	1.663
1.5	3.456	4.927	6.949	3.030	4.327	5.990
2.0	7.378	10.517	17.466	6.563	9.372	15.362
2.5	17.441	24.862	42.328	17.690	25.261	40.623
3.0	27.170	38.731	81.059	27.711	39.570	80.193
3.5	7.060	10.064	91.123	8.522	12.169	92.362
4.0	4.840	6.899	98.002	3.380	4.827	97.189
>4.0	1.378	1.964	99.986	1.967	2.809	99.998
Total	**70.150**	**100%**	**100%**	**70.030**	**100%**	**100%**
Starting weight	**70.500**			**70.050**		

Cumulative weight percent curves were also derived from information in Table 5.1 and can be seen in Figures 5.3 and 5.4. From the cumulative curves, percentiles can be extracted to allow calculation of the graphic mean, inclusive graphic standard deviation (sorting), and inclusive graphic skewness (Boggs, 2001). Table 5.2 gives the calculated values from the cumulative curves.

Table 5.2: Cumulative curve calculations for mean, sorting, and skewness.

Sample →	**BQ1S1A**	**BQ1S1B**
Graphic mean (phi)	2.53	2.53
Inclusive graphic standard deviation (sorting) (phi)	0.63	0.65
Inclusive graphic skewness	0.077	-0.105

Sand size fraction (phi) and weight (g) for sample BQ1S1A

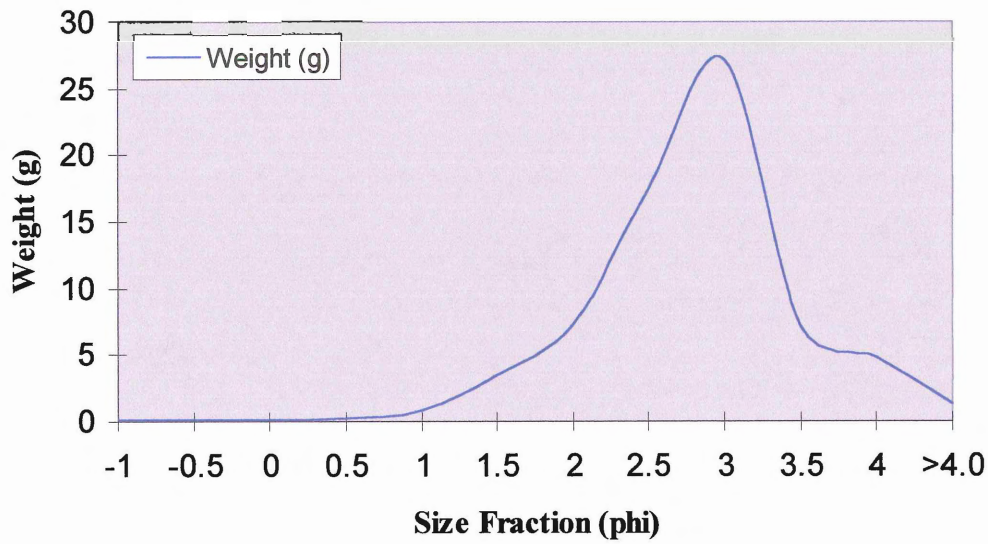


Figure 5.1: Distribution of sand size (phi) vs. weight (g) for sample BQ1S1A.

Sand size fractions (phi) and weight (g) for sample BQ1S1B

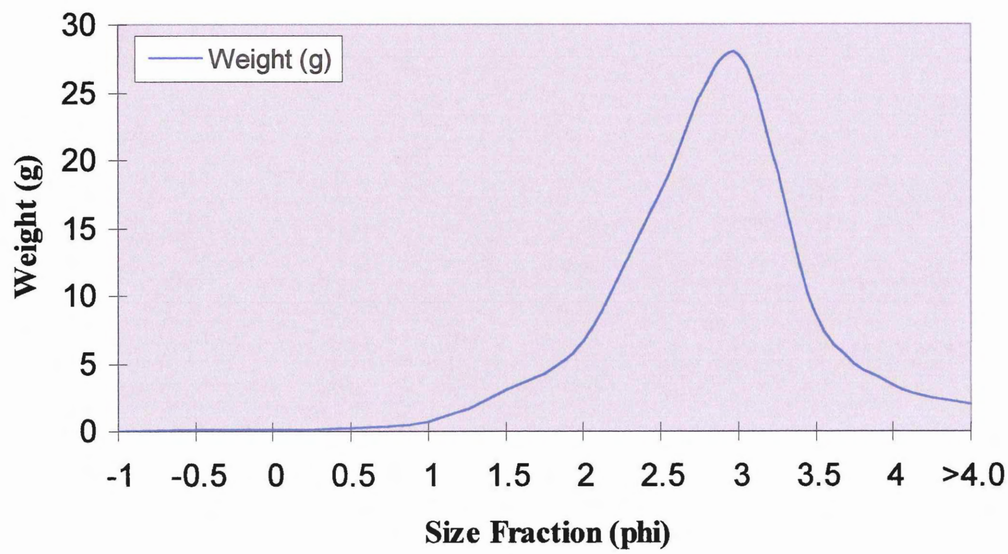


Figure 5.2: Distribution of sand size (phi) vs. weight (g) for sample BQ1S1B.

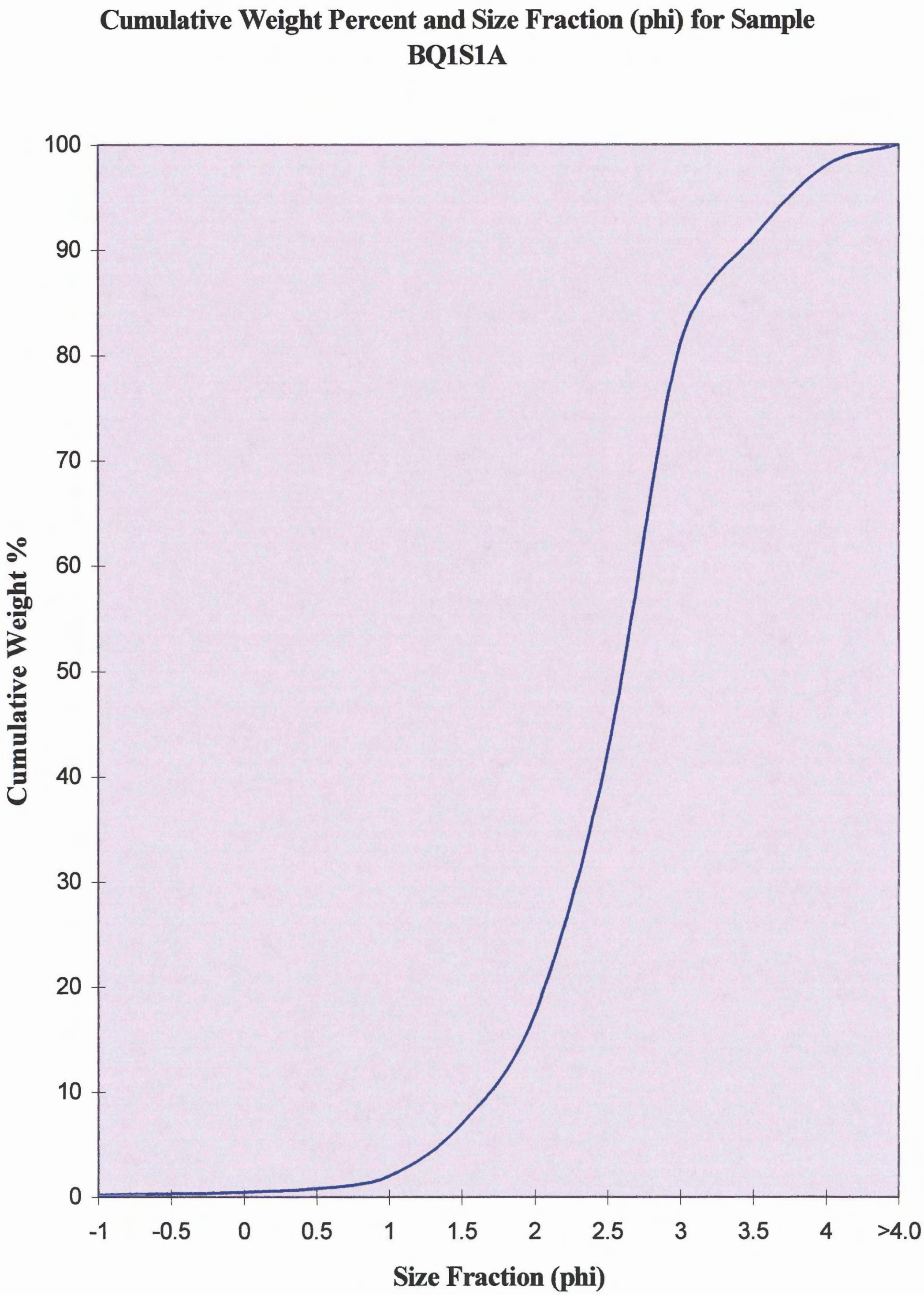


Figure 5.3: Cumulative weight percent vs. sand size (phi) for sample BQ1S1A.

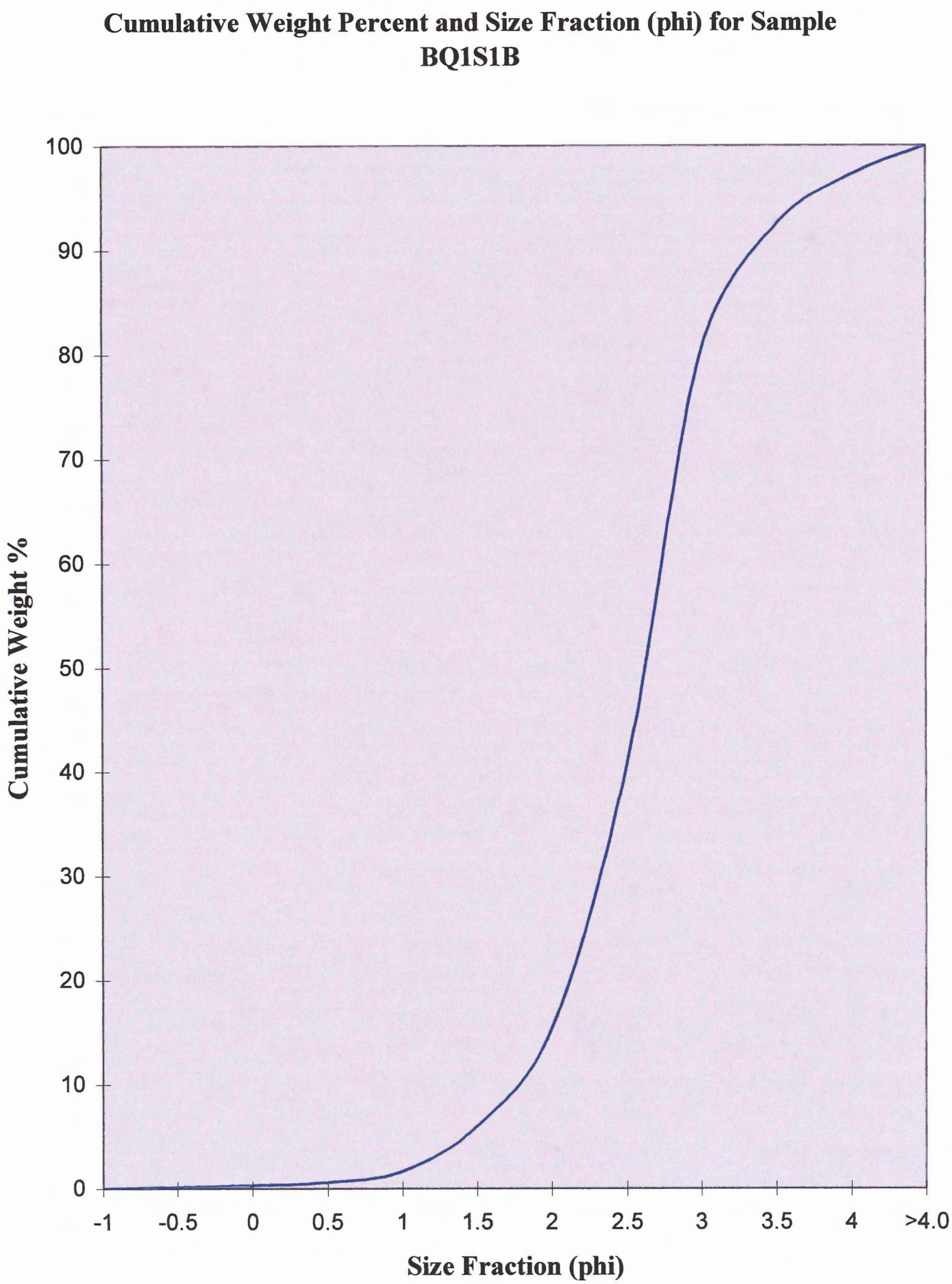


Figure 5.4: Cumulative weight percent vs. sand size (phi) for sample BQ1S1B.

Using the parameters set out in Boggs (2001) from Folk and Ward, verbal terms are given for the numerical values derived. For the graphic mean both samples have the same values of 2.53 phi, medium-grained sand. For the sorting parameter the two values are similar, implying moderately well sorted sand. For the skewness parameter, both samples lie within the +0.10 - -0.10 range, nearly symmetrical. These results show the close similarity of these two samples.

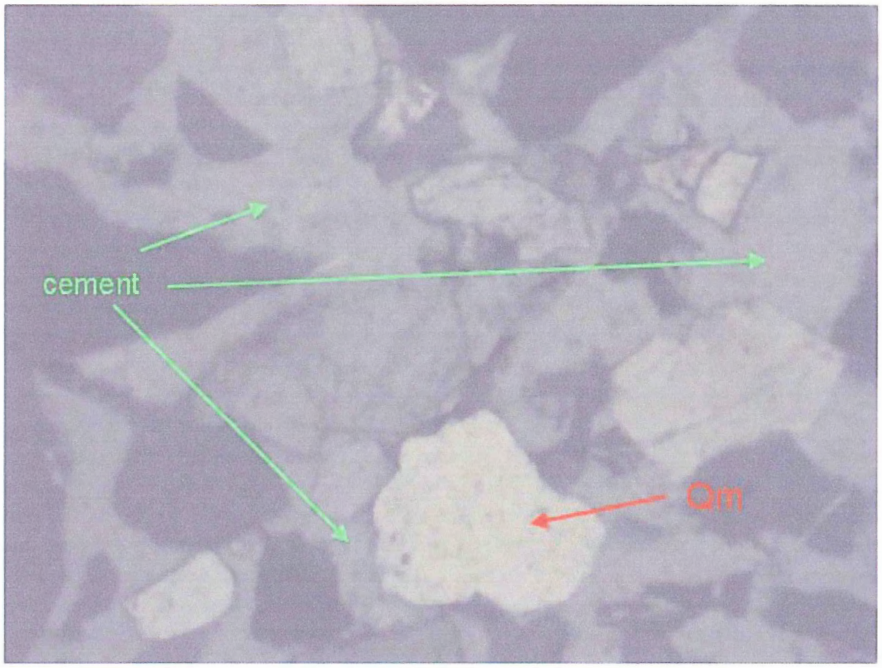
5.2: Thin sections

Avondale: Slides: KF-03-1 to KF-03-4

The sediments in this set of thin sections have undergone efficient sorting, as indicated by the limited distribution of grain size. Below are descriptions of grains that were observed. Tables 5.3 and 5.4 give a summary of the grain types and their percent in the sample out of 500 points recorded.

The quartz is both mono-and polycrystalline, with the majority and the largest grains being monocrystalline (Fig. 5.5 A & B). About 50% of the grains are fractured and surrounded by gypsum cement (Fig. 5.6 A & B). There are clean extinction patterns seen, as well as undulose, which suggests different sources or types of quartz grains (Fig. 5.7). Inclusions of muscovite, rutile and zircon (Fig. 5.8) are found with the quartz. The majority of the quartz grains also have a rim of clay and iron oxides surrounding them, seen as a yellow/red outline (Fig. 5.9). Some grains had partial crystal faces. A few grains show evidence in their appearance of metamorphic origin. Authigenic overgrowths can also be seen in some grains.

A



B

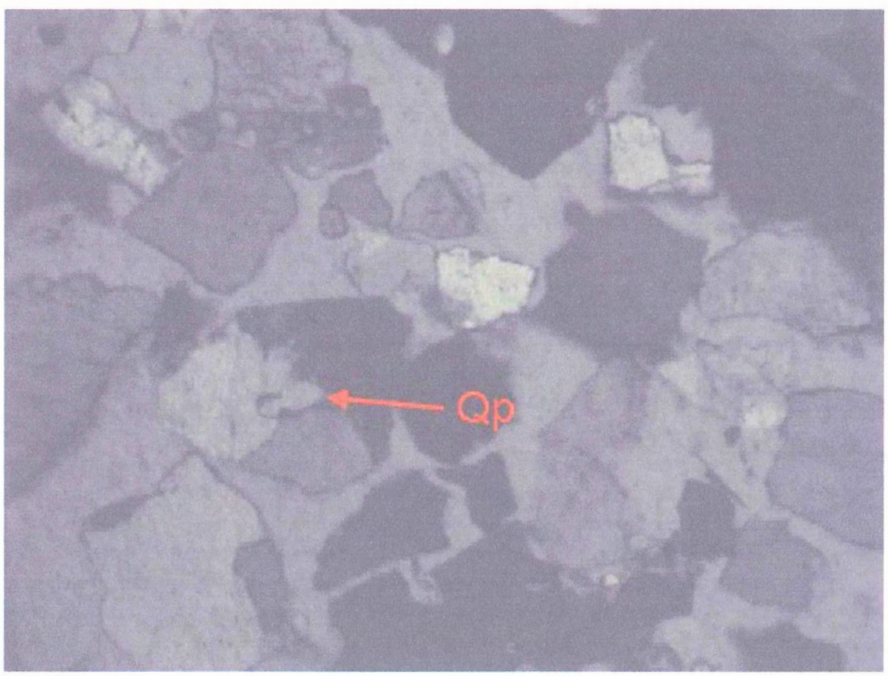
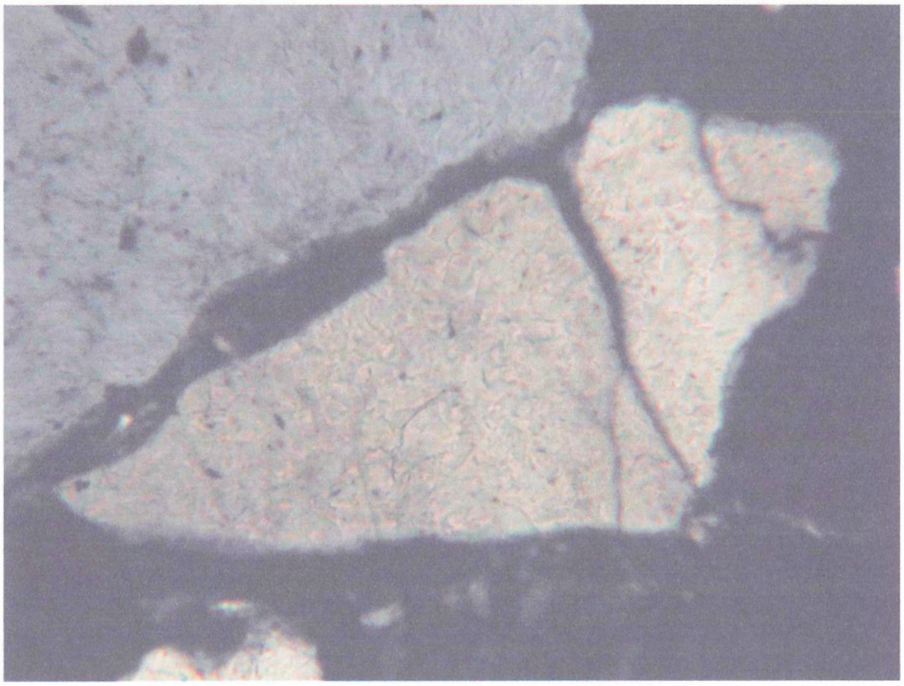


Figure 5.5: A) Monocrystalline quartz (Qm; red) and gypsum cement (green); Avondale slide KF-03-4. Magnification X 3.2, XPL. **B)** Polycrystalline quartz (Qp); Avondale slide KF-03-2. Magnification X 3.2, PPL.

A



B

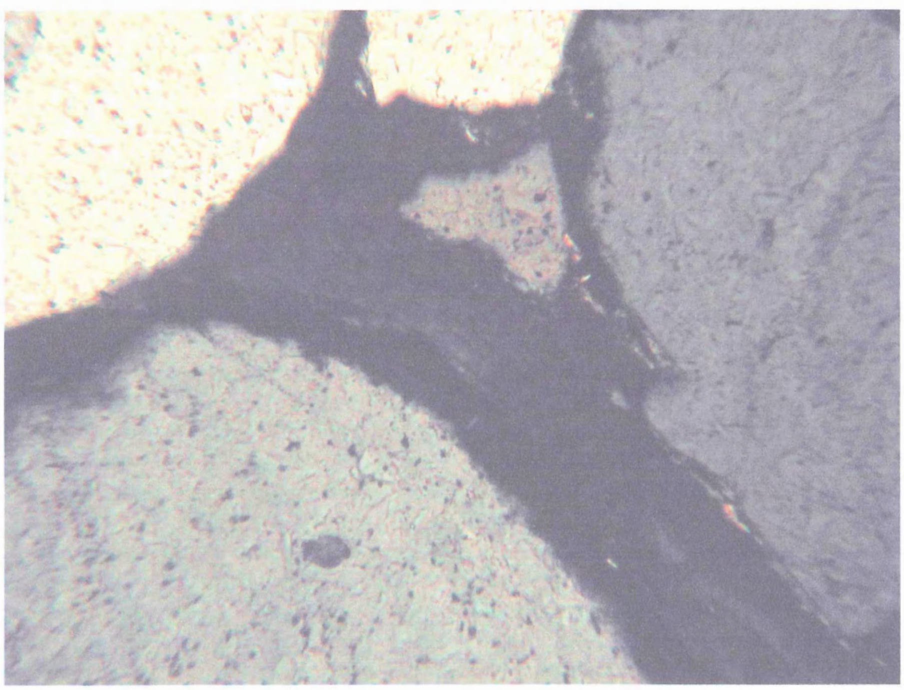


Figure 5.6: A) Fractured quartz grain surrounded by gypsum cement; Avondale slide KF-03-4. Magnification X 10, XPL. **B)** Many quartz grains surrounded by dark gypsum with good cleavage filling between quartz grains as cement. Magnification X10, XPL.

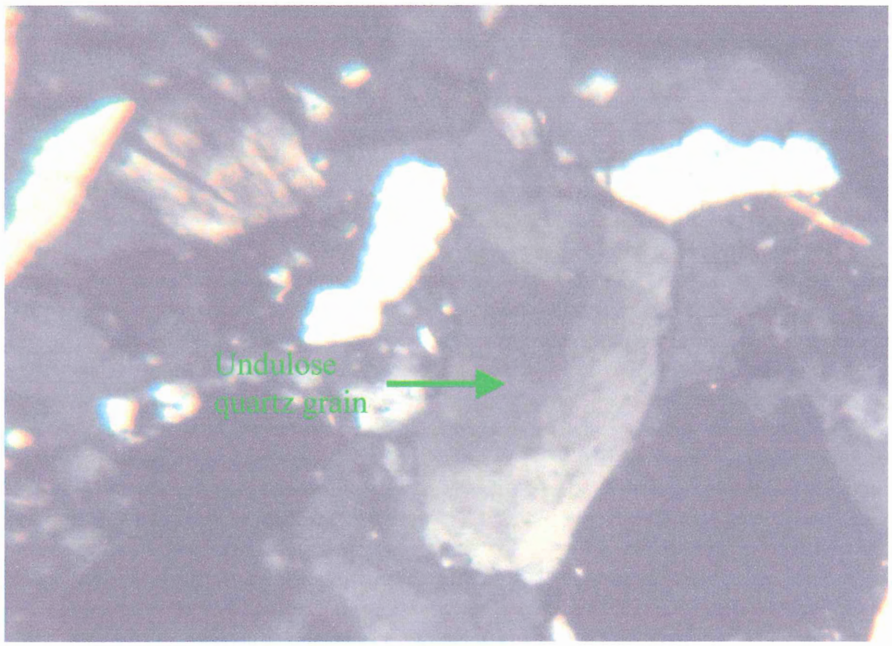


Figure 5.7: Undulose extinction patterns in quartz grains; Avondale slide KF-03-4. Magnification X 5, XPL.

A

B

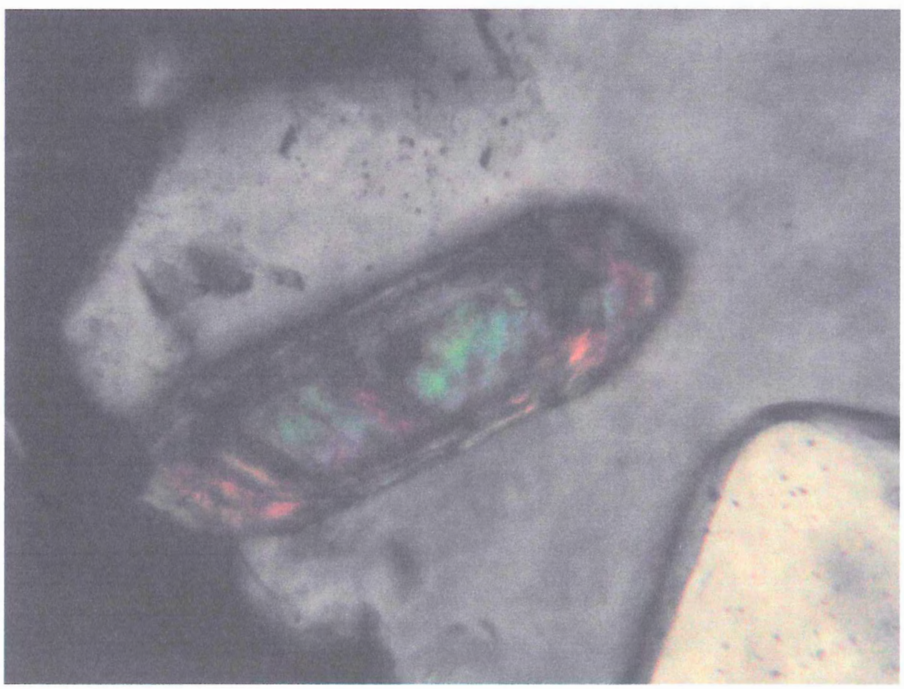


Figure 5.8 : Zoned zircon with quartz, Avondale slide KF-03-2. **A)** Magnification X 50, PPL, **B)** Magnification X 50, XPL.

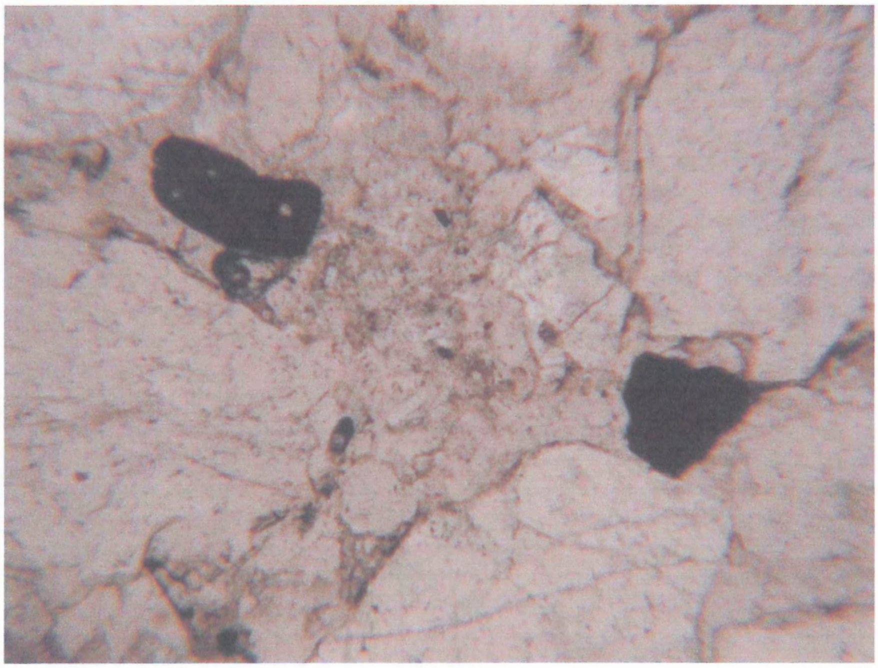


Figure 5.9: Iron oxide rim and grains surrounding quartz grains; Avondale slide KF-03-2. Magnification X 5, PPL.

Table 5.3: Point count data for grain amount out of 500 points counted

Slide →	KF-03-2	KF-03-3	KF-03-4	BQ 1S1	BQ 1S4	BQ 4S2	MS-2
Grain	**/500**	**/500**	**/500**	**/500**	**/500**	**/500**	**/500**
Qm; Quartz monocrystalline	237	216	186	236	196	199	212
Qp; Quartz polycrystalline	70	56	55	28	58	100	37
Feldspar	33	50	53	5	10	31	8
Plagioclase	1	2	0	6	5	0	0
Cement; (Gypsum)	78	107	135	0	0	134	0
Matrix; (Fe oxide/clay)	25	27	2	0	97	25	22
Mica; Muscovite	4	2	0	0	4	0	0
Staurolite	0	0	1	6	4	0	0
Tourmaline	0	0	1	0	0	0	0
Opaque	3	2	0	17	81	0	11
Rock Fragments	4	7	6	46	45	2	0
Pore space	45	41	62	149	0	9	210
Clay aggregate	0	0	0	6	0	0	0

Table 5.4: Summary of grain types and percentages

Slide→	KF-03-2	KF-03-3	KF-03-4	BQ1S1	BQ1S4	BQ4S2	MS-2
Grain	**%**	**%**	**%**	**%**	**%**	**%**	**%**
Qt: Quartz monocrystalline	47.4	43.2	37.2	47.2	39.2	39.8	42.4
Qp: Quartz polycrystalline	14.0	11.2	11.0	5.6	11.6	20.0	7.4
K-feldspar	6.6	10.0	10.6	trace	2.0	6.2	1.6
Plagioclase	trace	trace	Trace	1.2	trace	trace	trace
Cement; (Gypsum)	15.6	21.4	27.0	--	--	26.8	--
Martrix; (Fe-oxide/clay)	5.0	5.2	Trace	trace	19.4	5.0	4.4
Mica; muscovite	trace	trace	Trace	trace	trace	trace	trace
Staurolite	trace	trace	Trace	1.2	trace	trace	trace
Tourmaline	trace	trace	Trace	trace	trace	trace	trace
Opaque	trace	trace	Trace	3.4	16.2	trace	2.2
Rock Fragments	trace	1.4	1.2	9.4	9	trace	trace
Pore space	9.0	8.2	12.4	29.8	--	1.8	42.0
Clay aggregate	trace	trace	Trace	1.2	trace	--	trace

* trace < 1%
* %'s derived from point count data table 5.3.

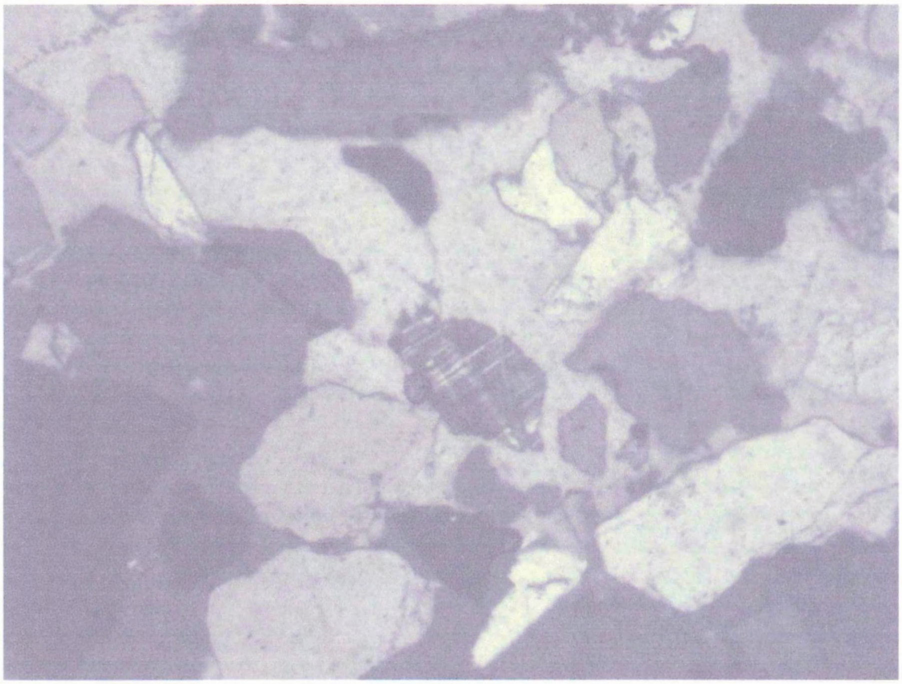
The feldspar grains observed were microcline and orthoclase (in order of abundance) (Fig. 5.10 A). Few grains of plagioclase were noted (Fig. 5.10 B). The grains are sub-angular to angular, with a greater percent of fractured grain as compared to quartz, at about 60%. A few granophyric, textured grains (Fig.5.11) are atypical of the South Mountain Batholith (SMB), which is a possible source of this material. The feldspars show extensive weathering and alteration in their appearance, which is cloudy, cleavages opened, and there are pores in them.

Most grains of muscovite that are observed are found within quartz grains, although, some are enclosed by the gypsum cement as separate grains (Fig. 5.12). Some grains are split along the cleavage, by the cement, into individual plates. Many of the grains are bent, probably due to compaction of the material.

Sparse grains of inclusion-rich staurolite are sub-rounded to rounded (Fig. 5.13). The abundant inclusions are quartz but have small amounts of feldspar, zircon and traces of biotite.

The gypsum is found in a poikilitic texture, with large cement crystals enclosing other grains and having optical continuity covering large areas of the rock. The gypsum cement is also visible in hand specimen as light sparkling material. The cement forms up to 27 % of some slides (Table 5.4) and considerably diminishes the pore space in the material. The identification of the gypsum was difficult in the thin-section examination because the low birefringence is similar to quartz, but the presence of gypsum was confirmed by XRD.

A



B

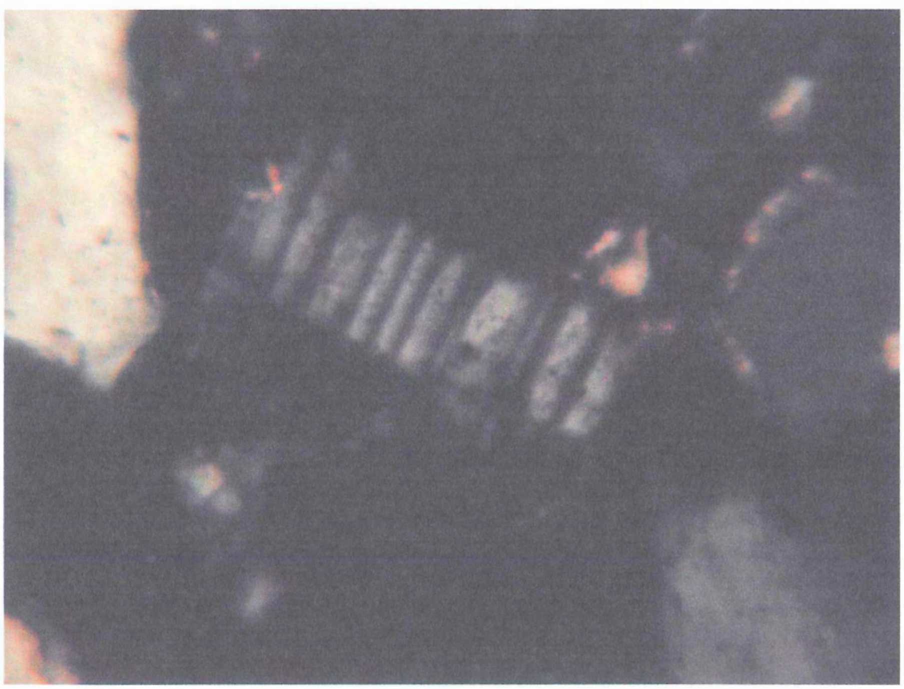


Figure 5.10: A) Feldspar, microcline; Avondale slide KF-03-3. Magnification X 3.2, XPL. **B)** Feldspar, plagioclase; BQ 1S1. Magnification X 20, XPL.

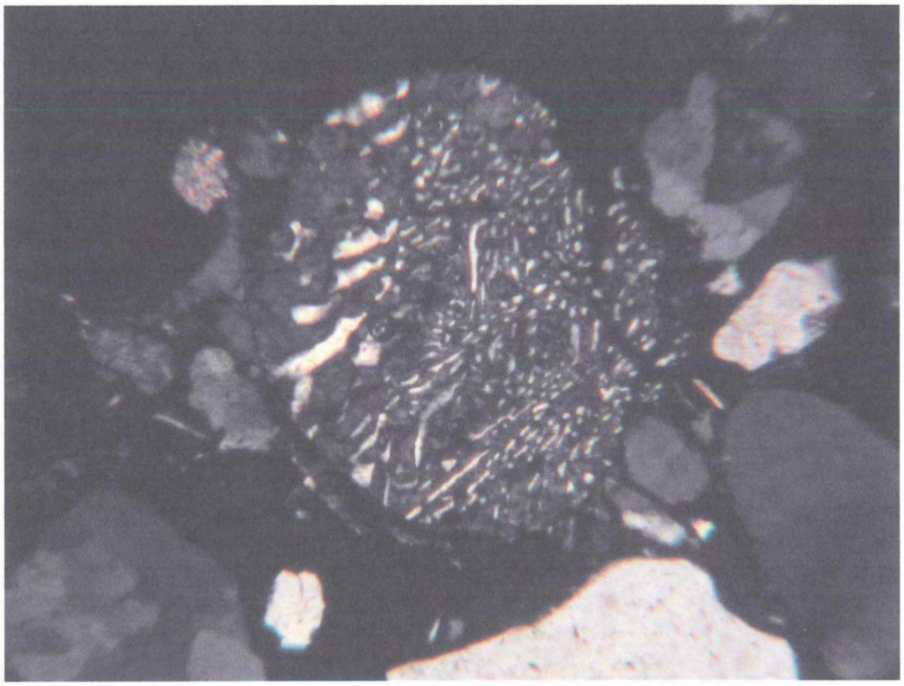


Figure 5.11: Granophyric (or micrographic texture) textured feldspar; Avondale slide KF-03-4. Magnification X5, XPL.

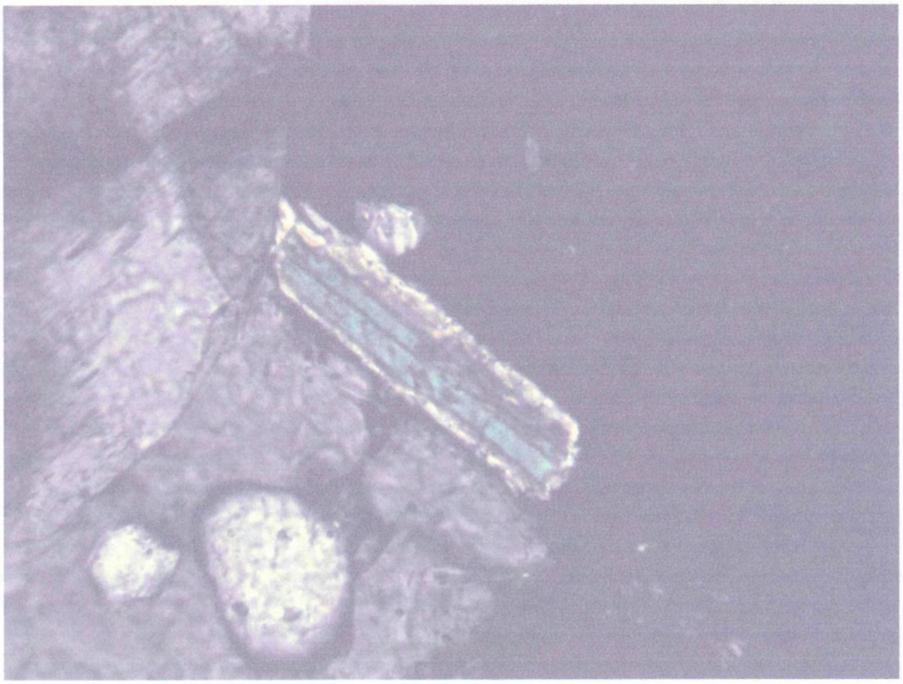


Figure 5.12: Typical muscovite grain; Avondale slide KF-03-4. Magnification X 20, XPL.

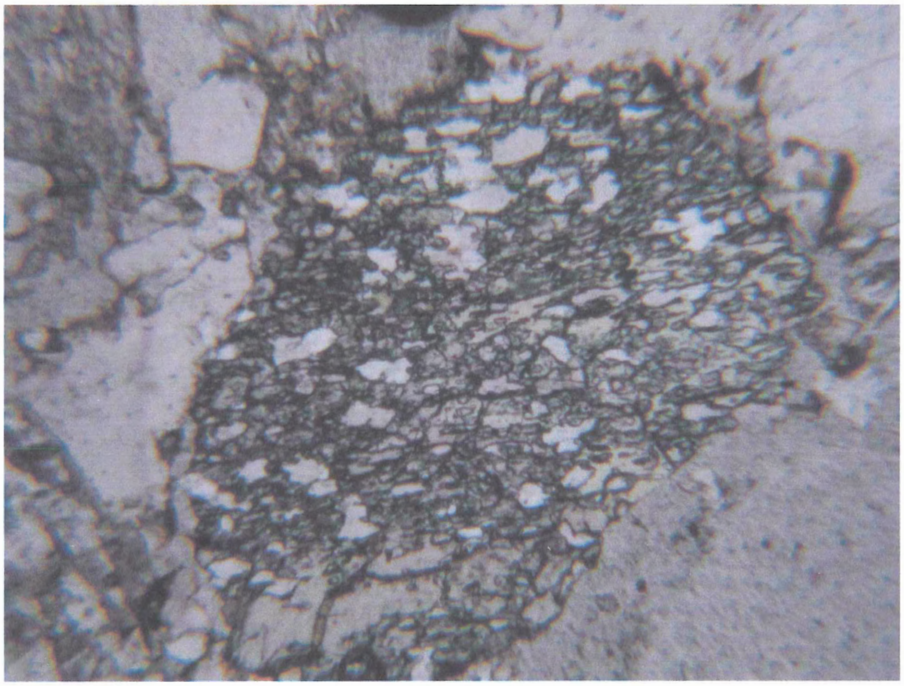


Figure 5.13: Inclusion-rich staurolite grain; Avondale slide KF-03-1. Magnifiaction X5, PPL.

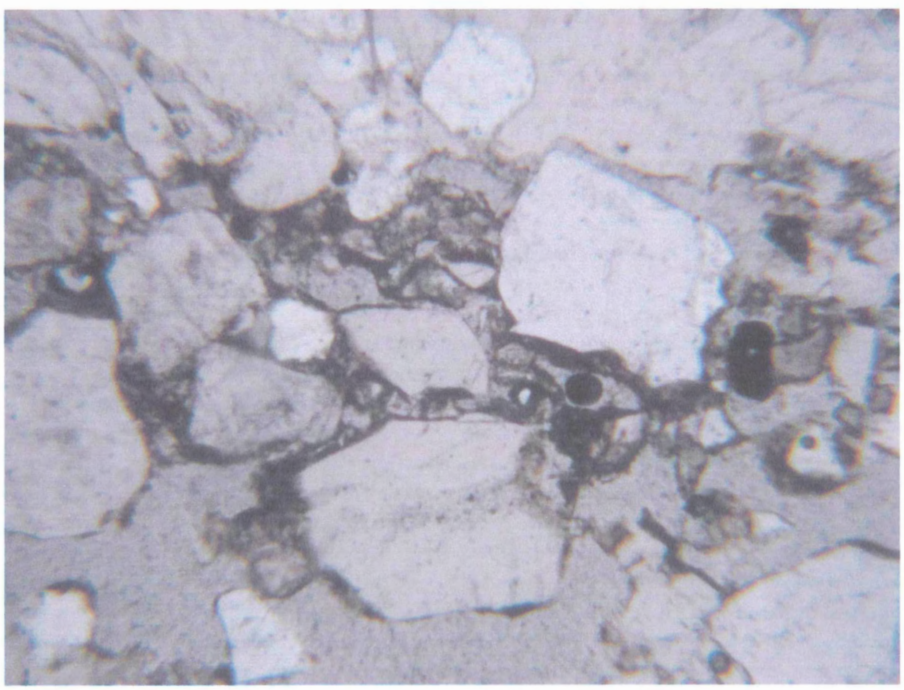


Figure 5.14: Clay/iron oxide matrix, dark brownish material between quartz grains; Avondale slide KF-03-3. Magnification X5, PPL.

A matrix of clay and iron oxides is present locally where the gypsum cement is absent, but only in patches (Fig. 5.14). It is also common as rims or pellicles around other grains in the slides. Other matrix types include groups of small grains of quartz.

Trace amounts of rutile, ilmenite and tourmaline are present in the Avondale slides.

Bailey Quarry

The Bailey Quarry thin sections BQ 4S1 and 4S2 are very much like the Avondale sections. The majority of the grains are quartz, feldspar, rutile, ilmenite, tourmaline, muscovite, biotite, zircon, clay, chlorite (Fig. 5.15) and rock fragments. Quartz grains and feldspars are fractured in proportions of 40-50 % and 60%, respectively, as in the Avondale sections. Rims of iron oxides are also present in these sections. There are areas of grey/yellow matrix patches that contain embedded quartz grains where the matrix has wrapped around the grains. Biotite is found only within grains of quartz (Fig. 5.16).

The BQ 1S1 and 1S4 thin sections are fine grained with abundant quartz and feldspar, as in the Avondale and BQ 4 samples, but there are numerous plagioclase grains in BQ 1S1. BQ 1S1 is also different in that it is unconsolidated sand and contains amphibole (hornblende). Biotite is also seen with quartz grains, at ~1%. Other grains include ilmenite, staurolite, tourmaline, siltstone clasts, chert grains, zoned or overgrown feldspar, and bent muscovite.

Rock fragments and clay aggregates were seen in some thin sections in sparse amounts.

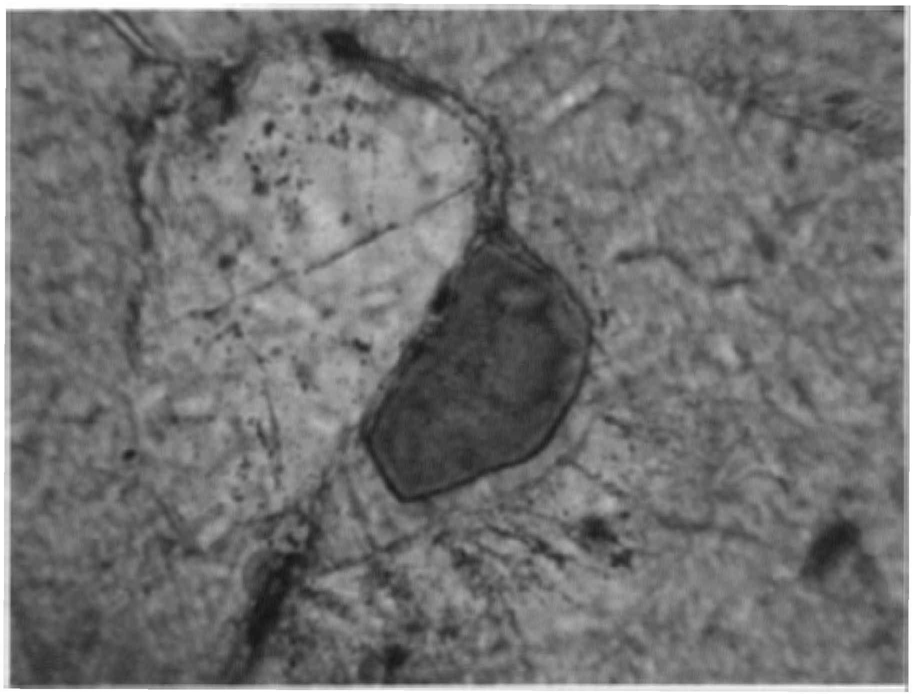


Figure 5.15: Chlorite, Avondale slide KF-03-4. Magnification X 20, PPL.

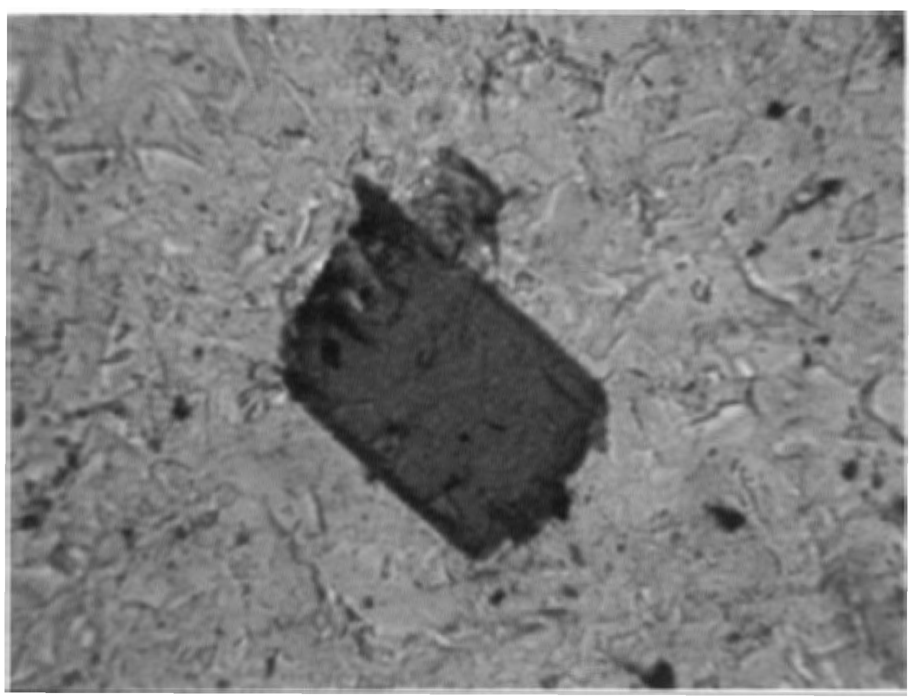


Figure 5.16: Biotite embedded within quartz grains; Slide BQ 4S2. Magnification X20, PPL.

McKay Settlement

This sample closely resembles other sections, especially the Avondale and BQ 4S 1 and 2. The material is quartz-rich with lesser amounts of feldspar, muscovite, zircon, tourmaline, rutile, ilmenite and clay. Gypsum cement is not present in this sample and the material is loose, quartz-rich, well-sorted sand and gravel. The quartz grains here are 0.2 mm- 2 mm in apparent diameter with sparse larger grains that are rounded to angular. Both monocrystalline and polycrystalline grains are present.

5.2.1 Mineral abundance: point counts

Point counts were done on seven out of the nine thin sections in this study (Tables 5.3 and 5.4).

Table 5.5 gives the percent recalculated to 100% for quartz total (Qt) (mono and polycrystalline quartz), feldspar (K-feldspar + plagioclase), and rock fragments (lithics). Figure 5.17 plots total quartz (Qt), feldspar, and rock fragments (lithics), to apply Folk's 1968 classification. Figure 5.18 A plots Qt, feldspar, and rock fragments (lithics), whereas Figure 5.18 B plots monocrystalline quartz (Qm), feldspar, and rock fragments (lithic; with polycrystalline quartz), to apply Dickinson's 1988 classification of detrital modes.

All the samples are strongly quartzose. Slide MS-2 with > 95% quartz content is classed as a quartzarenite, KF-2, KF-3, KF-4, and BQ4S2 with > 75% quartz content and more feldspar than rock fragments are classed as subfeldsarenite, and BQ1S1 and BQ1S4 with quartz content > 75% but with more rock fragments than feldspar are classed as sublitharenite (Fig. 5.17). Quartz and feldspars, with minor amounts of rock fragments, dominate the majority of samples.

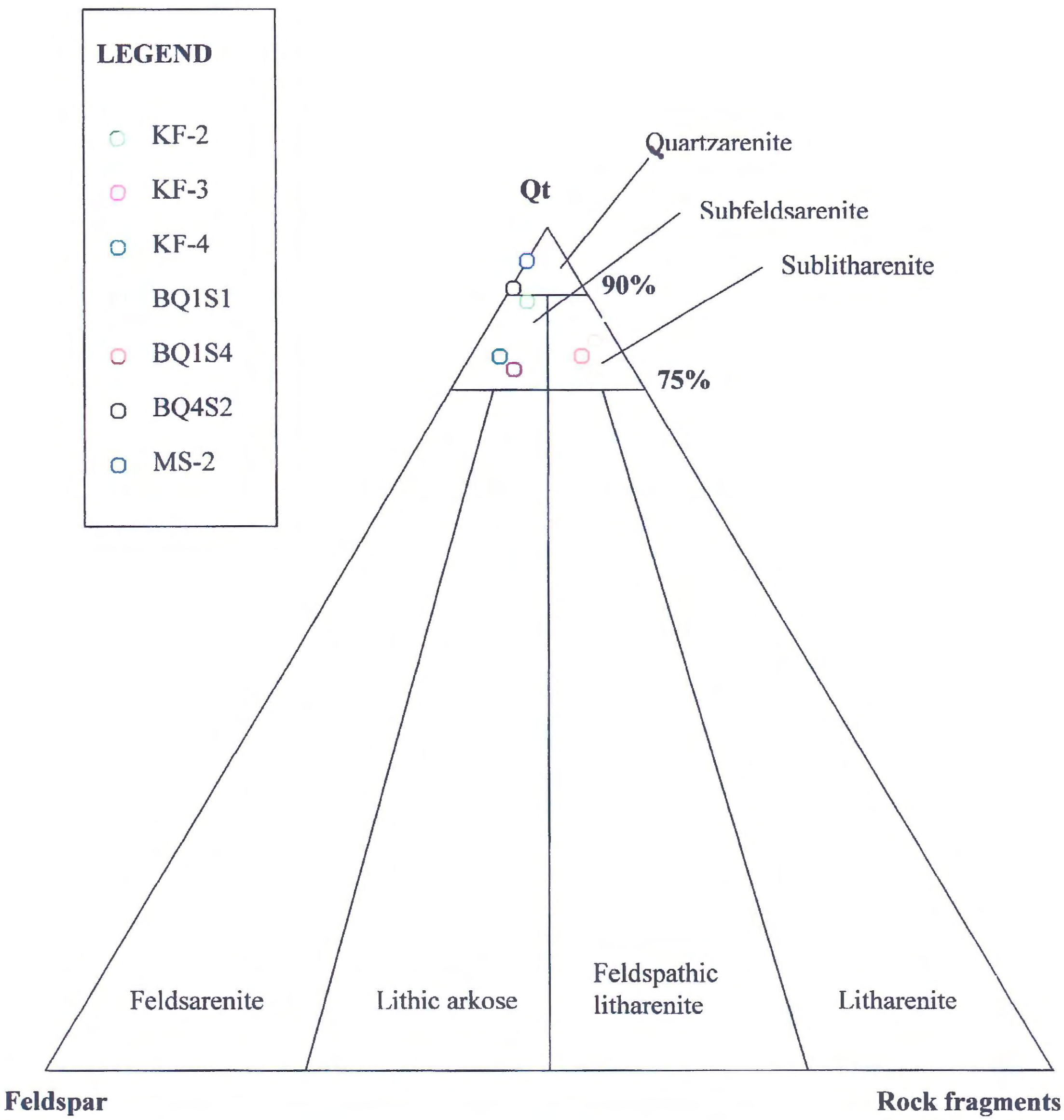


Figure 5.17: Ternary plot of Cretaceous units from Avondale, BQ, and MS (Folk, 1968).

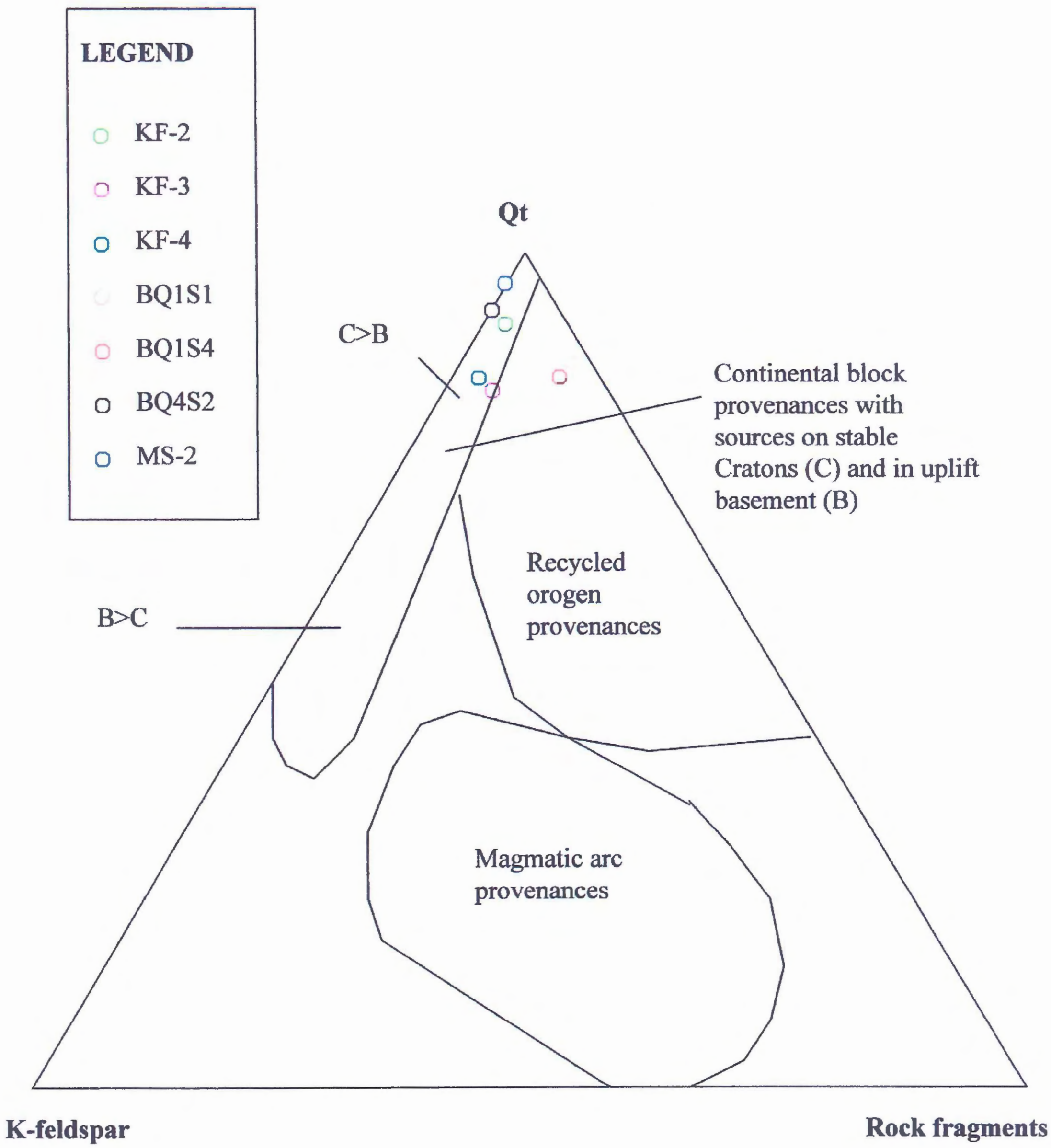


Figure 5.18 A: Ternary plot of Cretaceous units from Avondale, BQ, and MS (Dickinson 1988). See Figure 3.2.

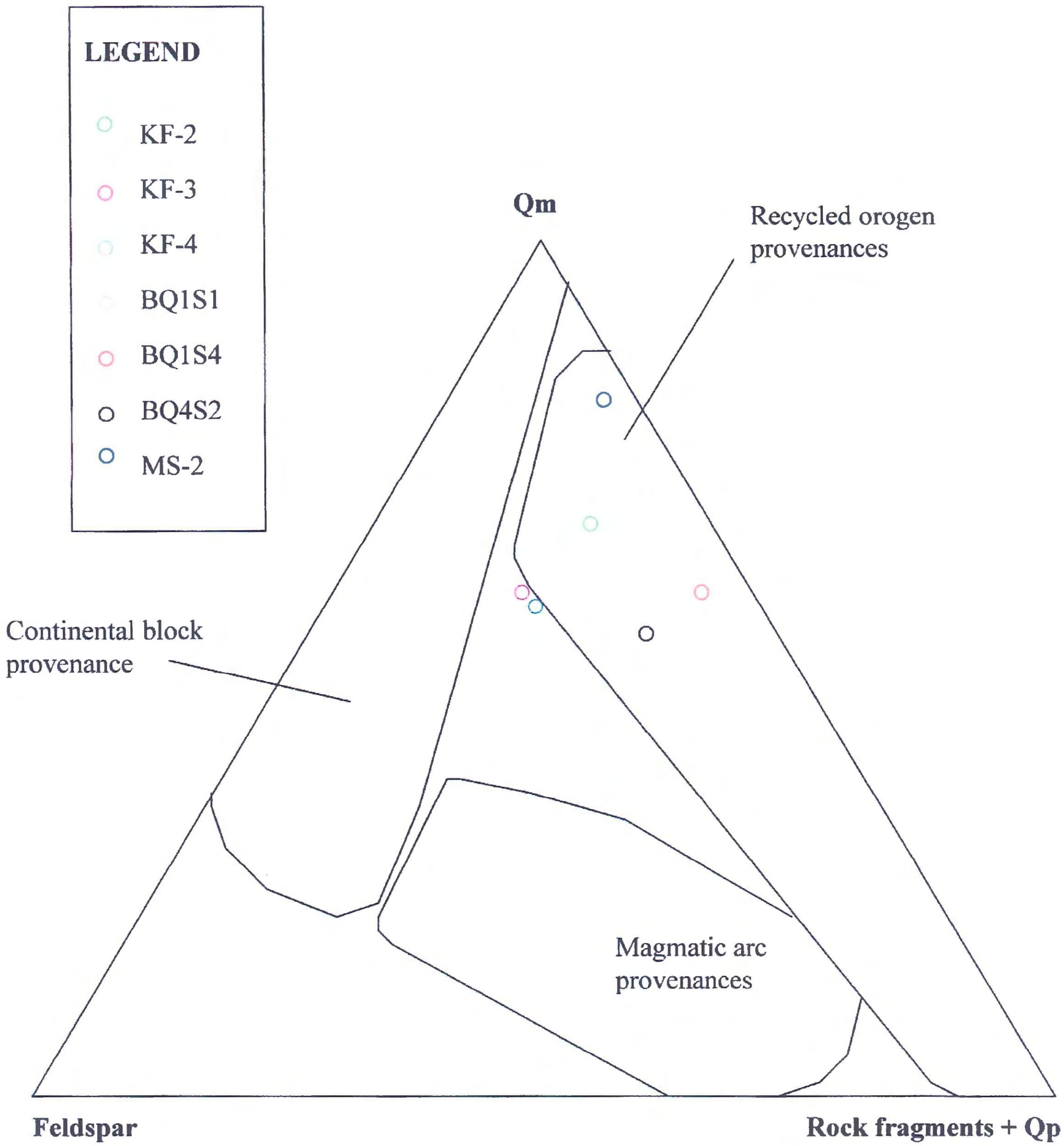


Figure 5.18 B: Ternary plot of Cretaceous units from Avondale, BQ, and MS (Dickinson 1988).

Table 5.5: Percentage values recalculated to 100%.

Slide → Grain	KF-2 %	KF-3 %	KF-4 %	BQ1S1 %	BQ1S4 %	BQ4S2 %	MS-2 %
Qt	89.0	82.1	80.3	82.0	80.6	90.1	96.9
Qm	68.7	65.2	62.0	73.3	62.2	60.0	82.5
Qp	20.2	16.9	18.3	8.7	18.4	30.1	14.4
Feldspar	9.9	15.7	17.6	3.4	4.8	9.3	3.1
Rock fragments	1.1	2.1	2.1	14.6	14.6	0.6	0
Rock fragments + Qp	21.4	17.2	20.4	23.3	33.0	30.7	14.4

Samples KF-2, KF-3, KF-4, BQ4S2, and MS-2 show continental block provenance with sources on stable cratons (C) and in uplifted basement (B) (Fig. 5.18 A). The values fall in an area where C>B with an increase in landscape stability. Samples BQ1S1 and BQ1S4 fall in an area where provenances are from recycled orogens. With Qp added to rock fragments (Figure 5.18 B), samples KF-2, BQ1S1, BQ1S4, BQ4S2, and MS-2 fall in the recycled orogen region (where quartz > chert). Two samples KF-3 and KF-4 fell on the border of the recycled orogen region (but closer to the recycled orogen than to continental block orogen). These results will be discussed further in section 5.4.

5.3: X-Ray Diffraction

The XRD was used to determine if certain minerals were present and to confirm that gypsum was the cementing agent. Appendix A shows the result of the XRD preformed on material from the Avondale locality. The results show that gypsum is present in significant proportions along with quartz, microcline and orthoclase, in order of abundance. Thin section observations show gypsum as large poikilotopic crystals. From the XRD output, percentages can be calculated for quartz, feldspar and gypsum (Table

5.6), showing a reasonable similarity to results from the point count information (Table 5.5).

Table 5.6: Recalculated percents for Qt, K-feldspar, and gypsum. Highlighted values are those that most closely resemble the XRD output.

	Thin sections							
Source →	**KF-2**	**KF-3**	**KF-4**	**BQ1S1**	**BQ1S4**	**BQ4S2**	**MS-2**	**XRD**
Grain	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
Qt	82.7	**62.8**	**56.2**	96.0	94.4	**64.4**	96.9	**64.0**
K-feldspar	9.2	**12.0**	**12.4**	4.0	5.6	**6.7**	3.1	**3.3**
Gypsum	8.1	**24.7**	**31.4**	N/A	N/A	**28.9**	N/A	**32.7**

5.4: Interpretation

5.4.1 Sorting (transport)

Figure 5.19 is a representation of sorting and skewness parameters in relation to river or beach derived sediments as determined from a suite of modern samples (Friedman and Sanders, 1978). Both samples fall just below the line, within the beach sand category. However the original sample set showed considerable overlapping in the fields so these samples, where they fall just over the boundary between beaches and rivers, may well represent flow channels of rivers.

5.4.2 Provenance

The undulose nature of some of the quartz grains (Fig. 5.7) is typical of some crystals in the South Mountain Batholith (SMB), so these grains may have originated from the SMB. This mode of extinction is also found in quartz from many other sources. Two slides contain 'sheaved quartz' or stretched metamorphic quartz grains that may have had a source in the Meguma Group, Goldenville or Halifax Formations, which lie to the south (4-8 km) and west (10-12 km) of the field areas.

Sorting vs. Skewness for Samples BQ1S1A and BQ1S1B

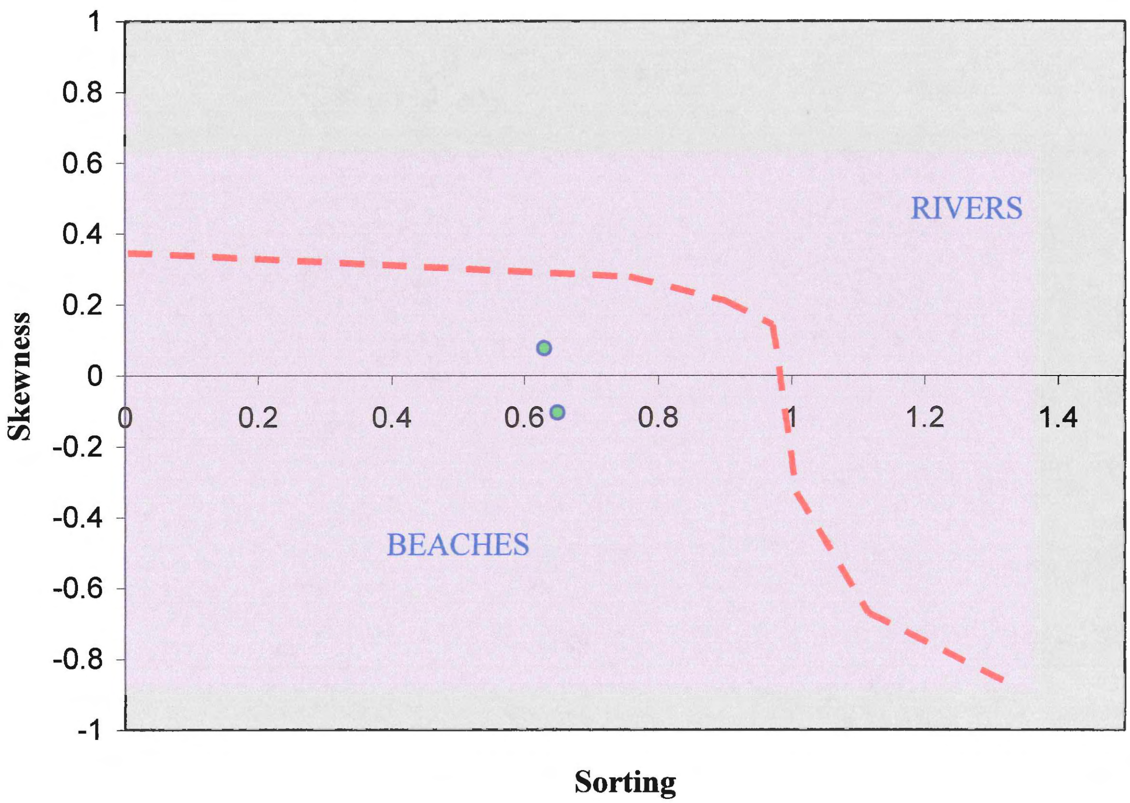


Figure 5.19: Sorting vs. skewness for samples BQ1S1A and BQ1S1B. The red line indicates the division between beach and river sediments, The green points represent the samples (from Friedman and Sanders, 1978).

The feldspars have been altered by chemical weathering, as indicated by their brownish cloudy appearance, opened cleavage, and open pores. Although they are important constituents, not enough of the sample is feldspar to classify the material as sub-arkose. One granophyric textured grain sheds doubt on the South Mountain Batholith as a source for this grain (personal communication, Dr. D.B. Clarke, 2004).

Traces of amphibole (hornblende) and the presence of staurolite suggest sources other than the SMB (MacDonald, 2001; personal communication, Dr. D.B. Clarke, 2004). Comparison of the heavy mineral assemblages found in this study to those found by Gobeil (2002) in the West Indian Road Cretaceous reveal that the make up is closely similar. The concentration of these resistant minerals strongly suggests recycling of the material, and may indicate long transport, which tends to concentrate these minerals (Gobeil, 2002). The occurrence of staurolite suggests a metamorphic origin, although whether the grains are first cycle or polycyclic is unknown (Gobeil, 2002). The sources may have been south-western Nova Scotia, possible the Meguma Group.

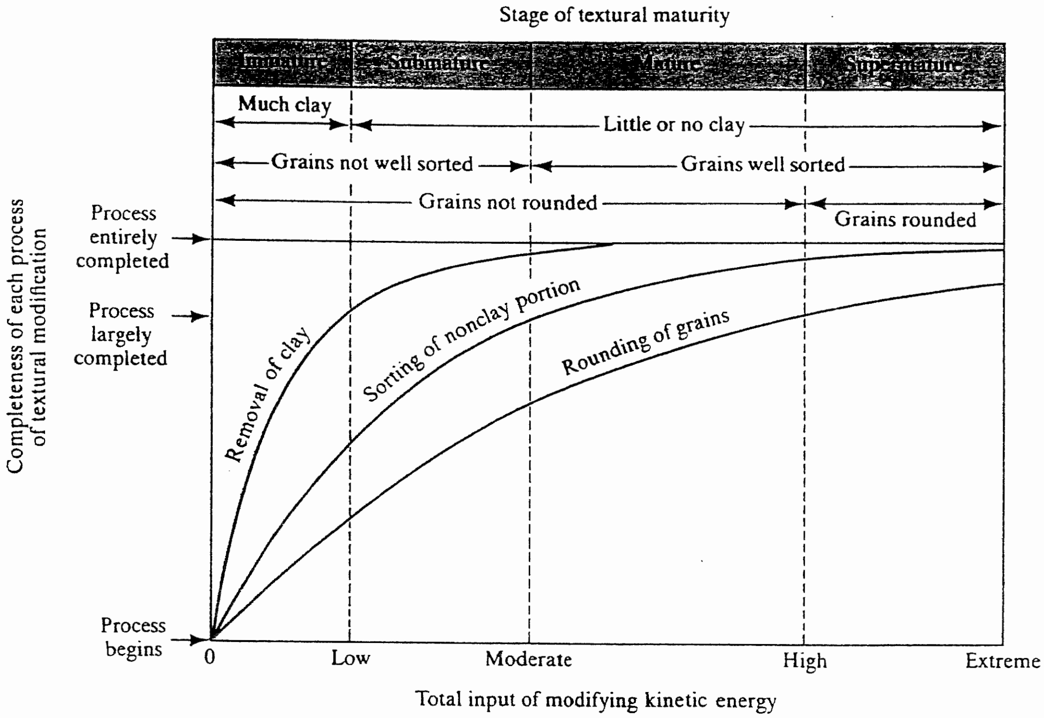
Muscovite in slides from this study closely resembled grains that were described in the West Indian Road Pit Cretaceous unit by Gobeil (2002). The similarities between the muscovite grains found at both Cretaceous occurrences, may allow date and source information that was derived for the West Indian Road Pit occurrence to be applied to the localities in this study. The single age population of muscovite grains derived by Gobeil (2002), of 374 Ma, implies a common source for the muscovite grains. Gobeil (2002) suggested that, given the evidence from the sands of recycling the muscovite grains probably originated from the erosion of the surrounding muscovite-bearing sandstones of the Horton Group.

Biotite in slides from the Bailey Quarry and at least one from the Avondale locality were found only within quartz grains (Fig. 5.16). Similar types of grains are common occurrences in parts of the SMB (MacDonald, 2001; Clarke and Bogutyn, 2003).

The clay minerals in the Cretaceous clay units reflect the minerals that were weathered to produce them (Ehlers and Blatt, 1980), either materials undergoing weathering during the Cretaceous or material that was previously present in the Cretaceous material. Both explanations may be the cause of the low proportions of feldspars and other minerals in the sands. Extensive weathering was probably happening to form the clays. As weathering continues in warm and humid climates with good drainage, as during the Cretaceous, clays are transformed to a point where they only contain aluminium and silicon, which is kaolinite - the most abundant clay formed under these conditions (Ehlers and Blatt, 1980). Kaolinite, although not found in large proportions in the field localities of this study, is abundant within the Cretaceous material of onshore Maritime deposits.

The depositional environment of these grains can be looked at in terms of their textural maturity or the amount of kinetic energy placed on a grain to give the sediment texture (Ehlers and Blatt, 1980). Figure 5.20A shows the kinetic energy in relation to textural modification and Figure 5.20B shows the use of the derived maturity in relation to the energy required for certain environments. As shown, the sample in this study shows well-sorted grains with little clay and with angular to sub-rounded grains, with sub-rounded grains more common than angular grains. This places the sample in this study in the mature textural range. When this is applied to Figure 5.20B, the majority of the

A



B

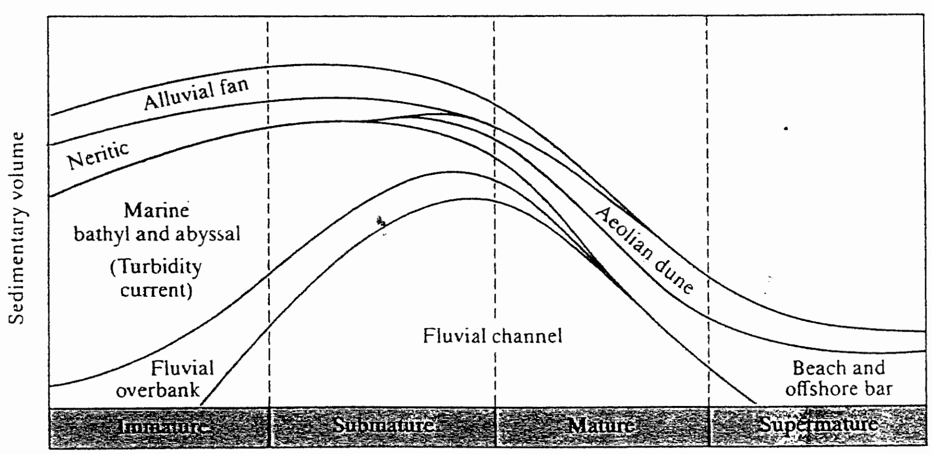


Figure 5.20: **A)** Textural maturity of sands as a function of input kinetic energy (Ehlers and Blatt, 1980, from Folk, 1951). **B)** Relationship among sedimentary volumes, textural maturity, and environment of deposition (Ehlers and Blatt, 1980).

sediment corresponds with fluvial channel sediment which corresponds to the interpretations made earlier in Chapter 4.

With the majority of the grains being angular, it is not certain what was the ultimate or proximal source, so it can be thought that it was probably derived from sandstone units that are found within the area. Figure 5.18A suggests that the majority of samples in this study fall into the stable craton source group, but Figure 5.18B shows that, with Qp placed as a rock fragment, some samples fall in the recycled orogen source group, according to Dickinson (1988).

5.4.3 Diagenesis

The original porosity and permeability of the Cretaceous sediments has changed through diagenesis. In some samples, the pore space that was available when the well sorted, quartz-rich gravel and sand was deposited has been filled with gypsum cement (Table 5.4: 15.6-26.8%) from movement of ground water through the adjacent evaporites of the Windsor Group. This cement has also virtually eliminated the permeability of some samples, as in BQ4S2 with 26.8% gypsum and only 1.8% pore space. Some, but not the majority of grains, have been compressed together, and in some cases the grains penetrate slightly into the neighbouring grains. The actual percentage of pore space that was lost due to the cementation of gypsum can be judged from Table 5.5. These percents vary but where cementation has occurred there has been a significant amount of porosity loss. The samples that have undergone the most change through diagenesis are KF-2, KF-3, KF-4, and BQ4S2, which all show cementing and therefore a loss of pore space (Table 5.4). Pore space percents for these samples are 9.0, 8.2, 12.4, and 1.8 %, respectively. Two poorly cemented samples have 29.8% (BQ1S1) and 42% (MS 2) pore space, however these samples are loose so the thin section porosity is not an accurate reflection of the original, in-situ porosity for these samples.

Chapter 6: Age Analysis

6.1: Paleobotany

Charcoal collected from the Bailey Quarry (site BQ 4) was found in association with clay, sand, and quartz-rich gravel and is black/brown in colour (Fig. 4.9). From these samples, the presence of ginkgos (cf. *Ginkgoxylon*), conifers (cf. *Taxodioxylon*, cf. *Cupressinoxylon*, and cf. *Protocupressinoxylon*) and angiosperms (which had indeterminate features for a generic identification) have been confirmed. Figure 6.1 A and B shows scanning electron microscope (SEM) images of angiosperm and conifer wood showing features that are present. The material is dominantly mature trunk wood with small fractions of juvenile material (twigs and branches). There are visible tree rings, although they are subtle and irregular on many of the samples. Some of the conifer woods have been identified as *Protocuppresinoxylon*, wood from the extinct family *Cheirolepidodiaceae.*

6.2: Palynology

Clay collected for localities BQ4S4, BQ4S5, BQ1S2, and WD was sent to Dr. R. Fensome for palynomorph analysis. Sample BQ4S4 and BQ4S5 yielded abundant Cretaceous material (Table 6.1).

BQ1S2 had overwhelming amounts of Carboniferous material. There was one specimen of *Cicatricosisporites spp.*, similar to those found in the BQ4S4 and BQ4S5 samples, but this could represent contamination. Similar samples were found in the West Indian Road Pit, which are widely interpreted as Cretaceous but yielded Carboniferous assemblages (personal communication R. Fensome, 2004). Interpretations on the paleoenvironmental settings have not yet been confirmed.

A

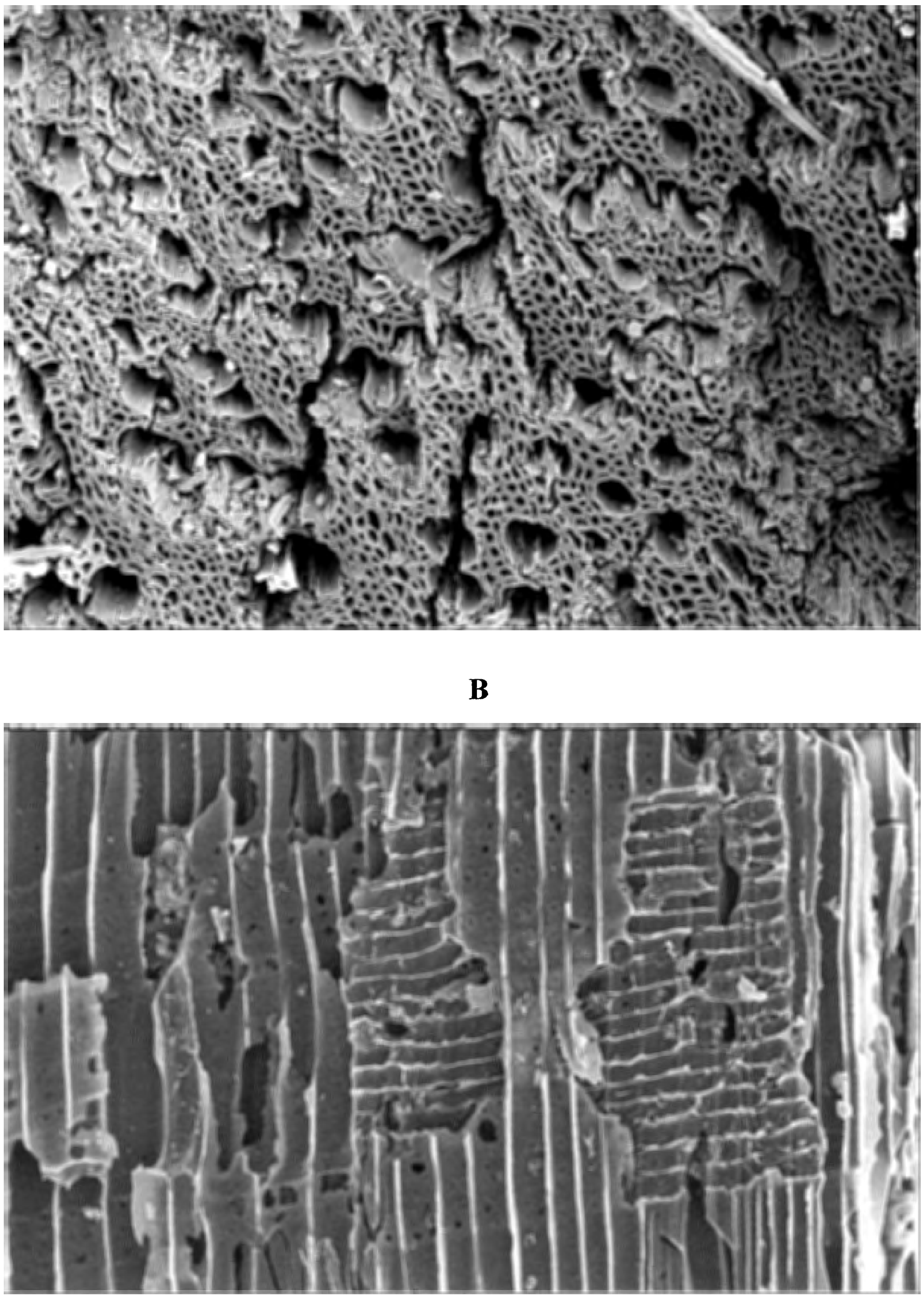


Figure 6.1: A) angiosperm wood showing vessel members **B)** conifer wood showing tracheids, tracheid pits, cuppressoid cross-field and rays (probably Cuppressinoxylon)

Table 6.1: Palynomorph assemblages from samples BQ4S4 and BQ4S5.

Bryophyte spores (sparse)	Fern spores (diverse)	Gymnosperm pollen	Algal cysts (uncommon)
Aequitriradites spinulosus	*Cicatricosisporites minutaestriatus; Cicatricosisporites spp.; Concavissimisporites spp.; Deltoidospora australis; Deltoidospora punctatus; Densoisporites spp.; Gleicheniidites senonicus; Laevigatosporites; Pilosisporites trichopapillosus; Pilosisporites verus; Plicatella spp.;* (one) *Rotverrusporites major; Trilobosporites spp.; Vallizonosportites zonaus*	*Bisaccate* (common but not dominate)*; Cycadopites spp.*	*Schizosporis reticulates*

Sample WD was taken from the organic layer in the Wentworth Dark Quarry. This sample represents Quaternary deposits or older material strongly contaminated with recent material.

No angiosperm pollen or marine palynomorph specimens where recognized in these samples.

6.3: Age Interpretations

The charcoal was shown to have ginkgo, conifer and angiosperm species. Cheirolepids, which have been identified, became extinct around the Cretaceous-Tertiary boundary, giving an age of Aptian-Maastrichthian for the BQ 4 sediments. The presence of angiosperm species also suggests a post-Jurassic age, as the earliest are known to be Albian. No angiosperm species were identified from the clays at BQ4; their presence would be indicative of Albian. However, angiosperm species were identified in the charcoal sample collected at BQ4. Many of the fern species found in BQ4 samples (Table

6.1) have an age range of earliest Aptian. The presence of *Trilobosporites spp.,* the diversity of *Cicatricosisporites* (striate fern spores without radial projection), and lack of *Plicatella* and *Appendicisporites* (striate fern spores with radial projections) could suggest an age as early as Hauterivian, but the presence of angiosperm species in charcoal renders this unlikely. Also the pollen and spore ranges in this part of the Cretaceous are not well known (personal communication, R. Fensome, 2004) so the angiosperm-determined age of Albian is probable. Cretaceous age has been determined for the BQ4 and is probable for the BQ1 locality, however the other localities are not certain.

6.4: Environment Interpretations

The charcoal fragments also show the formation of rings, which is consistent with the sub-tropical climate of the Early Cretaceous period with slight seasonal rainfall (Falcon-Lang et al., 2002). Angiosperm species are also in accord with a braided river system, as these early angiosperm species seem to have preferred this unstable setting. For example angiosperm species in Cretaceous units in the Czech Republic were only found in these disturbed systems (Falcon-Lang *et al*., 2003). The conifer wood that was present would have dominated stable niches like mires (Alvin *et al*., 1981; Falcon-Lang *et al.,* 2001). No dinoflagellates were identified in the samples, which is in accordance with a non-marine setting.

Given the large amounts of charcoal found in the deposits of this age, it may be possible to link high oxygen concentrations in the environment to abundant fires that produced the charcoal.

Chapter 7: Discussion and Conclusions

7.1: Source of onshore strata

The localities in this study area overlie Carboniferous Windsor Group material. Their similarity in lithology and characteristics to other known Cretaceous occurrences in Nova Scotia has led to the speculation that they too are of Cretaceous age. Until now direct evidence has been unavailable to confirm the Cretaceous possibility. Analysis of palynomorph assemblages and charcoal fragments in this thesis confirm the Cretaceous dates for some of the field areas -- BQ4 and probably BQ1. The palynomorph assemblages and charcoal identification specifically confirmed BQ4 to be Cretaceous. The finding of angiosperm species in the charcoal samples are the limiting factor which give the deposit a date of Albian or younger, which is when the first known angiosperms evolved. Avondale, BQ2 and MS are correlated to the BQ4 locality by lithology (similar grain composition and classification) (Fig. 5.17, 5.18 A and B), point count percentages (Table 5.4 and 5.5), and XRD output (Table 5.6), which support a Cretaceous attribution for these undated sites.

The material at these localities is strongly quartzose. MS-2 is classed as a quartzarenite, KF-2, KF-3, KF-4, and BQ4S2 as subfeldsarenite, and BQ1S1 and BQ1S4 as sublitharenite (Fig. 5.17). The majority of the quartz grains are sub-angular to sub-rounded, so transportation would have occurred but either not over extensive distances or fragments were rounded and broken at the same time, creating some angular fragments. There are also polycrystalline grains present. This might suggest that transport was minimal for those grains to have stayed intact, but the component quartz grains appear strongly welded. Given this and the similarities to the material found in the West Indian

Road Pit, the most probable sources for the sedimentary material are the Goldenville and Halifax formations of the Meguma Cambrian-Ordovician and/or the Carboniferous Horton, Windsor, Canso, Riversdale, Cumberland, Pictou, or Stellarton Groups (Williams et al., 1985; Gobeil, 2002).

Saprolites, in-situ paleoweathered horizons, verify warmer climates at several times in the geologic history of southern Nova Scotia, and their preservation patterns suggest much thicker and wider distribution than seen today (O'Beirne-Ryan and Zentilli, 2003). The eroded material from these types of deposits may have formed the sediment for the Cretaceous silica sand and clay deposits in the Carboniferous sequences in Nova Scotia (O'Beirne-Ryan and Zentilli, 2003). Saprolites of pre-Pleistocene age found on the granitoids of the SMB highlands could have been exposed to weathering during the Mesozoic, with associated karstification in the carbonates and evaporites of the Windsor Group (Davies et al., 1984). This occurrence would have then led to the deposition of Aptian-Albian quartzose sediments (Stea et al., 1995). The localities in this study seem to have filled a karsted surface laced with "trenches", sinkholes and collapsed caves. The sediments would originally have covered a very irregular surface, rather than forming a flat sheet that would have been later broken up by karstic sagging and dissolution of gypsum. This inference reflects the form of areas like Gays River and possibly the core deposit in this study, which are found along carbonate/evaporite contacts or are similar to the other localities in this study, small and confined.

The extensive dark chocolate brown/black clay and organic material found in association with the BQ 4 locality, similar to that found in the West Indian Road Pit, suggest an oxygen-reduced, closed environment that was sub-aerial, shown by the presence of charcoal material. The thickness of this unit also suggests that these conditions went on for some time without disturbance. Pieces of the charcoal material were also transported by the braided river system.

The sedimentology of the localities confirms a fluvial environment (as suggested for other sites by Stea and Pullan (2001) and Gobeil (2002)), which is supported by the appearance of only terrestrial fossils in the palynomorphs that were identified. The sediments were deposited under a subtropical climate based on global climate studies (Atlantic Geoscience Society, 2001), and given the formation of tree rings in the charcoal, there was probably some degree of seasonality. The clay units were deposited in a lacustrine or flood plain environment, based on their sediment features and the non-marine nature of the palynomorphs and fire-derived charcoal. From the presence of the angiosperm fragments in the charcoal -- plant types that preferred these unstable disturbed settings (Falcon-Lang et al., 2001) -- a braided river system is likely.

Core 685 from the Bailey and Millers Creek Quarry area shows similarities to the Cretaceous deposits in the Gays River Lead-Zinc Mine. The term 'trench' is used when describing the Gays River deposit -- a term used by mine geologists to describe long, narrow, sinuous, sediment-filled karstic occurrences (Davies et al., 1984). Figure 4.12 B shows where the core was extracted. Karst features in Gays River are controlled by pre-existing faulting and lithological contacts (Davies et al., 1984). The core deposit is similar to the 'trench' fill described in Gays River, which consists of gravels, sand, silt, clay, and minor coaly materials that are semiconsolidated (Davies et al., 1984). This similarity in deposition and sediment type may allow the Cretaceous age determined in Gays River to be applied to the units in the core.

Given the confirmation of the Cretaceous age in BQ4 and BQ1 and probable Cretaceous age for other units, Avondale, BQ2, and possibly the sand unit in WD, these units should be referred to the Chaswood Formation, as defined by Stea and Pullan (2001). The exact connection to the West Indian Road Pit, the most extensive Cretaceous outlier onshore in Nova Scotia, is still unclear. However, the other findings of this report are enough to confirm the Cretaceous age of most of the material, which is the first step in understanding the complex nature of these deposits.

Few deposits of this kind are known onshore in Nova Scotia so their significance and documentation is crucial in understanding other Cretaceous units onshore and offshore for economic and scientific reasons.

7.2: Relation of onshore to offshore units

In respect to the onshore Cretaceous deposits, parts of the Missisauga and Logan Canyon formations may be correlated broadly with the Chaswood Formation based on age. In particular, both the offshore Naskapi Member and the Chaswood Formation middle member show palynomorphs of Aptian to Albian age (Eisnor, 2002). With a rise in sea level, coarse sediments are trapped further inland in river systems, leaving finer sediments such as those found in the middle member of the Chaswood Formation and the Logan Canyon Formation, Naskapi Member to be transported further downstream (Gobeil 2002).

Drainage patterns for this material offshore are unclear, but during the Cretaceous period the field area covered was a fluvial environment that had river drainage to offshore across Nova Scotia. Three other major rivers are shown to drain on to the Scotian Shelf from the Bay of Fundy and central Nova Scotia (Fig. 7.1). These drainage patterns persisted through most of the Cretaceous and were responsible for the offshore deposits that are being exploited for oil and gas today.

7.3: Conclusions

The main objectives of this thesis were to determine the field relations, structure, stratigraphy, environment of deposition, provenance and age of the field localities. Through fieldwork, sample collection and analysis, field relations, structure and stratigraphy were established. The classification of material in this study's localities was determined to be quartzarenite (BQ4S2 and MS-2), subfeldsarenite (KF-2, KF-3 and KF-4) and sublitharenite (BQ1S1 and BQ1S4 according to Folk (1968). These deposits were found to occur in sinkholes, karst areas, and "trenches" that are found in the evaporites of the Windsor Group.

The environment of deposition was determined through grain size analysis, composition and the relation of these properties to the known Cretaceous deposits at West Indian Road Pit. From this it was determined that the Cretaceous occurrences in this study were of fluvial origin, a braided river system. The sands and gravels in this study may represent variously channel-base sands, bars, and sand flats.

The provenance of the Cretaceous units was determined through the use of percentages derived from point count data that allowed the samples from the localities to be plotted according to the classification of Dickinson (1988). This revealed that the source of the Cretaceous deposits were recycled orogen provinces (KF-2, BQ1S1,

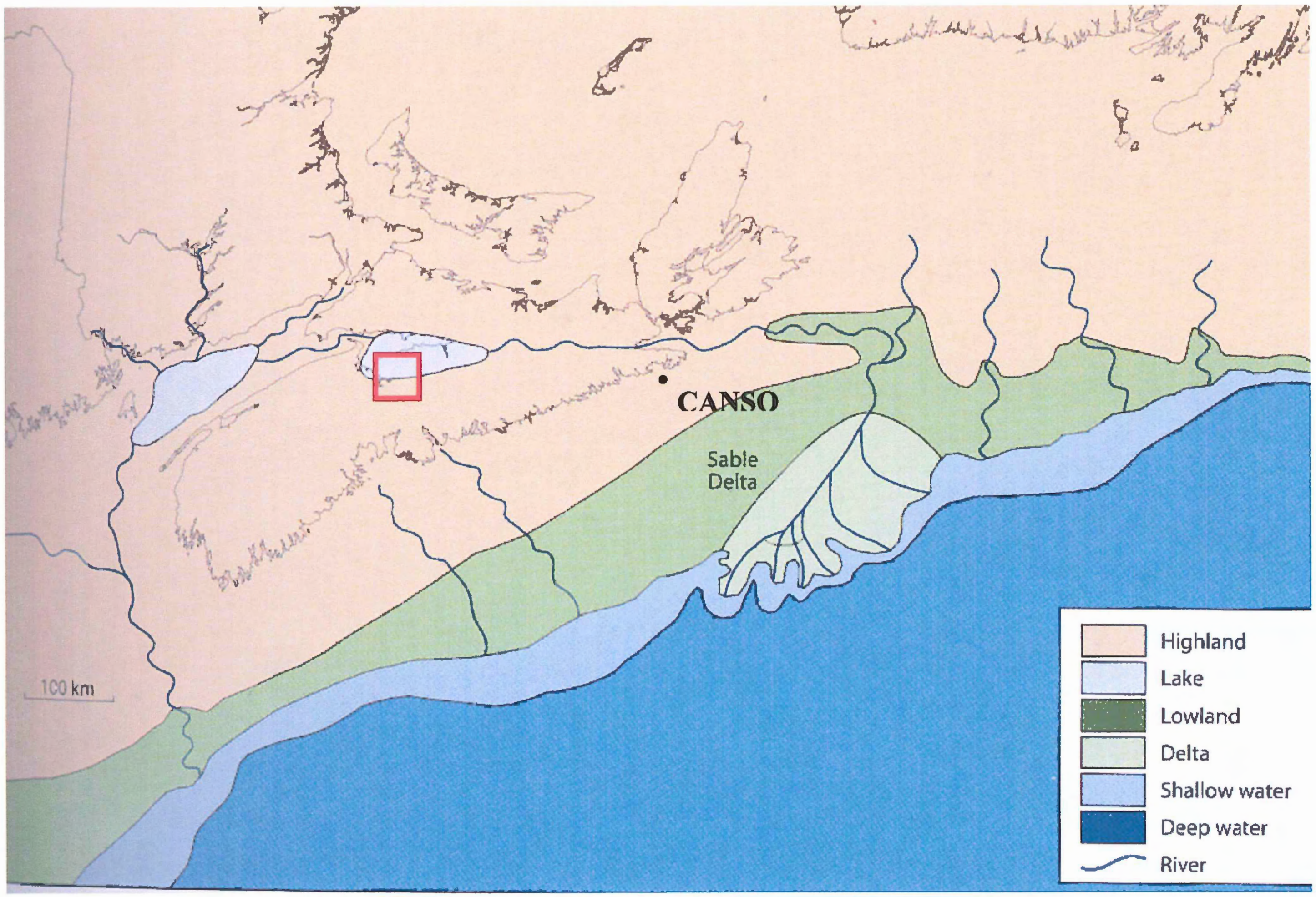


Figure 7.1: Regional paleogeography in the early Cretaceous (Modified from Atlantic Geoscience Society). Red indicates field area in this study.

BQ1S4, BQ4S2 and MS-2) and mixed orogen (KF-3 and KF-4) between continental block provenances (on the boundary; Fig. 5.18 B). This, along with the similarities to the West Indian Road Pit material, suggests that the main source for the material in this study was the Meguma Group and/or Carboniferous Formations.

The age of the deposits in this study was determined through palynology and paleobotany. Based on the identification of angiosperm species in the charcoal it was determined that the age was Aptian-Albian, which was confirmed through the palynomorph assemblages that were identified. However, an older age cannot be ruled out for some localities. No marine palynomorphs were identified, which solidified the interpretation of a terrestrial environment in a braided fluvial system.

The outcrops in this study are of braided fluvial systems that occurred in the Cretaceous period. Their source is mainly locally recycled material that was deposited in the karstified evaporates of the Windsor Group during the humid climate of the Cretaceous.

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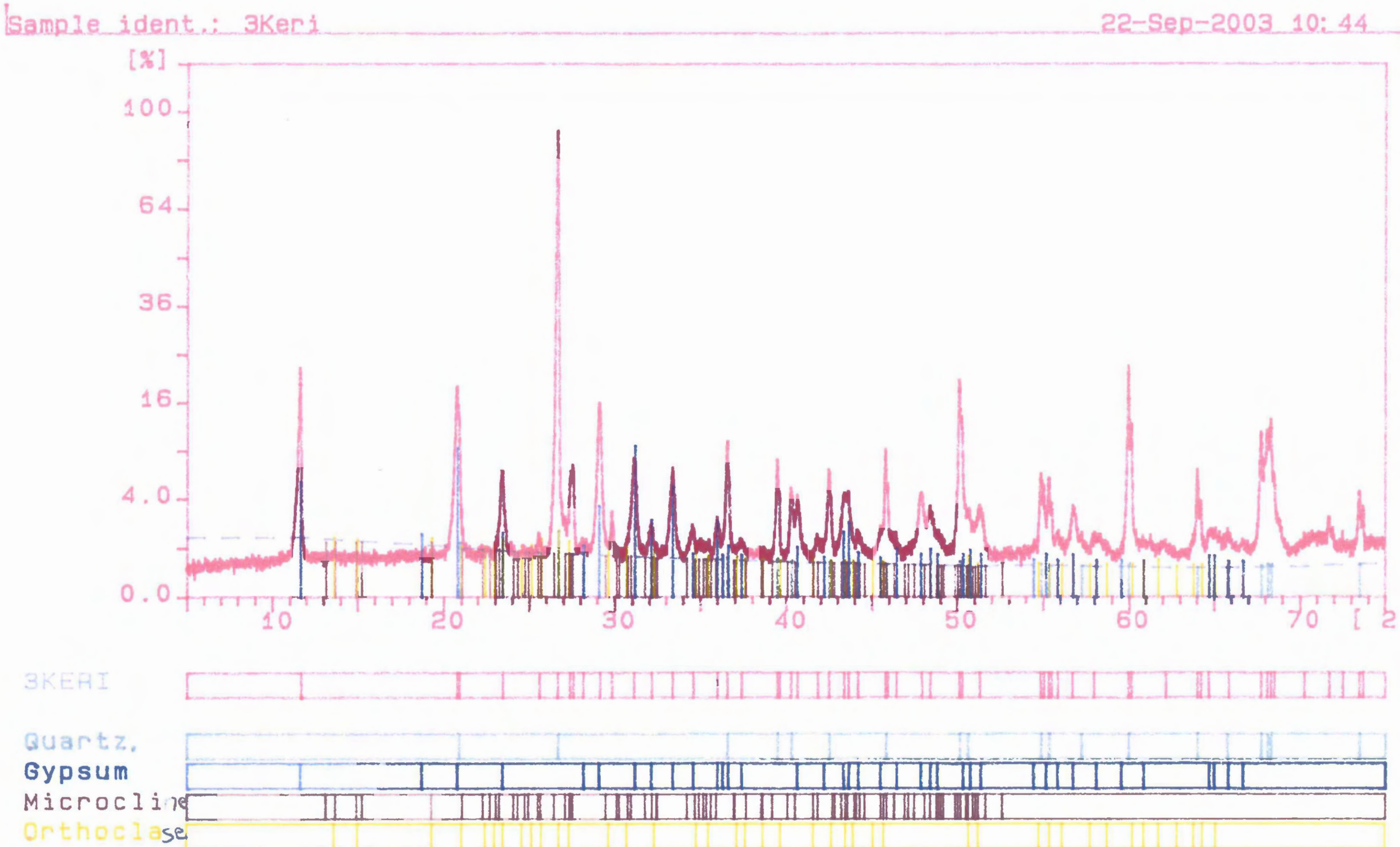
Appendix A: X-Ray Diffraction

APPENDIX A



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3KERI
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