HEAVY MINERAL PROVENANCE STUDIES ON THE WALLACE RIVER FORMATION OF THE PICTOU GROUP BETWEEN TATAMAGOUCHE AND RIVER JOHN, NOVA SCOTIA

by

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Submitted in partial fulfillment of the requirements for the Degree of Bachelor of Science with Honours in Geology, Dalhousie University, Halifax, Nova Scotia.

March 1980

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B.Sc. HONOURS THESIS

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Title: HEAVY MINERAL PROVENANCE STUDIES ON THE WALLACE RIVER FORMATION OF THE PICTOU GROUP BETWEEN TATAMAGOUCHE AND RIVER JOHN, NOVA SCOTIA

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Time Allotment

	Hours
Field work (mapping and sampling)	40
Petrographic work (includes thin-section point-counting, studies on grain size and shape, and determination of plagioclase composition)	50
Compilation of figures, tables, and maps	50
Research	100
Time spent in actual writing of thesis	45
Total time spent	285

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Abstract

Heavy mineral provenance studies were conducted on sandstones of the Wallace River Formation (Pictou Group) over an area of roughly 200 km^2. As well, three major heavy mineral provinces were established. The strata cropping out between Tatamagouche and River John was mapped and fluvial environments suggested for the sandstones, shales and conglomerates comprising the formation.

The Wallace River Formation can be subdivided into three members which are, from oldest to youngest, the Wentworth Member, the Balfron Member, and the Waugh River Member. The Wentworth Member was deposited dominantly by braided fluvial systems, with minor input by meandering systems. The Balfron Member was deposited by braided fluvial systems, whereas the Waugh River Member was deposited almost exclusively by meandering fluvial systems.

Twenty-four sandstones from 22 localities were studied using thin-section point-counting of grains. Eleven heavy minerals were identified and three main heavy mineral provinces were established; a hornblende province, a hypersthene-augite province, and a widespread garnet province. The latter has been subdivided into local garnet-epidote and garnet-tourmaline provinces.

Provenance determinations using heavy minerals, quartz, feldspar and rock fragments indicate a dominantly metamorphic source terrain, with variable input from mafic igneous, granitic, and older sedimentary rocks, and minor contribution by volcanic and pegmatitic sources.

ACKNOWLEDGEMENTS

I wish to thank Dr. Paul Schenk, my thesis advisor, for his suggestions and help in developing this thesis. I also wish to thank Dr. Hope-Simpson of St. Mary's University for the use of the Swift Point-Counter and the use of the facilities of the geology department at that university. I greatly appreciate the discussion of the thesis topic among my fellow students, especially Phil Fralick, who gave informative criticism of the thesis. The aid of Clo Leone in typing the text of the thesis and Dianne Crouse in typing the remainder was greatly appreciated. I would also like to thank my wife, Mary, for her valuable moral support during the writing of this thesis.

I. Introduction

The Wallace River Formation of the Pictou Group constitutes about 75 percent of the sedimentary rock of Pennsylvanian age between Tatamagouche and River John, Nova Scotia. The formation covers roughly 200 km^2 in this area and has been subdivided into three members (Roscoe et al., 1972). They are, from oldest to youngest, the Wentworth Member, the Balfron Member and the Waugh River Member. The Wallace River Formation was deposited approximately 300 million years ago and ranges from Middle to Upper Pennsylvanian in age (Fig. 1). The terrigenous fluviatile and minor lacustrine sediments of this formation consist of red, brown, grey and green sandstones, siltstones and shales, as well as polymictic conglomerate (Bell, 1927). Many of the sandstones are highly micaceous and split along planes because of concentrations of muscovite and biotite. Most sandstones are cemented by silica and/or organics; calcite cement occurs only where the sandstone bed is in proximity to shale or siltstone. The grain size of the sandstones used for the heavy mineral studies ranged from medium-fine-grained (0.33-0.12 mm) to very fine-grained (0.12-0.06 mm). When individual compositions are plotted on a triangular diagram of quartz-feldspar-rock fragments distribution, the sandstones of the Wallace River Formation fall among the fields of subarkose, sublitharenite and quartz arenite (Folk, 1968). Most of the sandstones are classified as sublitharenites (Fig. 2).

Stratigraphic Column

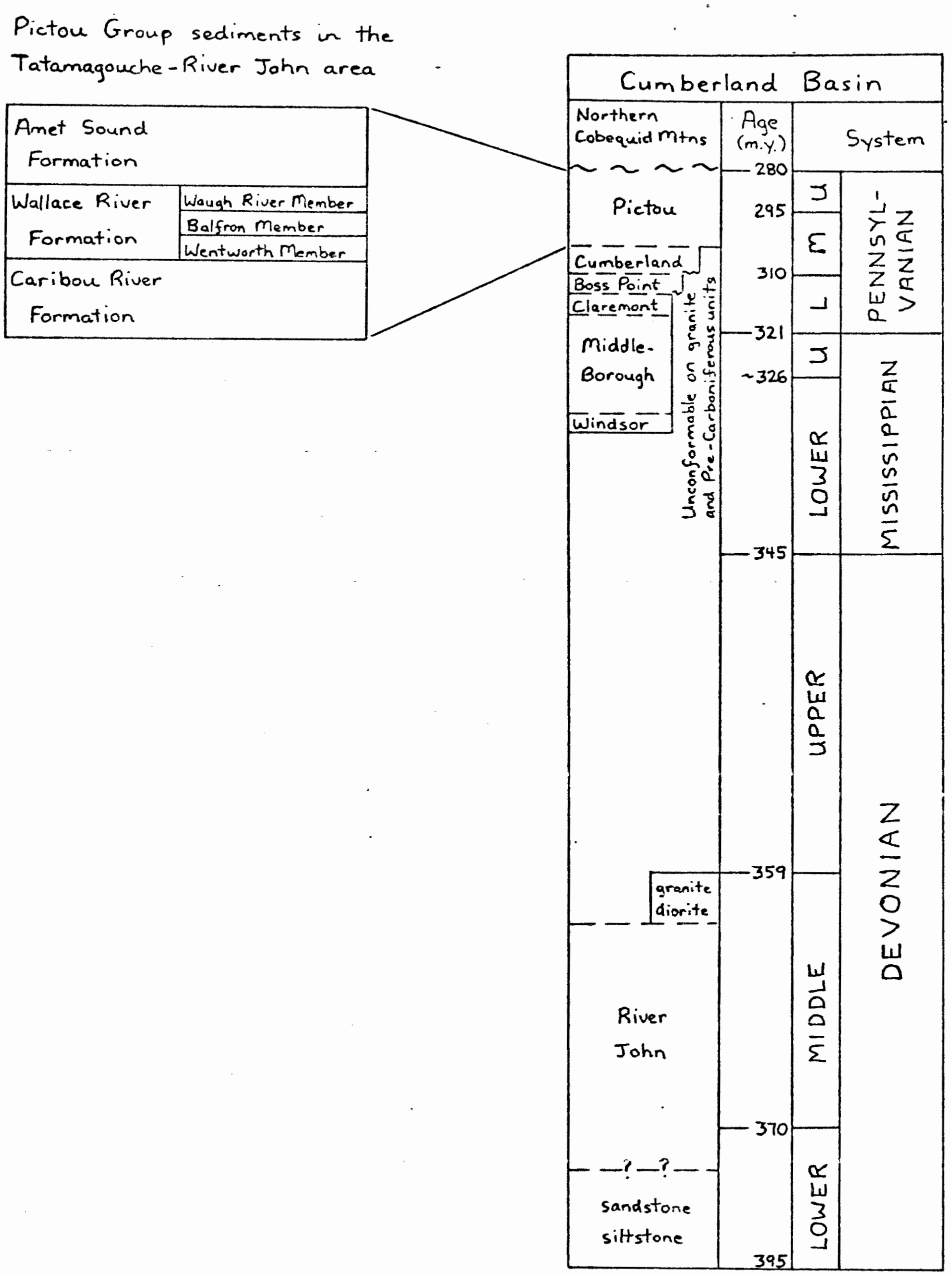
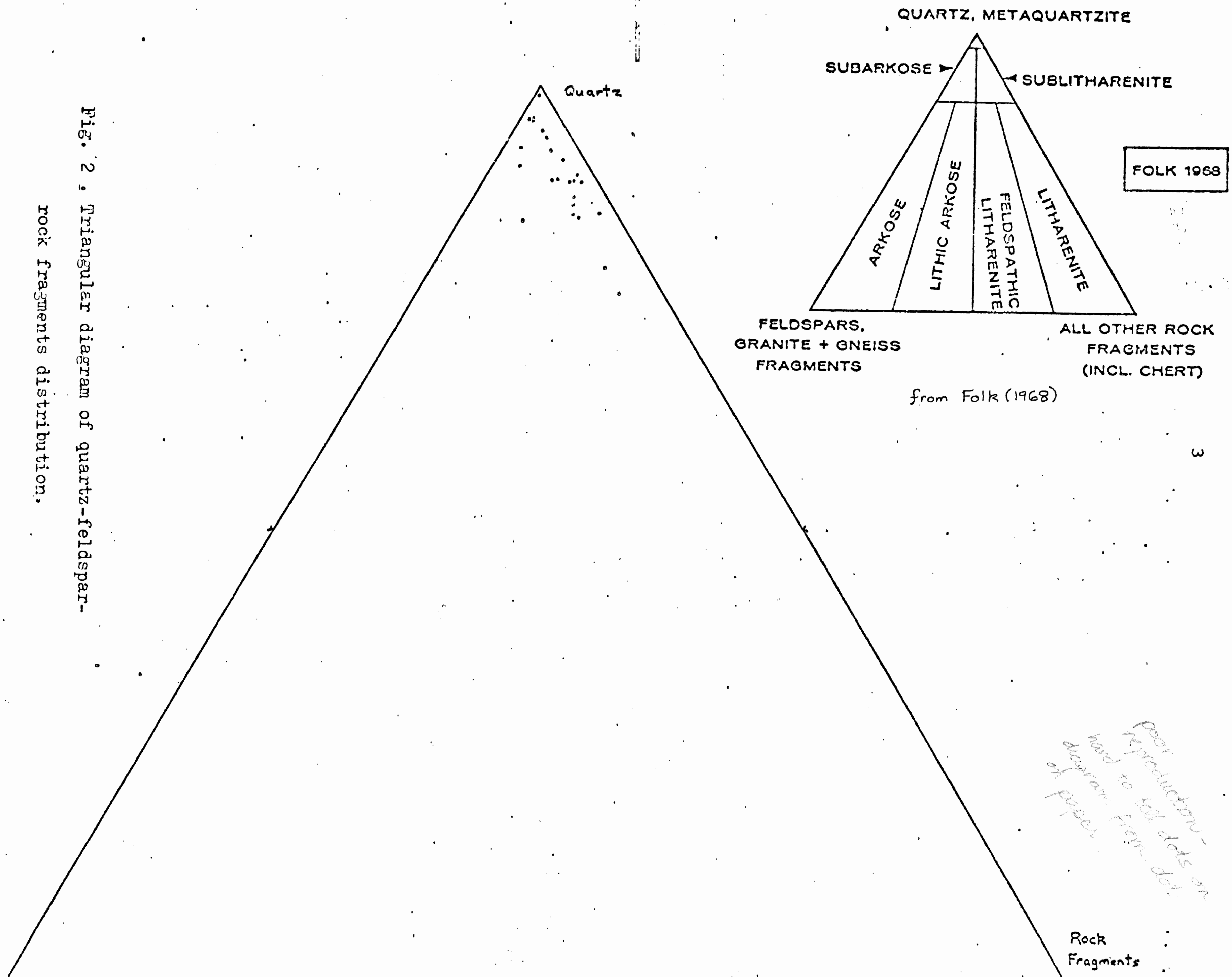


Fig. 1 . Stratigraphic column of the Cumberland Basin - Northern Cobequid Mountains region.



from Folk (1968)

Fig. 2. Triangular diagram of quartz-feldspar-rock fragments distribution.

poor reproduction - hard to tell dots on diagram from dots on paper

II. Sampling and Sample Preparation

During the fall of 1978 and 1979, the author mapped the outcrop and collected rock samples in the thesis area (Map 1). The study was initiated while the author was employed by Wyoming Minerals Corporation in 1978. The samples taken covered a wide range of sedimentary rocks; shales, siltstones, sandstones and conglomerates. Ultimately, the sandstones were the only lithology used for thin-section point-counting of heavy minerals.

Outcrops along the roadside and in various streams and rivers were mapped and sampled, with outcrop locations plotted on a 1:50,000 base map. The western limit for the sample area was provided by the French River and the eastern limit by the River John. Outcrops along the river banks were mapped for up to 500 m from the intersection of the road and river in some instances. An effort was made to establish consistent areal sampling intervals so that rocks from one locality were not given overemphasis for the heavy mineral studies. The western and eastern parts of the area are represented fairly well, but very few samples were taken from the central region due to a lack of outcrop.

A total of 52 standard, unstained thin sections were cut from 26 rocks from 23 different localities. Three of the sediments were siltstone/shale and the slides from these were not point-counted. The remainder represent 24 sandstone samples from 22 localities. For most of the rocks, two thin sections were cut parallel to each other and vertical to the bedding. Five sandstones are represented by one thin section each, and two others had three thin sections made. Oriented rock samples averaged 3 cm by 10 cm by 10 cm in size. Hand specimens of conglomerate were not used for thin section study.

III. Method of Study

The apparatus used in this study was a Swift Point-Counter constructed by James Swift and Sons Limited, Basingstoke, England. It was mounted on the stage of a Leitz SM-POL polarizing microscope and the grains counted under medium (80x) power. A horizontal spacing of 0.5 mm and a vertical spacing of 0.6 mm were used.

At least 400 grains, excluding altered grains and rock fragments, were counted for each slide. Proportions of cement were also recorded, yielding a total of 500-600 point-counts per slide.

Fifteen different minerals were identified; five types of rock fragments and three varieties of cement were also noted. The proportions of total grains in each slide were recalculated to 100 percent and the relative percentage of cement in the rock was also recorded. The results are tabulated in the Appendix.

This study was initiated partly in hopes of delineating heavy mineral provinces within the Wallace River Formation. A further goal was to attempt to correlate the heavy minerals with their initial parent rock type; to determine the provenance of these minerals and of the Wallace River Formation in general.

IV. Depositional History of the Wallace River Formation

A. Introduction

The interbedded sandstones, siltstones, shales and conglomerates of the Wallace River Formation constitute more than 75 percent of the Pictou Group in the study area. These dominantly fluviatile and minor lacustrine sediments were deposited during the Middle to Upper Pennsylvanian in the Cumberland Basin. Up to 2100 m (7000 ft) of Pictou Group sediments were laid down in this basin following post-Cumberland Group crustal movement. The history of the Pictou Group was one of extension of the plain of sedimentation with resulting overlap upon the positive areas (Bell, 1927). The Wallace River Formation lies unconformably on strata of the Boss Point Formation (Riversdale Group) and the Cumberland Group. In the study area, this formation is also unconformable on rocks of the River John Group.

B. Wentworth Member

The oldest unit of the Wallace River Formation, the Wentworth Member, which crops out at locations 10 and 11, consists of red-brown to grey-brown sandstone interbedded with polymictic conglomerate. Most of the sandstone is thin- to thick-bedded, with minor friable, brecciated, reduced red-brown sandstone. Conglomerate units are up to one metre in thickness, containing greater than 50 percent quartz rock fragments from 4-10 mm in size. Carbonaceous plant fragments, coated with malachite, are abundant in some localities. At locations 14, 15 and 16, the Wentworth Member consists of interbedded grey-green to brown sandstones and shale (mudstone). Carbonaceous plant remains are present in medium- to fine-grained grey-green sandstone.

C. Balfron Member

The Balfron Member is the coarsest-grained unit of the Wallace River Formation. The member consists primarily of interbedded medium- to coarse-grained sandstone and conglomerate. In the western part of the study area, grey to brown coarse-grained sandstone with numerous clasts greater than 2 mm grades upwards into conglomerate. At locations 17 and 18, near the contact with the Wentworth Member, fine-grained thin- to medium-bedded sandstone and siltstone passes upwards into this coarser facies. Several beds of conglomerate 5-10 cm thick crop out at this location (Fig. 3). At location 32 on the French River, grey, micaceous, massive to thin-bedded sandstone grades vertically into and is interbedded with conglomerate units. Average grain size of the conglomerate clasts is 5-10 mm.

The Balfron Member near the River John consists of grey, cross-bedded, coarse-grained sandstone interbedded with micaceous conglomerate (locations 21, 22, 23, 24). On the River John, a cliff section displays a mudstone to siltstone platform passing unconformably upward into a basal conglomerate which in turn grades up into coarse-grained sandstone and interbedded coarse-grained sandstone and conglomerate (location 27). Massive sandstone units have oval channel fills of pebble conglomerate averaging 2 m in width, as well as individual pebble beds delineating channel bottoms (Fig. 4).

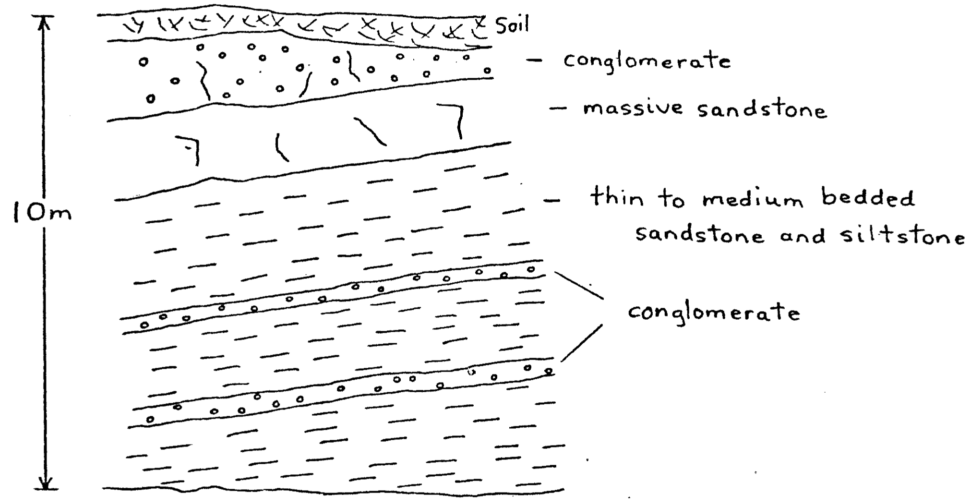


Fig. 3 . Outcrop at locations 17 and 18.

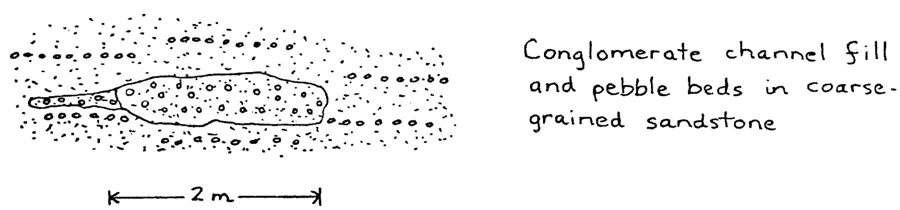


Fig. 4 . Pebble conglomerate channel fill at location 27.

D. Waugh River Member

The youngest unit, the Waugh River Member, is a fine-grained facies consisting mainly of interbedded brown to grey-brown micaceous sandstone and siltstone/shale. The shale is generally friable with many reduced (green) layers. An excellent outcrop occurs at location 7 on the French River, where alternating thin-and medium-bedded siltstone passes upward into alternating massive sandstone and thin-bedded siltstone. This in turn passes up into alternating thin-bedded sandstone and siltstone. The massive sandstone units at this outcrop have thin parallel laminations grading up into small-scale cross-lamination. Flute marks and fossilized plant fragments are found at the base of each sandstone unit (Fig. 5). Near the River John (location 30), heavily weathered fine-grained grey-brown sandstone is interbedded with conglomerate of mainly sedimentary (siltstone/shale) origin.

E. Fluvial Environments

The fluvial processes operating during deposition of the Wentworth Member were dominantly those of braided streams, with some input by meandering streams or lacustrine sedimentation. The presence of braided systems is attested to in the field by lag deposits of conglomerate grading up into the thin- to thick-bedded sandstone representing shifting channel bars. Abundant broken plant fragments may indicate a high-energy environment for these sandstones. During times of low base flow (in perhaps a more arid climate), siltstone and shale could accumulate on small flood-plains along the rivers. This could be a seasonal effect whereby braided

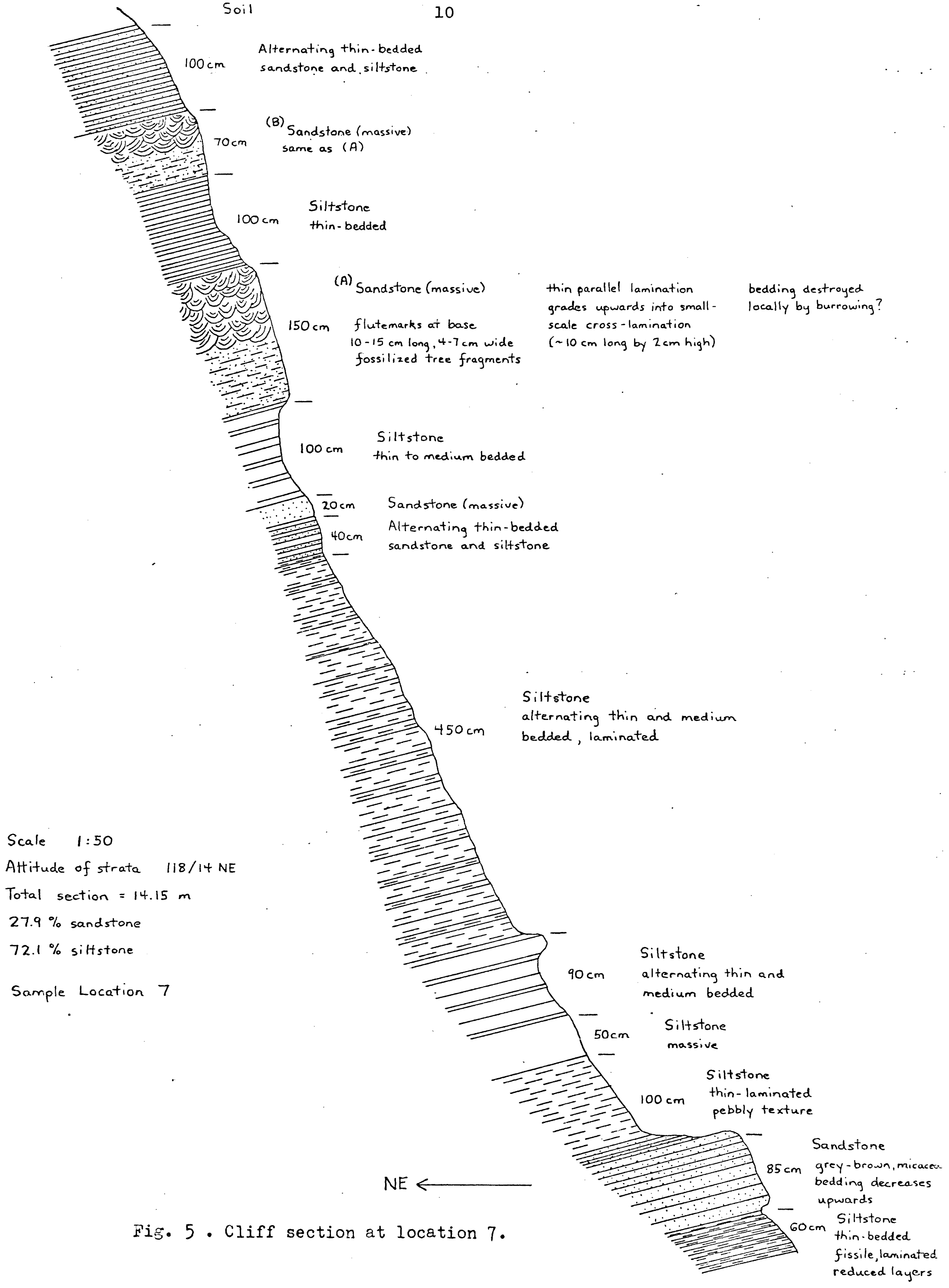


Fig. 5 . Cliff section at location 7.

streams operating during a rainy, humid season give way to lower-energy fluvial processes during a semi-arid period. It was suggested by Bell (1927) that semi-arid conditions were present during deposition of much of the Pictou Group, despite the need of general humid conditions to explain the widespread occurrence of flora.

The Balfron Member, consisting of interbedded medium- to coarse-grained sandstone and conglomerate, was deposited almost exclusively by braided systems. Possible uplift of the source area could account for braided streams developing on surfaces of a higher slope and consequently providing more coarse detritus to this unit. Conglomerate units representing channel fills and scours are widespread, as are coarse-grained cross-bedded sandstones indicative of migrating channel bars. Shale is rare to nonexistent throughout the Balfron Member, suggesting a sustained period of high-energy fluvial transport over deposition of the entire member.

The Waugh River Member was deposited dominantly by low-energy fluvial systems. This unit consists mainly of interbedded sandstone, siltstone and shale with minor conglomerate. The meandering nature of stream transport is clearly illustrated in the cliff sections of this member, especially at location 7 (Fig. 5). Here the fine-grained top of one meandering stream cycle and the bottom of another cycle are exposed. The outcrop consists of 72 percent siltstone and 28 percent sandstone over the entire section. The thin- to medium-bedded, laminated siltstone represents the backswamp (floodplain) assemblage, whereas individual massive sandstone units represent the coarser-grained channel deposits (point bar and channel floor lag). Alternating thin-bedded sandstone and siltstone are indicative of channel-marginal deposits (levees and crevasse-splay). Walker (1976) gives a good viewpoint on the use of facies in vertical sequences. The channel deposits of a meandering system represent lateral accretion deposits, whereas the floodplain assemblage (levees, crevasse-splay and backswamp deposits) represent vertical accretion deposits. The section cropping out at location 7 probably represents a meandering system with a high sinuosity. Meandering streams with a low sinuosity and higher current velocity deposit coarser-grained material in the channels. This fluvial environment can still be distinguished from that of a braided system by the interbedded thick sandstones and siltstones of the floodplain assemblage.

Relative tectonic stability of the source area(s) kept this meandering system operating throughout deposition of most of the Waugh River Member.

V. Light Minerals

A. Quartz

Quartz, in monocrystalline and polycrystalline form, is the major grain component of all the sandstones studied from the Wallace River Formation. Content ranges from 64 to 90 percent of all grains (Appendix). Most quartz grains display high to medium sphericity and are subangular to subrounded (Table 1). Very few of the rocks studied consist dominantly of either rounded or angular grains.

Some quartz crystals have secondary quartz cement overgrowths indicating derivation from an older sandstone, and several grains have mineral

Table 1. Shape of quartz grains

Slide No.	Sphericity	Roundness
0	high-medium	angular
1	high	subangular
3a	high-medium	subangular-subrounded
3b	high-medium	subrounded
6	high-medium	subrounded-rounded
8	high	subangular-subrounded
10	high-low	subrounded
11b	high	subangular-subrounded
14	high	subrounded-rounded
15	low	angular-subangular
16	medium-low	subangular-subrounded
18	high	subrounded
19	high	subangular-subrounded
20	high	angular
21	high-low	subrounded
22	high-medium	subangular
23	high-medium	subangular-subrounded
24	high-low	angular-subangular
25	high-medium	subangular
26	high-low	subangular
27b	medium-low	angular-subangular
30a	high-low	subangular-subrounded
30b	high-medium	subangular-subrounded
32	high-medium	subangular-subrounded

inclusions of tourmaline, representing a granitic source (Blatt, 1967). Fluid inclusions are common in some quartz grains, but nowhere abundant, indicating either a granitic or gneissic origin for these grains (Blatt et al., 1972). Polycrystalline grains are discussed in the section on rock fragments.

There is a consistent decrease in the degree of sorting of quartz grains with increasing grain size. Sandstones with an average grain size greater than or equal to 0.25 mm display a widespread bimodal distribution of quartz grains. In these rocks, the majority of grains is 0.30-0.50 mm in size, whereas the remainder measures 0.12-0.17 mm.

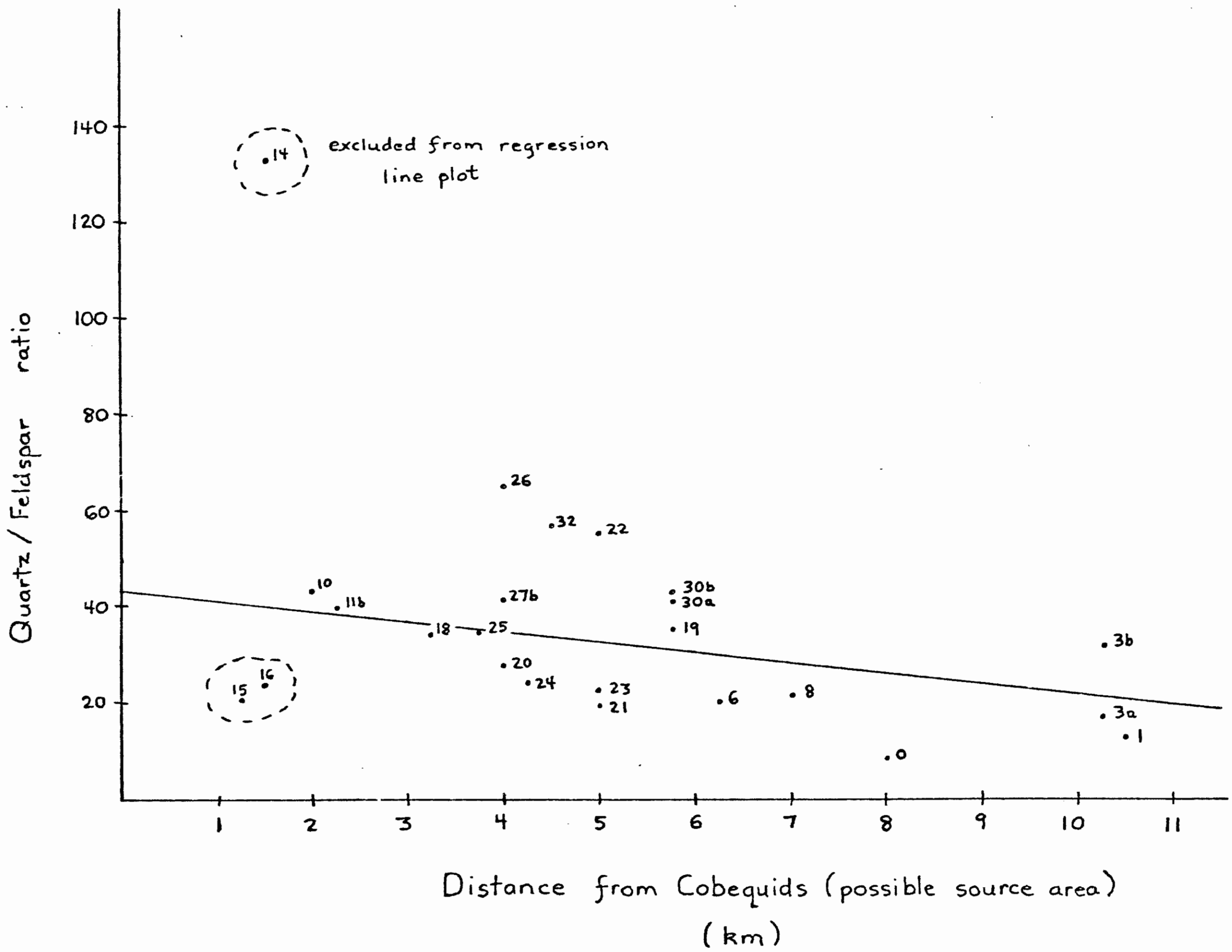
B. Feldspar

The sandstones of the Wallace River Formation have a low feldspar content, ranging from 1 to 7 percent of total grains counted. All samples show varying degrees of feldspar destruction and replacement, probably mainly as a result of post-depositional alteration. Many feldspars are partly replaced by authigenic chlorite, muscovite and clay minerals. Consequently, most of the altered grains counted per slide were likely originally feldspar. Since the thin sections were not stained, untwinned feldspars could only be recognized by features such as alteration, cleavage, fracture and relief. Due to the large number of grains being counted, it was not possible to attempt optical figures for suspected feldspar grains. Despite feldspar alteration and possible counting errors, the author believes that the feldspar proportions obtained are fairly accurate.

To attempt a determination of the survival rate of feldspars with geologic age, the quartz/feldspar ratio was plotted against distance to the north from the Cobequid Highlands for each sandstone (Fig. 6). The sediments strike east-west, which roughly parallels the lineament of the Cobequid Highlands. The beds dip and young in a northerly direction. The scatter plots display a fairly good correlation to the experimental regression line, except for one sandstone that had a quartz/feldspar ratio of over 130/1 (location 14). The regression line reveals the overall trend of the data and is the "best fit" through the plotted points. The data revealed a general decrease in the quartz/feldspar ratio with decreasing age and increasing distance from the Cobequids. On the average, the quartz/feldspar ratio for a sandstone two km from Cobequids is twice that for a similar rock ten km distant. This eight km horizontal difference is roughly equivalent to a stratigraphic interval of 1400 to 2000 m.

The results indicate that alteration of the feldspars following deposition has likely been the major factor in the decreasing feldspar-content with increasing age and depth of burial. This alteration could be caused by intrastratal solutions. These are essentially pore waters released upon compaction of the unconsolidated sediment together with older, possibly more saline waters from underlying strata. Diagenesis and fluids are closely related and influence each other. Varying pH of these solutions may allow certain minerals, such as feldspar and quartz, to be preferentially replaced by new mineral phases (Friedman and Sanders, 1978).

If the observed enrichment trend of feldspar is due to alteration of grains after deposition, then the amount of feldspar transported from



Regression Line

$Y = 43.1 - 2.0x$

$r = 0.37$

Fig. 6 . Survival rate of feldspars with geologic age.

various sources might not have varied substantially through the depositional history of the Wallace River Formation.

There is a general fining upwards in section and laterally northward in strata of this formation. It is possible that feldspar was apparently preferentially enriched in the finer sediments (youngest) due to breakdown of larger feldspar grains into numerous small ones. It has been noted that the average grain size of a sandstone is reflected by the size of feldspar grains; the larger the grain size of the rock, the larger the individual size of feldspar grains.

The composition of plagioclase was determined using extinction angles measured on polysynthetic twins, with the aid of a standard petrographic microscope. The plagioclase in every sandstone was sodic, consisting of andesine and/or oligoclase (Table 2). Andesine was more common than oligoclase. There was no evidence found for the formation of authigenic feldspar.

Oligoclase (An_{10-30}) is very common in persilicic igneous rocks (syenite, granite, rhyolite) and common in other igneous rocks. It also occurs occasionally in granite pegmatites and some metamorphic rocks. Andesine (An_{30-50}) is common in many igneous rocks, especially diorites and andesites. It is also found in metamorphic rocks (Kerr, 1977).

Studies of plagioclase as an indicator of provenance were conducted by Pittman (1970). He found that untwinned and unzoned andesine and oligoclase are representative of sodic plagioclase-bearing metamorphic rocks whereas zoned and twinned andesine and oligoclase are derived from

Table 2. Plagioclase composition

Slide No.	Composition
0	Andesine
1	Andesine
3a	Oligoclase-Andesine
3b	Andesine
6	Oligoclase-Andesine
8	Oligoclase
10	Oligoclase-Andesine
11b	Oligoclase-Andesine
14	trace Plagioclase
15	Oligoclase-Andesine
16	Oligoclase
18	Oligoclase-Andesine
19	Oligoclase-Andesine
20	Oligoclase-Andesine
21	Andesine
22	Oligoclase-Andesine
23	Oligoclase-Andesine
24	Andesine
25	Andesine
26	Andesine
27b	Oligoclase-Andesine
30a	Oligoclase-Andesine
30b	Oligoclase-Andesine
32	Oligoclase-Andesine

Note: from 8-12 grains of plagioclase were identified per slide igneous rocks. Since most of the plagioclase in the Wallace River Formation is twinned and apparently not volcanic in origin, it has probably been derived from a granitic source. Plagioclase composition in metamorphic rocks can be used to determine the metamorphic facies. The epidote-amphibolite subfacies of the greenschist facies has a plagioclase composition of An_{15-30} whereas the upper limit of the amphibolite facies is marked by a plagioclase composition of An_{50} (Blatt, 1967). However, most schists, phyllites, slates and older sediments contribute little or no feldspar to younger sediments; the only metamorphic rock that does yield substantial amounts of plagioclase is a gneiss (Folk, 1959). Thus, plagioclase in this instance can indicate that a granitic source did exist, yet it cannot give much information on the relative amount of contribution by this rock type.

Microcline and orthoclase are common K-feldspars in these sandstones. Orthoclase occurs in igneous rocks whereas microcline is found mainly in plutonic and metamorphic (gneissic) rocks (Pittman, 1970).

In the western part of the study area, plagioclase and K-feldspar are found in roughly equal amounts in over 50 percent of the samples, whereas in the eastern part plagioclase is much more common than K-feldspar. Here, K-feldspar is as abundant as plagioclase in only one out of ten sandstones. This could be due to preferential destruction of K-feldspar in the eastern region following deposition or it could indicate a different source for the feldspars.

Sodalite, a feldspathoid, was identified in two sandstones. This mineral is confined to soda-rich igneous rocks (syenites).

VI. Rock Fragments

Rock fragments constitute from less than 1 to 17 percent of the total grains counted in the study area. Most common are metamorphic and sedimentary rock fragments. Metamorphic rock fragments include quartz-mica schists, sillimanite-mica schists and gneiss. The Balfron Member is the richest in metamorphic rock fragments, followed closely by the Wentworth Member. The youngest unit, the Waugh River Member, has varying amounts of metamorphic rock fragments. To the west, the older beds of this member are enriched in these rock fragments whereas the younger beds have none. The single sandstone sampled in the eastern region also displays a scarcity of metamorphic rock fragments.

Sedimentary rock fragments include coarse-grained (siltstone) and fine-grained shale fragments. Since these particles do not survive extensive transport, they are likely derived from a local source. This assumption has been verified by field and petrographic observation which indicate that in some cases, the shale clasts are derived directly from units underlying the sandstone.

Total rock fragments have been plotted against distance from the Cobequid Highlands and the results presented in Figure 7. To give a better regional interpretation, sedimentary rock fragments were then excluded from total rock fragments and the data was replotted (Fig. 8). Except for two groupings of low-rock fragment sandstones, a trend of decreasing percentage of rock fragments with increasing distance from the Cobequids was noticed. Sample 14 was excluded from the regression line plot as it is thought to represent a reworked sandstone. Samples 27b, 30a and 32

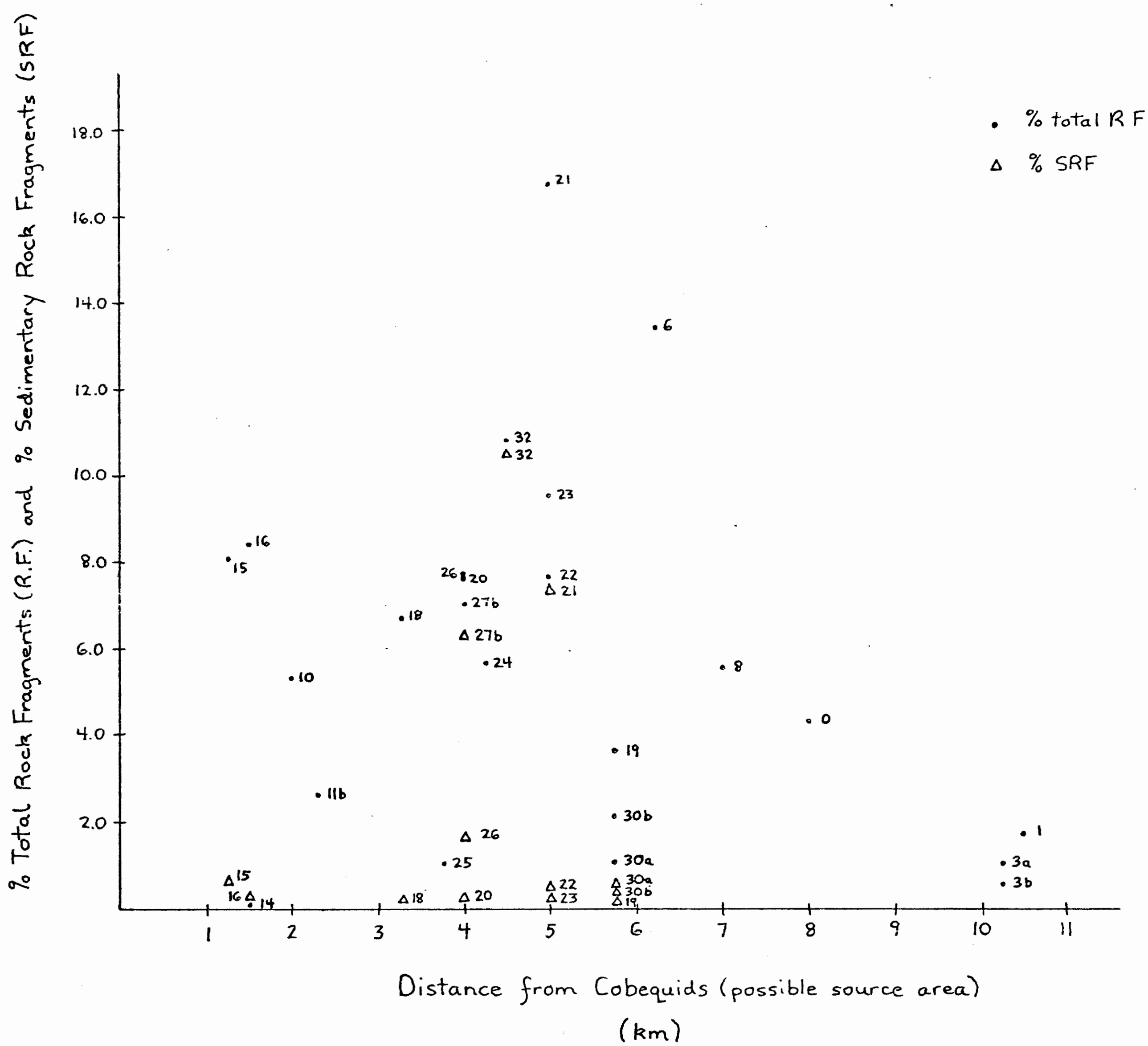
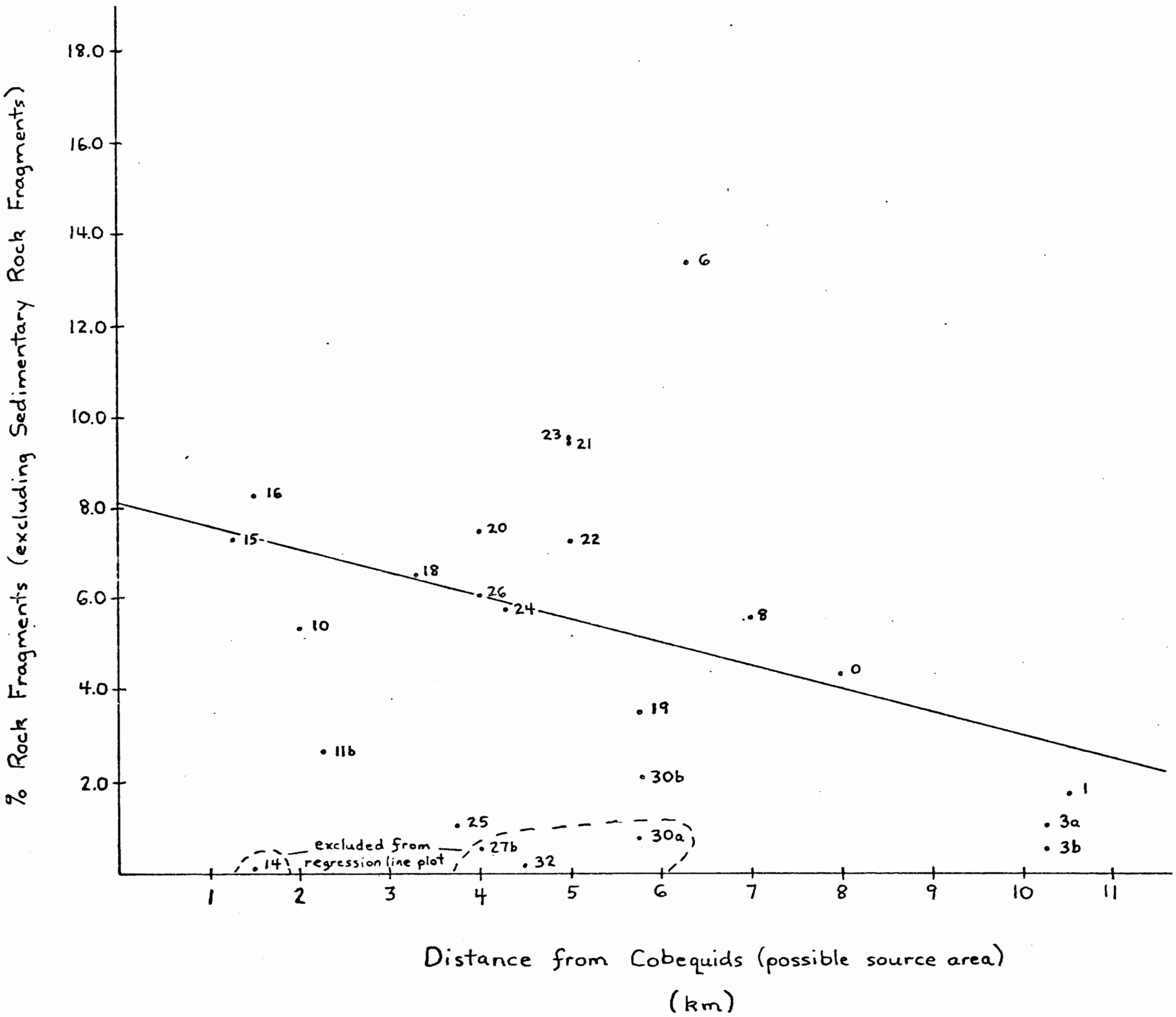


Fig. 7 . Percentage of total rock fragments and sedimentary rock fragments versus distance from Cobequids.



Regression Line

$Y = 8.1 - 0.50x$

$r = 0.42$

Fig. 8 . Percentage of total rock fragments (excluding sedimentary rock fragments) in sandstones with distance from Cobequids.

were left out as they have mainly reworked shale/siltstone clasts, probably from a local source.

The observed trend is due mainly to the destruction of rock fragments during transport or to the inability of the fluvial system to carry these particles over long distances. The energy of the fluvial regime decreases to the north, as witnessed by the deposition of finer-grained sediments.

The most stable rock fragments are those of polycrystalline quartz. This monomineralic rock fragment is preferentially enriched in sandstones farthest from the Cobequids. The number of grains in each aggregate varies from several to more than 15 individuals. Many rock fragments consisting of more than 5 grains display elongate shapes and irregular interlocking, indicative of a gneissic origin. Other quartz rock fragments appear to have been derived from granitic, schistose and older sandstone sources. Quartz rock fragments from granitic sources have common fluid inclusions and a particle size of roughly 0.5 mm. Schistose quartz rock fragments have rare fluid inclusions and an average particle size of 0.2 mm. Those from sandstone sources are rounded and can have abraded overgrowths of former cement (Blatt, 1967 and Blatt et al., 1972).

Volcanic and plutonic rock fragments are rare and were identified in very few sandstones (locations 21, 23, 24). Because of their relatively large grain size, plutonic (intrusive) rock fragments break down quickly into their individual components. Volcanic rocks probably did not contribute much material to the sediments of the Wallace River Formation.

VII. Cement

The sandstones of the Wallace River Formation are mainly cemented by silica and/or organics. Virtually every rock is grain-supported, with cement scattered through the sediment and usually comprising less than 15 percent of the total rock. The replacement of quartz and feldspar by authigenic calcite is apparent in several cases, where calcite cement reaches 17 percent of the sandstone. Friedman and Sanders (1978) state that the most favorable location for quartz replacement by calcite is near the upper contact of sandstone with shale, where calcite may replace up to 50 percent of the original quartz. In the Wallace River Formation, calcite cement is always associated with unstable shale rock fragments. Field work shows that calcite-cemented sandstones always occur near the top and bottom of sandstone units in contact with shale. Waters of pH greater than 9 circulating through an oxidized (red) sandstone will dissolve silica and precipitate calcite from solution (Friedman and Sanders, 1978). These waters originate in the shales, in which a loose, open packing yields up to 70 percent porosity in the unconsolidated sediment. Upon compaction, the pore waters are expelled and enter the underlying sandstone unit. Groundwaters of pH greater than 9 are not uncommon in the subsurface environment (Friedman and Sanders, 1978). This is the process believed to have taken place following burial and lithification of some of the sandstones in the study area.

Total cement ranges from 3 to 25 percent of the rock, averaging 14 percent over the whole area. Younger sediments generally have a lower cement-content than older strata.

An attempt was made to correlate the opaque/organics ratio with relative depth of burial, since many of the opaque grains are undoubtedly authigenic, having formed as a replacement of the organics (Fig. 9). The results show no increase or decrease in the ratio with depth. Eighty percent of the scatter plots lie below an opaque/organics ratio of 1 and it is revealed that, for most of the sandstones, the original ratio has remained relatively unchanged with geologic time.

VIII. Heavy Minerals

A. Introduction

Eleven different heavy minerals were identified during point-counting of thin sections from the medium-fine to very fine-grained sandstone of the Wallace River Formation. They are, in approximate order of decreasing abundance: opaques, biotite, muscovite, chlorite, garnet, clinopyroxene (augite), orthopyroxene (enstatite and hypersthene), epidote, hornblende, tourmaline and zircon. Tourmaline and zircon are found only in trace amounts in several slides.

Early heavy mineral studies in North America were concentrated on tracing heavy mineral zones in sands over large distances from borehole data. This work was usually done in conjunction with petroleum exploration. Examples of this type of study are those papers by Bornhauser (1940) and Cogen (1940). These authors were able to establish up to seven heavy mineral zones, interfingering along the strike of the sand bodies.

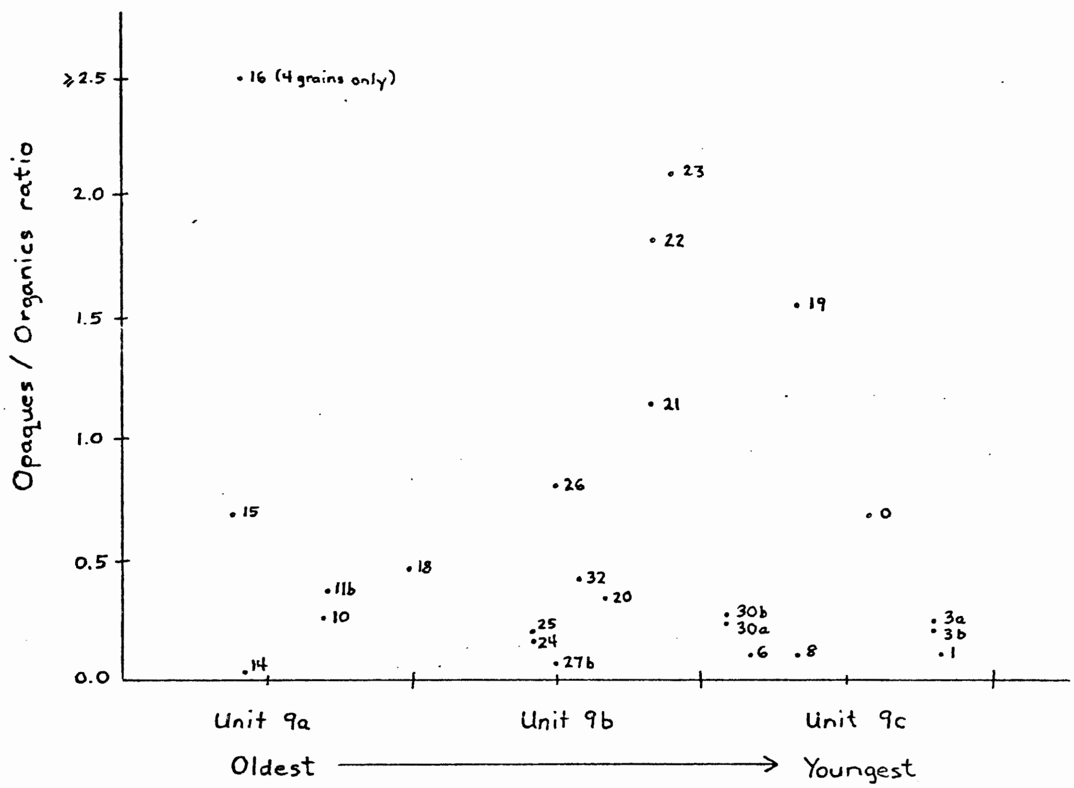


Fig. 9 . Opaque/organics ratio with corresponding depth of burial.

B. Sedimentary Processes

The type of heavy mineral assemblage preserved in a first-cycle sandstone unit will depend ultimately on the source area, weathering effects, mechanical abrasion during transport, selective sorting and post-depositional destruction of grains (van Andel, 1959). Recycling of material usually results in a relative depletion of heavy minerals in the resulting sediment. Heavy minerals from various sources may be mixed, causing a further complexity in the observed assemblage.

The effect of weathering on the composition of sediments in basins with moderate to rapid rate of deposition can be negligible (van Andel, 1959). Thus, weathering may not play a role in modifying heavy minerals of the Wallace River Formation, with the possible exception of the Waugh River Member, which was deposited by a low-energy fluvial system. Due to the high-energy regime of much of the deposition in this area, mechanical abrasion does affect the grain size and shape of the heavy minerals. Although most garnet grains are angular to subangular, smaller pyroxene grains are dominantly rounded to subrounded in thin section. Thiel (1940) found that over great distances of transport, a mineral sequence of increasing resistence to abrasion can be established, whereby quartz > tourmaline > garnet > hornblende > apatite. For the Wallace River Formation, this could be rewritten as quartz > tourmaline > garnet > (epidote) > pyroxene > hornblende, based on grain size and shape.

Selective sorting of heavy minerals can be explained in terms of hydraulically equivalent particles, defined as all particles that settle through water at the same rate (Friedman and Sanders, 1978). Rittenhouse

(1943) was one of the first advocates of this method of describing size distribution of heavy minerals in sediments. He found that this distribution is dependent on the hydraulic conditions at the site of deposition and the availability of various sizes of heavy minerals. Varying hydraulic conditions affect the deposition of heavy minerals much more than light minerals.

Selected heavy minerals from sandstones of the Wallace River Formation were used to demonstrate their hydraulic equivalent size relative to quartz (1.0) in the same sample. The results are recorded in Table 3. The figures were obtained by normalizing the sizes of heavy minerals in each slide to the corresponding quartz grain size, which was arbitrarily set at 1. In effect, size ratios of the heavy minerals to quartz (= 1) were found. An average value for each heavy mineral was then calculated. The values obtained from these sandstones for garnet (0.59) and tourmaline (0.70) are close to those determined for garnet (0.52) and tourmaline (0.80) by Friedman (1961). Experimental results indicate that spheres smaller than 0.18 mm settle according to the squares of their diameters whereas spheres larger than 0.18 mm settle according to the square roots of their diameters. The values in the hydraulic equivalent size table for the study area were not corrected for this change in settling velocity. However, since almost all the heavy mineral grains (except the micas) are smaller than 0.18 mm, the relative equivalent sizes among the heavy minerals are valid. The wide range in equivalent size of mica (1 to 3) is due to the platy nature of the mineral which enables flakes of different sizes to settle out of suspension at the same rate.

Table 3 . Hydraulic equivalent sizes of detrital grains

Slide	Quartz Grain Size (mm)	Quartz=1	Mica	Garnet	Pyroxene	Tourmaline	Epidote
0	0.125	1	1.14		0.50		
1	0.154	1	0.81	0.59	0.54		
3a	0.111	1	1.50	0.56	0.69		
3b	0.125	1	1.60	0.73	0.47		
6	0.200	1	1.11	0.45	0.33		
8	0.100	1	1.67	0.71	0.83		
10	0.083	1	2.40	0.75	0.60		
11b	0.071	1	2.33	0.74			
14	0.091	1	1.83		0.41		
15	0.167	1	3.50				
16	0.333	1	1.50		0.60		
18	0.286	1	1.75		0.35		
19	0.125	1	3.20	0.64	0.53		
20	0.143	1	2.33	0.58	0.30		
21	0.286	1	1.75	0.27	0.22	0.70	
22	0.100	1	2.00	0.71	0.45		
23	0.250	1	1.33	0.40	0.67		
24	0.154	1	1.63	0.36	0.33		0.33
25	0.105	1	1.58	0.53	0.79		0.68
26	0.286	1	2.04	0.35			
27b	0.100	1	1.82		0.33		
30a	0.100	1	1.82	0.56	0.45		
30b	0.095	1	2.33	1.05	0.81		
32	0.118	1	1.55	0.65	0.35		1.70
	Average :	1	1.85	0.59	0.50	0.70	0.90

Pettijohn (1941) noticed an apparent increase in complexity of heavy mineral suites with younging age, due to the differing degrees of persistence of heavy minerals with age. A compilation of heavy mineral analyses from sediments ranging in age from Precambrian to Recent is shown in Figure 10. From the data, Pettijohn created an order of persistence of heavy minerals (Table 4). In simpler terms, the stability series is the reverse of Bowen's reaction series.

The most widespread non-opaque heavy minerals in the Wallace River Formation are garnet and various pyroxenes. Figure 10 illustrates that garnet in Late Paleozoic sediments is highly stable and present in roughly the same amount as garnet in Recent sediments. However, pyroxenes are much less stable and are 4 to 5 times more common in Recent sediments than Late Paleozoic sediments. This indicates that up to 75 to 80 percent of the pyroxenes may have been destroyed following deposition in some cases. A further possibility is that pyroxenes were preferentially depleted during transportation, due to abrasion. Most grains observed were rounded to subrounded, indicative of wear during transport.

Most destruction of heavy minerals in the post-depositional environment is accomplished by intrastratal solutions circulating through sedimentary bodies. Their effects can be noticed even on highly stable garnet grains. Several garnets in thin section from the study area display corroded rims and replacement by opaque minerals. As well, introduction of calcite cement often masks the true proportions of heavy minerals in a sandstone.

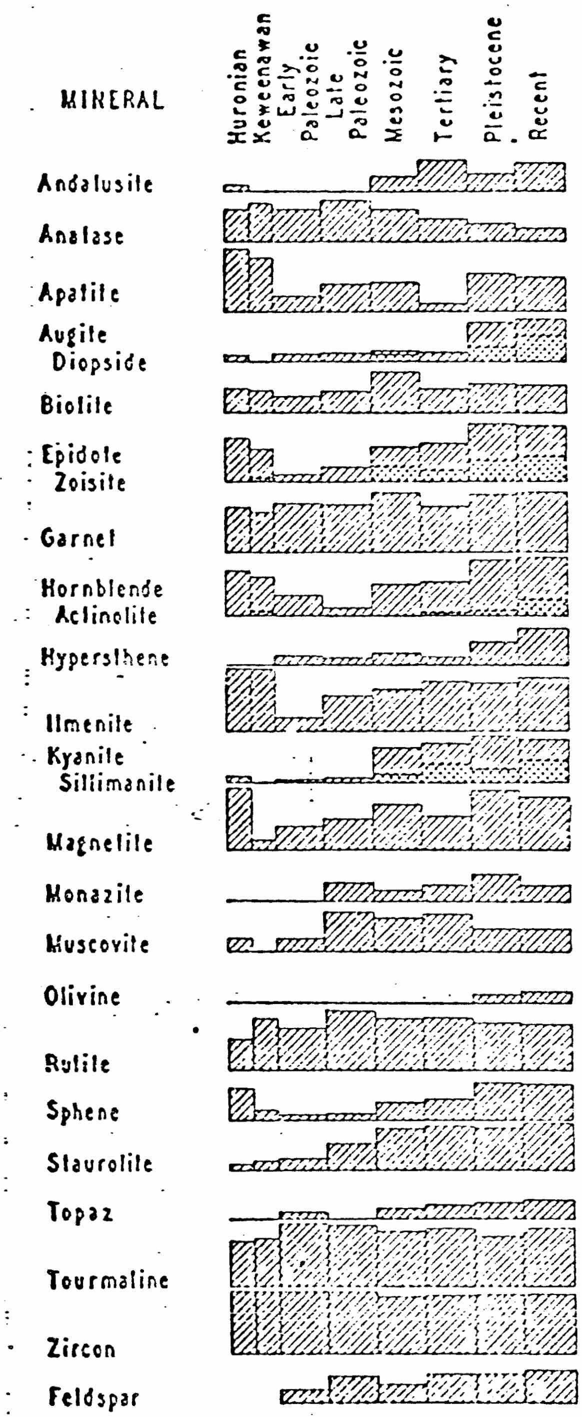


FIG. 1.—Frequency of Occurrence Chart. Based on Table 1

Fig. 10 . Heavy minerals in sediments ranging from Precambrian to Recent.

from Pettijohn (1941) p. 615

Table 4. Order of persistence of heavy minerals

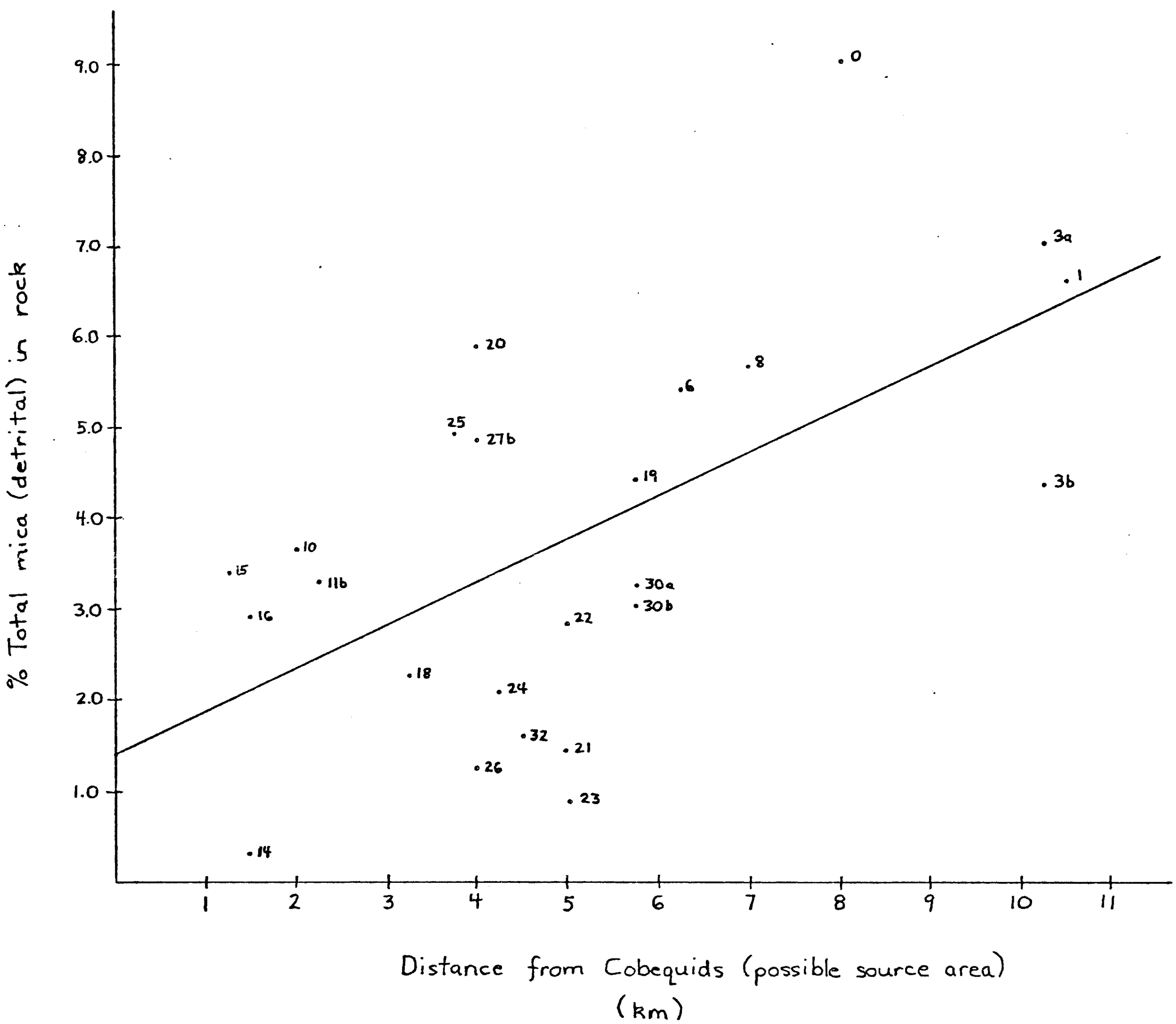
Most persistent	-3 anatase	10 kyanite
	-2 muscovite	11 epidote
	-1 rutile	12 hornblende
		13 andalusite
	1 zircon	14 topaz
	2 tourmaline	15 sphene
	3 monazite	16 zoisite
	4 garnet	17 augite
	5 biotite	18 sillimanite
	6 apatite	19 hypersthene
	7 ilmenite	20 diopside
	8 magnetite	21 actinolite
	9 staurolite	22 olivine Least persistent

from Pettijohn (1941) p. 618

C. Micas

Over the entire study area, biotite is more common than muscovite, which is in turn more abundant than chlorite. Micas can be found in both the light and heavy mineral separates of a sandstone, and in this study are considered heavy minerals. The author believes that biotite was originally much more common than the other micas, as many detrital biotite grains have been partly or completely replaced by authigenic chlorite and muscovite. The percentage of total detrital mica has been plotted against distance from the Cobequid Highlands (possible source area) in an attempt to reveal a regional distribution of mica in rocks of the Wallace River Formation (Fig. 11). The data indicates a trend of increasing mica-content with increasing distance from the Cobequids. On the average, sandstones 10 km distant from the Cobequids have total mica proportions twice that of sandstones only 2 km from the Cobequids. This is likely a relative rather than true enrichment pattern due to mica being transported over much greater distances than other heavy minerals prior to deposition. The source area has probably not changed substantially in composition over the deposition of the Wallace River Formation. Rather, the apparent mica-enrichment trend northward from the Cobequids is likely due to a change from high- to low-energy fluvial systems with time.

Biotite can be derived from almost all types of igneous and metamorphic terrains, and when very abundant, is suggestive of a volcanic source (Scholle, 1979). Muscovite is very common in metamorphic rocks and is also found in granites, whereas chlorite is found in most source rock types.



Regression Line

$Y = 1.4 + 0.47x$

$r = 0.59$

Fig. 11 . Regional distribution of mica in sandstones of the Wallace River Formation.

D. Garnet

Garnets are present in small and trace amounts in 18 of the 24 sandstones studied. They range in size mainly from 0.10 mm to 0.06 mm. Individual grains are mainly angular to subangular, with well-developed six-sided forms. Minor rounded to subrounded grains are occasionally corroded and partly replaced by opaques and chlorite. In some thin sections, zones of heavy minerals, predominantly garnet, were noticed. The relatively high stability of garnet facilitates its use in denoting garnet-rich and garnet-poor heavy mineral zones over large areas. Garnet (almandine) is derived mainly from high rank metamorphic rocks as well as hydrothermal veins and pegmatites (Pettijohn, 1975).

E. Pyroxenes

Pyroxene grains are found in 21 of 24 sandstones. Grain size ranges mainly from 0.07 to 0.05 mm. All grains were rounded to well-rounded, indicative of a lower stability during transport than that of garnet. Clinopyroxenes identified were mainly augite with some diopside, whereas the orthopyroxenes were mainly hypersthene with minor enstatite. Chemical instability has probably lowered the percentage of pyroxene in these sandstones. Both augite and hypersthene are characteristic of a mafic igneous source rock (Pettijohn, 1975). Enstatite is found mainly in subsilicic igneous rocks, whereas diopside is common in contact metamorphic and occurs in some metamorphic and igneous rocks (Kerr, 1977).

F. Epidote and Hornblende

Epidote is present in trace amounts in at least 5 sandstones and in a larger proportion in only 1 slide. The few grains studied were angular to subangular and the same size or larger than garnets from the same sediment. Epidote is chemically more stable than pyroxene but considerably less stable than garnet (Table 4). Epidote is a characteristic mineral of high- to low-rank metamorphic rocks. It can also be derived from altered igneous rocks (Pettijohn, 1975).

Hornblende was point-counted in slides from 2 sandstones and was present in trace amounts in 3 other sandstones. Most of the hornblende occurs in rocks of the Waugh River Member. Individual grains were angular to subangular. Hornblende has roughly the same chemical stability as epidote. This mineral is characteristic of felsic igneous, hydrothermal and high-rank metamorphic rocks (Pettijohn, 1975).

G. Tourmaline and Zircon

Tourmaline is present in trace amounts in 5 sandstones. Tourmaline grains are generally angular to subangular. This mineral is even more stable chemically than garnet, so its relatively rare occurrence when compared to garnet indicates a scarcity of source rocks contributing tourmaline to sandstones of the Wallace River Formation. One blue variety of tourmaline, schorlite, was identified. Schorlite is characteristic of granite pegmatites and can also be found in certain schists and gneisses (Krynine, 1946).

Zircon is found in trace amounts in only 2 sandstones. Although this mineral is very stable, slightly more so than tourmaline, detrital grains are invariably minute and difficult to detect in thin section. Zircon is derived from felsic igneous rocks and occasionally from metamorphic rocks (Pettijohn, 1975).

IX. Heavy Mineral Provinces

A. Introduction

Van Andel (1959) presents some questions on the validity of many heavy mineral interpretations. Theoretically, the number of possible heavy mineral assemblages is great, yet the number actually observed is small. The most common are hornblende-epidote, epidote, kyanite-zircon, staurolite-zircon, garnet-zircon-tourmaline and zircon-tourmaline. The possibility exists that these zones are controlled primarily by mineral stability rather than by provenance.

The action of intrastratal solutions in modifying heavy mineral provinces cannot be underestimated. It is best to keep in mind the chemical stabilities of the various heavy minerals when attempting to establish heavy mineral provinces for the Wallace River Formation.

B. Heavy Minerals

The percentage of garnet and minor epidote has been plotted against pyroxene percentage in the sandstones from the study area (Fig.12). This figure was intended primarily for provenance determination but also can be

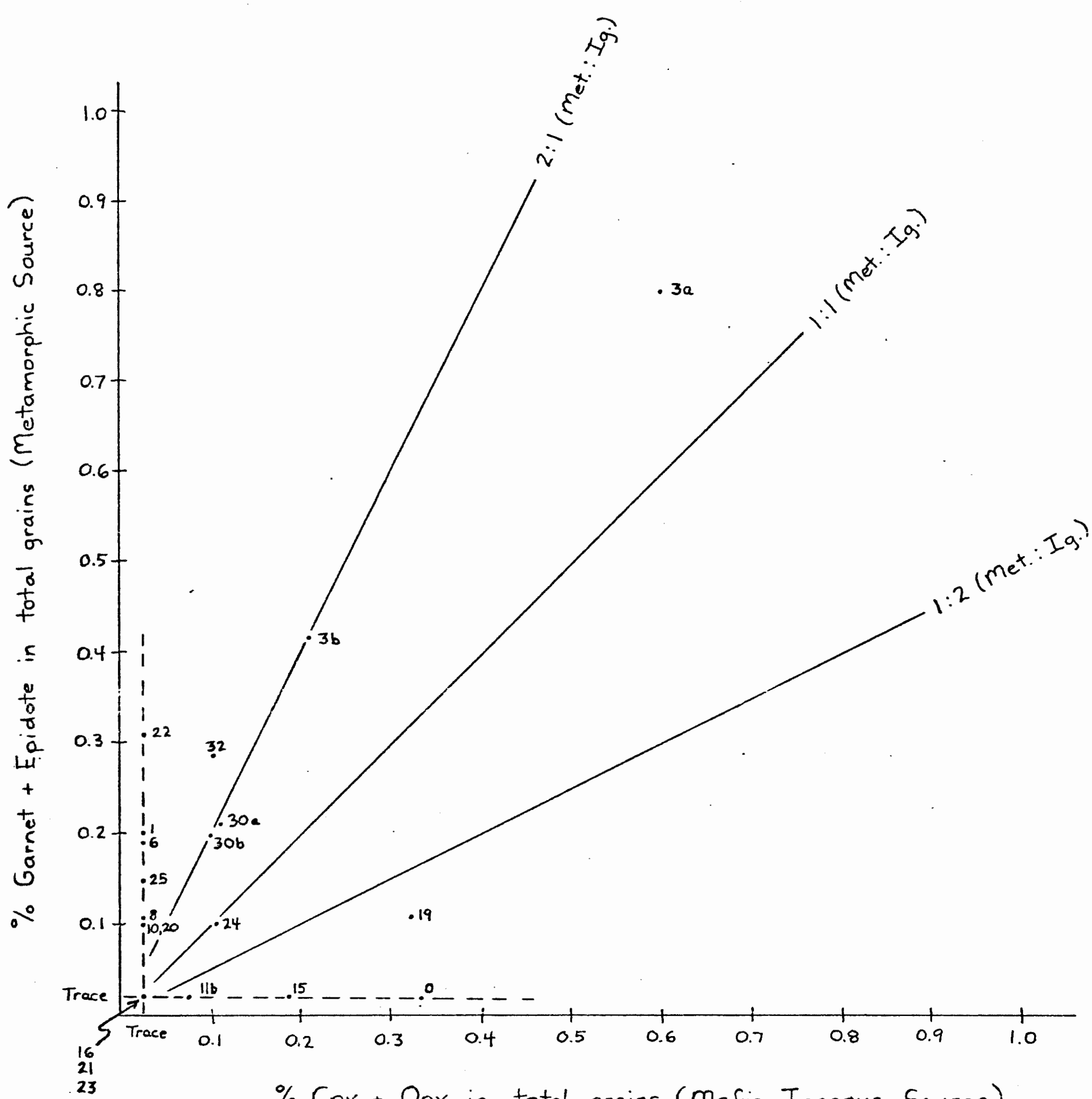


Fig. 12 . Provenance determinations using percentage of garnet + epidote (metamorphic source) versus percentage of clinopyroxene + orthopyroxene (mafic igneous source).

used to help establish heavy mineral provinces. The results reveal that 75 percent of the sandstones contain more garnet than pyroxene. This evidence is hardly conclusive though, due to the great difference in chemical stability between garnet and pyroxene. Several sandstones contain definitely more pyroxene (hypersthene, augite) than garnet and can be considered part of a pyroxene heavy mineral province (locations 0, 19).

Hornblende is only found in appreciable amounts at locations 1 and 3. This mineral is detected elsewhere only in trace amounts. Since hornblende is chemically more stable than pyroxene, which is widespread in the Wallace River Formation, this region can be considered part of a hornblende heavy mineral province.

The presence of epidote in the sandstones, even in trace amounts, can be used to designate garnet-epidote provinces in some areas (locations 21, 22, 24, 30). Because of its lower chemical stability relative to garnet, epidote proportions can be compared more directly with pyroxene proportions due to the greater chemical stability similarity between these minerals.

At locations 25, 26 and 27, garnet and tourmaline are present in roughly equal amounts, with minute percentages of pyroxene and epidote. A local garnet-tourmaline province could be established in this area.

In general, three regional heavy mineral provinces can be established: a hornblende province, a hypersthene-augite province and a widespread garnet province. The latter can be subdivided in certain localities into garnet-epidote and garnet-tourmaline provinces (Map 2).

X. Provenance of the Wallace River Formation

A. Introduction

When determining provenance for any sediment, it must be decided whether the material is first-cycle or second-cycle. Heavy mineral interpretation should be supported by paleocurrent data. Distances of transport are also important. Stanley (1965) found that sands in flysch of the French Alps could not be correlated over distances greater than 15 to 20 km.

There is evidence of both first- and second-cycle sandstones in the Wallace River Formation. Van de Poll (1973) found that sediment transport in the Pictou Group was in an easterly to northeasterly direction (Fig. 13). His studies were conducted in central and eastern New Brunswick, and he concluded that the highlands in that province were the main source of Pictou Group sediments. For the study area, considerable stream transport from the Cobequid Highlands northward was also possibly in operation. The author believes that the sandstones of the Wallace River Formation lie no more than 10 to 15 km from their source rocks.

B. Heavy Mineral Data

Garnet and epidote are characteristic minerals of high- to low-rank metamorphic rocks whereas clinopyroxene (augite) and orthopyroxene (hypersthene) are derived mainly from mafic igneous rocks (Pettijohn, 1975).

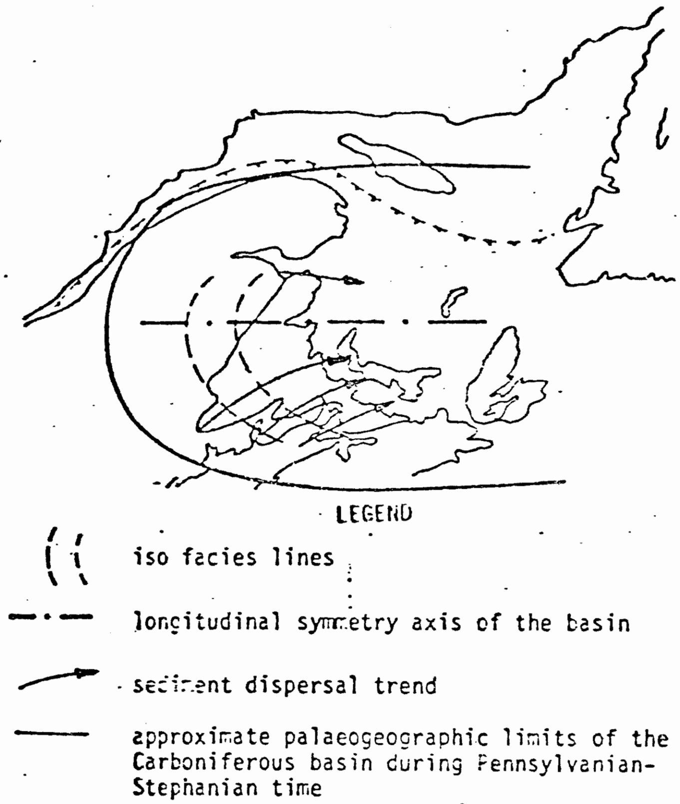


Fig. 3. - Paleocurrents of the Pictou Group in the Carboniferous Basin.

Fig. 13 . Paleocurrent directions of the Pictou Group in the Cumberland Basin.

from van de Poll (1973) p. 76

The percentages of these two groups of minerals have been plotted against each other to determine the relative importance of metamorphic and mafic igneous rocks in contributing detritus to the Wallace River Formation (Fig. 12). The results favour a metamorphic origin for most sediments as over 60 percent of the scatter plots fall above the line denoting a metamorphic/mafic igneous ratio of 2 to 1. Metamorphic rocks definitely contributed the garnets to these sediments, but due to the chemical instability of pyroxenes, the relative amount of metamorphic and mafic igneous contribution is not clear. Garnets (almandine) are very common in granulite facies metamorphic rocks and may occur in amphibolite facies rocks (Miyashiro, 1975).

The epidote present in some sandstones is probably metamorphic in origin as well, derived from schists or gneisses of the greenschist facies or epidote-amphibolite subfacies (ibid).

The high proportion of detrital mica could be due to breakdown of micaceous schists and related metamorphic rocks. The mica could also be derived from a variety of granites and pegmatites. Tourmaline (schorlite) is indicative of a minor pegmatitic source.

One interesting feature is the confinement of hornblende to the youngest rocks of the Waugh River Member. At present, hornblende granite of Devonian to Carboniferous age crops out to the south of the study area (Donahoe and Wallace, 1978). The introduction of hornblende into the sandstones could have shortly followed unroofing of the hornblende granite pluton. This change in mineralogy could also be due to changing transport direction over time.

C. Supporting Evidence

Light minerals and rock fragments can be used to help determine provenance for the Wallace River Formation. The shape and form of quartz grains, for instance, can aid in indicating whether a sandstone is first- or second-cycle. If most of the quartz grains in a sandstone are well-rounded and greater than 90 percent of the quartz is monocrystalline, then the sandstone is probably second-cycle (Blatt, 1967). The sandstone cropping out at location 14 is undoubtedly second-cycle. Detrital quartz, comprising 90 percent of total grains, has a high sphericity and is rounded to subrounded, and feldspar and rock fragments are present in amounts less than 1 percent.

Metamorphic and sedimentary rock fragments are present in appreciable amounts in many sandstones. The sedimentary rock fragments are derived locally from older siltstone and shale. The metamorphic rock fragments are dominantly sillimanite-mica and quartz-mica (muscovite) schists, with minor gneissic fragments.

The only metamorphic rocks cropping out to the south of the study area are Proterozoic or Paleozoic metavolcanics, quartzites, biotite schists, hornblende and feldspar-chlorite gneiss, biotite-muscovite ± garnet schist, amphibolite and granite gneiss of the Bass River Metamorphic Suite and the Mount Thom Complex (Donahoe and Wallace, 1978). Erosion has removed most of the outcrop from the Cobequids, but it is apparent that these metamorphic rocks once covered a much wider area.

Volcanic rock fragments are rare and probably have been derived from rhyolitic and dacitic flows of Silurian age which border the Wallace River Formation in part to the south.

Plagioclase in the sandstones is always andesine and/or oligoclase. Oligoclase is very common in persilicic igneous rocks such as syenite and rhyolite, whereas andesine is common in diorites and andesites. The plagioclase does not appear to be representative of a volcanic source, but rather a granitic one. Reworking of polymictic conglomerates of the River John Group (Devonian) likely contributed substantial material to sandstones of the Wallace River Formation, especially in the eastern half of the study area.

XI. Further Work Needed

This heavy mineral study has been concentrated on sandstones of the Wallace River Formation. Neither coarse-grained sandstones nor polymictic conglomerates were studied and it is felt that these rock types could yield further evidence in determining provenance. Conglomerates, for example, are rich in polymineralic rock fragments, allowing easier interpretation of source area.

Associated sediments ranging in age from Devonian to Pennsylvanian also were not studied. It is often difficult to distinguish material reworked from an older coarse-grained sediment from that from a primary source. Heavy mineral studies of sandstones should be conducted in conjunction with sampling of possible parent rock types. Blatt (1967) suggested that relative proportions of heavy minerals in the possible parent rocks be calculated to determine the relative stability of these minerals during transportation and deposition.

Further information on the chemical stability of minerals and rock fragments in the Wallace River Formation is needed to clearly establish heavy mineral provinces and provenance. As well, more data on paleocurrent directions is required in order to more accurately trace sediment transport.

XII. Conclusions

The heavy minerals of the Wallace River Formation of the Pictou Group can be used to establish heavy mineral provinces and contribute to determining provenance.

Three main heavy mineral provinces were determined. A hornblende province is centered around locations 1 and 3, and possibly extends along strike to River John. Interestingly, location 30, which lies to the south of the possible hornblende zone, contains trace hornblende. Sampling of sandstone units at the mouth of the River John is needed to verify extension of this province. A localized hypersthene-augite (pyroxene) province is centered about locations 0 and 19. The remainder of the area can be considered to be part of a regional garnet province, with a localized garnet-epidote province about location 30 and possibly extending westward to locations 21, 22 and 24 where epidote is present in trace amounts. A local garnet-tourmaline province is centered around locations 25, 26 and 27.

Provenance studies indicate that the source terrain was dominantly metamorphic, with appreciable input by mafic igneous, granitic and older sedimentary rocks, and minor contributions by volcanic and pegmatitic rocks. The composition of the metamorphic source area was schistose, as most metamorphic rock fragments are sillimanite and muscovite schist. The relative abundance of garnets among the heavy minerals indicates a high-grade metamorphic source. The provenance is possibly represented at present by the scattered outcropping of Proterozoic or Paleozoic metamorphics in the Cobequid Highlands to the south.

Rare volcanic fragments were likely contributed by Silurian andesites, dacites and rhyolites. A plutonic source is required for most of the plagioclase, whereas the pyroxenes suggest a mafic igneous source. There is evidence that hornblende granite (Devonian-Carboniferous) in the Cobequids was not unroofed until late in the depositional history of the Wallace River Formation. Granite pegmatites likely did contribute some material to this unit, as witnessed by the presence of schorlite (tourmaline) in some sandstones.

Reworking of older sandstones as a source of material for the sandstones in the study area is of minor importance. Only one sandstone (location 14) was definitely second-cycle. Other older sediments (conglomerates, shales) likely provided varying amounts of detritus to most rocks of the Wallace River Formation.

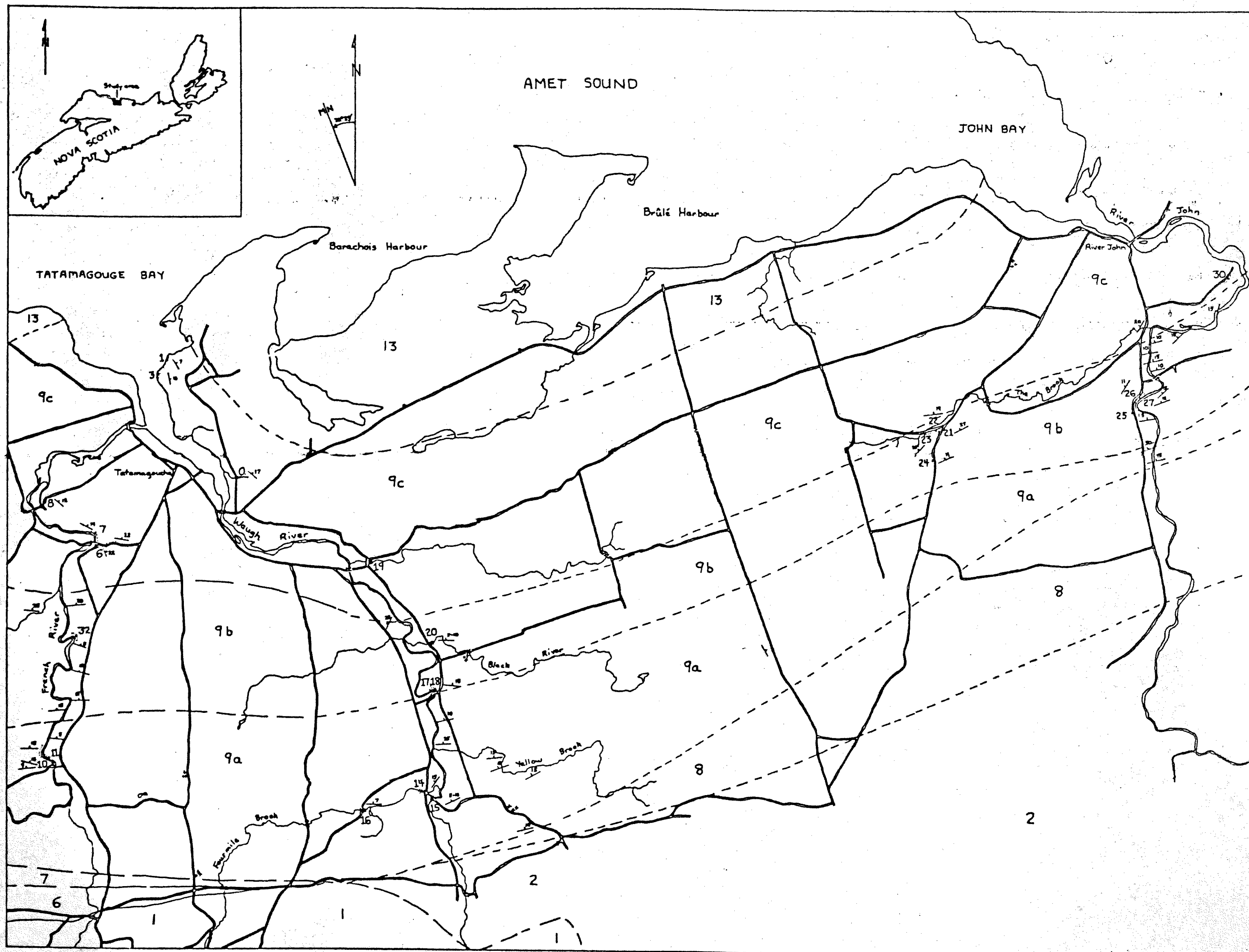
It is very important to note that the Pictou sediments in the Tatamagouche-River John area strike east-west, roughly paralleling the lineament of the Cobequid Highlands, and that they dip (young) to the north.

It is possible that the lateral fining sequence to the north is more appropriately looked at as a vertical fining upward sequence (P. Fralick, personal communication). If sediment transport was in an easterly direction through the Cumberland Basin and the Cobequid Highlands were covered by sediment during deposition of the Pictou Group, then this fining upwards sequence could possibly be explained by the continual erosion of the highlands to the west of the basin (ibid). If this were true, then the presence of hornblende in the youngest beds of the Waugh River Member might indicate a changing transport direction with time. Since the granitic rocks of the Cobequids are mainly hornblende granite to diorite (Donahoe and Wallace, 1978), these beds might date the uncovering of the Cobequid Highlands.

This study was conducted over a relatively small amount of Pictou Group strata cropping out in northern Nova Scotia. To gain a more regional interpretation of source areas or provenance for these Pennsylvanian sediments, heavy mineral studies should be undertaken throughout the Cumberland Basin of deposition.

Map 1

GEOLOGICAL MAP OF THE WALLACE RIVER FORMATION



STRATIGRAPHIC LEGEND

13	Amet Sound Formation (Pictou Group) - grey to red micaceous sandstone, shale, grit, conglomerate, limy beds
9	Wallace River Formation (Pictou Group) - 9c Waugh River Member, 9b Balfron Member, 9a Wentworth Member
8	Caribou River Formation (Pictou Group) - grey sandstone, grit, shale
7	CUMBERLAND GROUP - red to grey sandstone, siltstone, shale, conglomerate; coal
6	Boss Point Formation (Riversdale Group) - grey sandstone, grit, limestone pebble conglomerate, shale
2	RIVER JOHN GROUP and undifferentiated pre-Pictou strata
1	Pre-Middle Devonian volcanic, sedimentary, metamorphic, intrusive rocks

MAP SYMBOLS

Attitude of strata — inclined 10

Outcrop — broken, rubbly

Contacts

- stratigraphic contact
- approximate position of contact
- arbitrary separation between map units

Sample Locations • 14

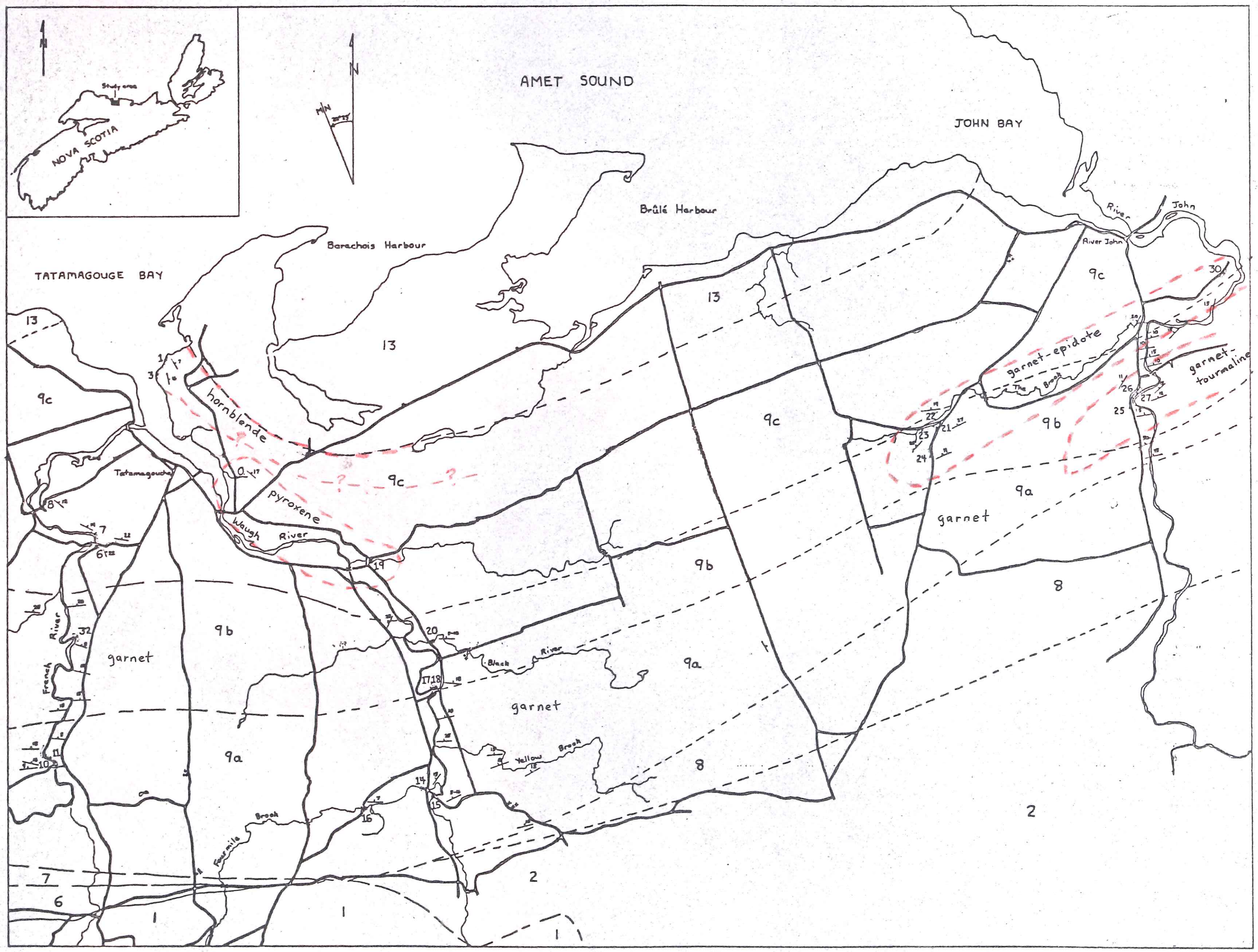
0 1 2 3 4 5

(km)

(after Roscoe et al, 1972)

Map 2 - Heavy Mineral Provinces

GEOLOGICAL MAP OF THE WALLACE RIVER FORMATION



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Sample Locations • 14

Heavy mineral provinces

0 1 2 3 4 5 (km)

(after Roscoe et al, 1972)

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APPENDIX

Slide No. O (1), (2) Rock No. O Grain size = 0.125 mm

Location No. O

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	281	63.15	300	65.08	581	64.13
K-feldspar	21	4.72	26	5.64	47	5.19
Plagioclase	4	0.90	14	3.04	18	2.00
Chlorite	13	2.92	10	2.17	23	2.54
Muscovite	28	6.29	16	3.47	44	4.86
Biotite	8	1.80	7	1.52	15	1.66
Orthopyroxene	2	0.45	Trace	—	2	0.22
Clinopyroxene			1	0.22	1	0.11
Garnet			Trace	—	Trace	—
Epidote	Trace	—			Trace	—
Hornblende	Trace	—	Trace	—	Trace	—
Sodalite						
Zircon	Trace	—			Trace	—
Tourmaline						
Opaques	13	2.92	7	1.52	20	2.21
Altered grains	65	14.61	51	11.06	116	12.80
Rock Fragments	10	2.25	29	6.29	39	4.30
MRF						
QRF						
VRF						
IRF						
SRF						
Total grains	445	100.01	461	100.01	906	100.02
Cement	1		2		Total	
Organics	22	4.71	8	1.71	30	3.31
Calcite						
Silica						
Total cement	22	4.71	8	1.71	30	3.31

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: Altered grains predominantly sericitized and chloritized (minor) feldspars

Opaques include pyrite

Opx is hypersthene, Cpx is augite

Slide No. 1 (1),(2)   Rock No. 1   Grain size = 0.125 mm

Location No. 1

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	354	69.14	353	71.60	707	70.35
K-feldspar	16	3.12	13	2.64	29	2.89
Plagioclase	15	2.93	6	1.22	21	2.09
Chlorite	12	2.34	9	1.83	21	2.09
Muscovite	18	3.52	14	2.84	32	3.18
Biotite	3	0.59	11	2.23	14	1.39
Orthopyroxene			Trace	—	Trace	—
Clinopyroxene						
Garnet	1	0.20	1	0.20	2	0.20
Epidote						
Hornblende	3	0.59	1	0.20	4	0.40
Sodalite	2	0.39	2	0.41	4	0.40
Zircon						
Tourmaline						
Opaques	4	0.78	6	1.22	10	1.00
Altered grains	70	13.67	73	14.81	143	14.23
Rock Fragments	14	2.73	4	0.81	18	1.79
MRF						
QRF						
VRF						
IRF						
SRF						
Total grains	512	100.00	493	100.01	1005	100.01
Cement	1		2		Total	
Organics	48	8.57	42	7.85	90	8.22
Calcite						
Silica						
Total cement	48	8.57	42	7.85	90	8.22

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: Some MRF's, Opx is hypersthene

Slide No. 3a (1) Rock No. 3a. Grain size = 0.10 mm
Location No. 3

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	329	66.06				
K-feldspar	8	1.61				
Plagioclase	11	2.21				
Chlorite	13	2.61				
Muscovite	14	2.81				
Biotite	8	1.61				
Orthopyroxene	1	0.20				
Clinopyroxene	2	0.40				
Garnet	4	0.80				
Epidote						
Hornblende	Trace	—				
Sodalite	1	0.20				
Zircon						
Tourmaline						
Opaques	18	3.61				
Altered grains	84	16.87				
Rock Fragments	5	1.00				
MRF						
QRF						
VRF						
IRF						
SRF						
Total grains	498	99.99				
Cement	1		2		Total	
Organics	77	13.39				
Calcite						
Silica						
Total cement	77	13.39				

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: non-opaque iron oxides? invariably found with organics ; true in many slides

Slide No. 3b(1) Rock No. 3b Grain size = 0.10 mm

Location No. 3

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	355	73.80				
K-feldspar	8	1.66				
Plagioclase	3	0.62				
Chlorite	15	3.12				
Muscovite	6	1.25				
Biotite	Trace	–				
Orthopyroxene	1	0.21				
Clinopyroxene	Trace	–				
Garnet	2	0.42				
Epidote						
Hornblende	1	0.21				
Sodalite						
Zircon						
Tourmaline						
Opaques	15	3.12				
Altered grains	72	14.97				
Rock Fragments	3	0.62				
MRF						
QRF						
VRF						
IRF						
SRF						
Total grains	481	100.00				
Cement	1		2		Total	
Organics	79	14.11				
Calcite						
Silica						
Total cement	79	14.11				

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes:

Slide No. 6 (1) Rock No. 6 Grain size = 0.167 mm
Location No. 6

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	346	65.41				
K-feldspar	6	1.13				
Plagioclase	11	2.08				
Chlorite	6	1.13				
Muscovite	10	1.89				
Biotite	13	2.46				
Orthopyroxene	Trace	—				
Clinopyroxene	Trace	—				
Garnet	1	0.19				
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques	5	0.95				
Altered grains	60	11.34				
Rock Fragments	71	13.42				
MRF	70	13.23				
QRF	1	0.19				
VRF						
IRF						
SRF						
Total grains	529	100.00				
Cement	1		2		Total	
Organics	47	8.10				
Calcite	4	0.69				
Silica						
Total cement	51	8.79				

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes:

Slide No. 7(1),(2)   Rock No. 7   Grain size = 0.059 mm
Location No. 7   Siltstone

	1		2		3	
Grains	# grains	%	# grains	%	# grains	%
Quartz						
K-feldspar						
Plagioclase						
Chlorite						
Muscovite						
Biotite						
Orthopyroxene						
Clinopyroxene						
Garnet						
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques						
Altered grains						
Rock Fragments						
MRF						
QRF						
VRF						
IRF						
SRF						
Total grains						
Cement	1		2		3	
Organics						
Calcite						
Silica						
Total cement						

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: Grain size too small for point-counting.
Predominantly calcite cement - cement supported rock.

Slide No. 8(1),(2) Rock No. 8 Grain size = 0.100 mm
Location No. 8

Grains	1 # grains	1 %	2 # grains	2 %	Total # grains	Total %
Quartz	366	77.54	363	78.40	729	77.97
K-feldspar	8	1.69	6	1.30	14	1.50
Plagioclase	11	2.33	9	1.94	20	2.14
Chlorite	5	1.06	9	1.94	14	1.50
Muscovite	12	2.54	8	1.73	20	2.14
Biotite	7	1.48	12	2.59	19	2.03
Orthopyroxene	Trace	—			Trace	—
Clinopyroxene						
Garnet	Trace	—	1	0.22	1	0.11
Epidote						
Hornblende	Trace ?				Trace ?	—
Sodalite						
Zircon						
Tourmaline						
Opaques	2	0.42	4	0.86	6	0.64
Altered grains	33	6.99	26	5.62	59	6.31
Rock Fragments	28	5.94	25	5.40	53	5.67
MRF	25	5.30	25	5.40	50	5.35
QRF	3	0.64	Trace		3	0.32
VRF						
IRF						
SRF						
Total grains	472	99.99	463	100.00	935	100.01

Cement	1		2		Total	
Organics	18	3.67	36	7.21	54	5.45
Calcite	1	0.20			1	0.10
Silica						
Total cement	19	3.87	36	7.21	55	5.55

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes:

Slide No. 10(1),(2)   Rock No. 10   Grain size = 0.083 mm
Location No. 10

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	366	76.89	372	77.82	738	77.36
K-feldspar	4	0.84	8	1.67	12	1.26
Plagioclase	1	0.21	4	0.84	5	0.52
Chlorite	4	0.84	8	1.67	12	1.26
Muscovite	6	1.26	3	0.63	9	0.94
Biotite	7	1.47	7	1.46	14	1.47
Orthopyroxene						
Clinopyroxene			Trace	—	Trace	—
Garnet	Trace	—	1	0.21	1	0.10
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques	11	2.31	9	1.88	20	2.10
Altered grains	50	10.51	42	8.79	92	9.64
Rock Fragments	27	5.67	24	5.02	51	5.35
MRF	26	5.46	21	4.39	47	4.93
QRF	1	0.21	3	0.63	4	0.42
VRF						
IRF						
SRF						
Total grains	476	100.00	478	99.99	954	100.00
Cement	1		2		Total	
Organics	34	5.78	45	8.43	79	7.04
Calcite	78	13.26	11	2.06	89	7.93
Silica						
Total cement	112	19.04	56	10.49	168	14.97

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: calcite cement varies substantially in concentration throughout the rock.

Slide No. 11b (1),(2),(3) Rock No. 11b Grain size = 0.071 mm
Location No. 11

	1		2		3	
Grains	# grains	%	# grains	%	# grains	%
Quartz	365	79.69	371	81.00	349	76.70
K-feldspar	Trace	—	4	0.87	2	0.44
Plagioclase	5	1.09	5	1.09	11	2.42
Chlorite	5	1.09	3	0.66	4	0.88
Muscovite	5	1.09	1	0.22	5	1.10
Biotite	10	2.18	6	1.31	7	1.54
Orthopyroxene						
Clinopyroxene					1	0.22
Garnet	Trace	—	Trace	—	Trace	—
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques	13	2.84	14	3.06	16	3.52
Altered grains	41	8.95	45	9.82	45	9.89
Rock Fragments	14	3.06	9	1.97	15	3.30
MRF	13	2.84	9	1.97	15	3.30
QRF	1	0.22				
VRF						
IRF						
SRF						
Total grains	458	99.99	458	100.00	455	100.01
Cement	1		2		3	
Organics	40	6.79	39	7.34	38	6.71
Calcite	91	15.45	34	6.40	73	12.90
Silica						
Total cement	131	22.24	73	13.74	111	19.61

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: Totals compiled on next page

Slide No. 11b(1), (2), (3)

	Total	
Grains	# grains	%
Quartz	1085	79.14
K-feldspar	6	0.44
Plagioclase	21	1.53
Chlorite	12	0.88
Muscovite	11	0.80
Biotite	23	1.68
Orthopyroxene		
Clinopyroxene	1	0.07
Garnet	Trace	—
Epidote		
Hornblende		
Sodalite		
Zircon		
Tourmaline		
Opaques	43	3.14
Altered grains	131	9.55
Rock Fragments	38	2.77
MRF	37	2.70
QRF	1	0.07
VRF		
IRF		
SRF		
Total grains	1371	100.00
Cement	Total	
Organics	117	6.94
Calcite	198	11.74
Silica		
Total cement	315	18.68

MRF=metamorphic rock fragments QRF=quartz rock fragments VRF=volcanic rock fragments IRF=intrusive rock fragments SRF=sedimentary rock fragments

Notes:

Slide No. 14(1), (2) Rock No. 14 Grain size = 0.091 mm
Location No. 14

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	409	91.91	397	89.41	806	90.66
K-feldspar	4	0.90	2	0.45	6	0.67
Plagioclase	Trace	—	Trace	—	Trace	—
Chlorite	Trace	—	Trace	—	Trace	—
Muscovite	1	0.22	Trace	—	1	0.11
Biotite	2	0.45	Trace	—	2	0.22
Orthopyroxene						
Clinopyroxene	Trace	—	Trace	—	Trace	—
Garnet						
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques	4	0.90	1	0.23	5	0.56
Altered grains	25	5.62	43	9.68	68	7.65
Rock Fragments			1	0.23	1	0.11
MRF						
QRF						
VRF						
IRF						
SRF						
Total grains	445	100.00	444	100.00	889	99.98
Cement	1		2		Total	
Organics	37*	7.68	234*	34.51	271	23.36
Calcite						
Silica						
Total cement	37	7.68	234	34.51	271	23.36

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: Slide 14(1) is grain-supported, with patches of organics
Slide 14(2) is cement-supported (organics)

Slide No. 15(2) Rock No. 15 Grain size = 0.167 mm
Location No. 15

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	366	66.18				
K-feldspar	4	0.72				
Plagioclase	13	2.35				
Chlorite	2	0.36				
Muscovite	2	0.36				
Biotite	15	2.71				
Orthopyroxene						
Clinopyroxene	1	0.18				
Garnet	Trace	—				
Epidote						
Hornblende						
Sodalite						
Zircon	Trace?	—				
Tourmaline						
Opaques	5	0.90				
Altered grains	100	18.08				
Rock Fragments	45	8.13				
MRF	30	5.42				
QRF	11	1.99				
VRF						
IRF						
SRF	4	0.72				
Total grains	553	99.97				

Cement	1		2		Total	
Organics	7	1.18				
Calcite						
Silica	35	5.88				
Total cement	42	7.06				

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: Some QRF's are of gneissic origin, euhedral plagioclase (minor)

Slide No. 16(1),(2)   Rock No. 16   Location No. 16   Grain size = 0.20 mm

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	375	75.15	367	69.25	742	72.11
K-feldspar	3	0.60	6	1.13	9	0.87
Plagioclase	10	2.00	12	2.26	22	2.14
Chlorite	3	0.60	Trace	—	3	0.29
Muscovite	1	0.20	11	2.08	12	1.17
Biotite	4	0.80	11	2.08	15	1.46
Orthopyroxene						
Clinopyroxene	Trace	—			Trace	—
Garnet	Trace	—			Trace	—
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques	1	0.20	3	0.57	4	0.39
Altered grains	65	13.03	71	13.40	136	13.22
Rock Fragments	37	7.42	49	9.25	86	8.36
MRF	20	4.01	30	5.66	50	4.86
QRF	17	3.41	18	3.40	35	3.40
VRF						
IRF						
SRF			1	0.19	1	0.10
Total grains	499	100.00	530	100.02	1029	100.01
Cement	1		2		Total	
Organics	Trace	—	Trace	—	Trace	—
Calcite						
Silica	28	5.31	36	6.36	64	5.86
Total cement	28	5.31	36	6.36	64	5.86

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: "fracture" lamellae in plagioclase, biotite strongly kinked

Slide No. 17 (1) Rock No. 17 Grain size = < 0.062 mm

Location No. 17 Siltstone

	1		2		3	
Grains	# grains	%	# grains	%	# grains	%
Quartz						
K-feldspar						
Plagioclase						
Chlorite						
Muscovite						
Biotite						
Orthopyroxene						
Clinopyroxene						
Garnet						
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques						
Altered grains						
Rock Fragments						
MRF						
QRF						
VRF						
IRF						
SRF						
Total grains						
Cement	1		2		3	
Organics						
Calcite						
Silica						
Total cement						

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: Slide shows contact between siltstone and very fine-grained sandstone/siltstone. Rock calcite-cemented. High in opaques (pyrite, Cu), organics. Opaques found along fractures and as disseminated grains. Dendritic opaques (U?)

Slide No. 18(1),(2) **Rock No.** 18 **Grain size** = 0.143 mm

Location No. 18

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	365	72.71	371	73.76	736	73.23
K-feldspar	Trace	—	4	0.80	4	0.40
Plagioclase	7	1.39	10	1.99	17	1.69
Chlorite	2	0.40	1	0.20	3	0.30
Muscovite	5	1.00	5	0.99	10	1.00
Biotite	7	1.39	3	0.60	10	1.00
Orthopyroxene						
Clinopyroxene						
Garnet						
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques	14	2.79	11	2.19	25	2.49
Altered grains	74	14.74	58	11.53	132	13.13
Rock Fragments	28	5.57	40	7.95	68	6.77
MRF	20	3.98	30	5.96	50	4.98
QRF	8	1.59	9	1.79	17	1.69
VRF						
IRF						
SRF			1	0.20	1	0.10
Total grains	502	99.99	503	100.01	1005	100.01
Cement	1		2		Total	
Organics	34	5.81	20	3.36	54	4.58
Calcite	9	1.54	12	2.02	21	1.78
Silica	40	6.84	60	10.08	100	8.47
Total cement	83	14.19	92	15.46	175	14.83

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: QRF's include those of gneissic origin.

Slide No. 19(1), (2) Rock No. 19 Grain size = 0.100 mm

Location No. 19

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	362	77.35	353	74.63	715	75.98
K-feldspar	4	0.85	2	0.42	6	0.64
Plagioclase	9	1.92	5	1.06	14	1.49
Chlorite	8	1.71	9	1.90	17	1.81
Muscovite	2	0.43	8	1.69	10	1.06
Biotite	8	1.71	7	1.48	15	1.59
Orthopyroxene	Trace	—			Trace	—
Clinopyroxene	2	0.43	1	0.21	3	0.32
Garnet	1	0.21	Trace	—	1	0.11
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline			Trace?	—	Trace?	—
Opaques	22	4.70	26	5.50	48	5.10
Altered grains	32	6.84	45	9.51	77	8.18
Rock Fragments	18	3.84	17	3.59	35	3.72
MRF	16	3.42	15	3.17	31	3.29
QRF	1	0.21	2	0.42	3	0.32
VRF						
IRF						
SRF	1	0.21			1	0.11
Total grains	468	99.99	473	99.99	941	100.00
Cement	1		2		Total	
Organics	21	3.98	10	1.92	31	2.96
Calcite	1	0.19			1	0.10
Silica	38	7.20	38	7.29	76	7.24
Total cement	60	11.37	48	9.21	108	10.30

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes:

Slide No. 20(1), (2)   Rock No. 20   Grain size = 0.125 mm

Location No. 20

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	345	68.18	354	72.10	699	70.11
K-feldspar	7	1.38	2	0.41	9	0.90
Plagioclase	9	1.78	7	1.43	16	1.60
Chlorite	7	1.38	5	1.02	12	1.20
Muscovite	7	1.38	5	1.02	12	1.20
Biotite	18	3.56	17	3.46	35	3.51
Orthopyroxene						
Clinopyroxene	Trace	—	Trace	—	Trace	—
Garnet	1	0.20	Trace	—	1	0.10
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques	20	3.95	20	4.07	40	4.01
Altered grains	53	10.47	43	8.76	96	9.63
Rock Fragments	39	7.71	38	7.74	77	7.72
MRF	34	6.72	33	6.72	67	6.72
QRF	4	0.79	5	1.02	9	0.90
VRF						
IRF						
SRF	1	0.20			1	0.10
Total grains	506	99.99	491	100.01	997	99.98
Cement	1		2		Total	
Organics	67	10.89	50	8.39	117	9.66
Calcite						
Silica	42	6.83	55	9.23	97	8.01
Total cement	109	17.72	105	17.62	214	17.67

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: some strained plagioclase lamellae

Slide No. 21(1),(2) Rock No. 21 Grain size = 0.250 mm
Location No. 21

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	362	68.56	360	65.10	722	66.79
K-feldspar	3	0.57	Trace	—	3	0.28
Plagioclase	19	3.60	15	2.71	34	3.15
Chlorite	4	0.76	1	0.18	5	0.46
Muscovite	2	0.38	5	0.90	7	0.65
Biotite	1	0.19	3	0.54	4	0.37
Orthopyroxene						
Clinopyroxene						
Garnet	Trace	—	Trace	—	Trace	—
Epidote	Trace	—			Trace	—
Hornblende						
Sodalite						
Zircon						
Tourmaline			Trace	—	Trace	—
Opaques	12	2.27	20	3.62	32	2.96
Altered grains	50	9.47	42	7.59	92	8.51
Rock Fragments	75	14.22	107	19.35	182	16.85
MRF	41	7.77	45	8.14	86	7.96
QRF	6	1.14	4	0.72	10	0.93
VRF	4	0.76	2	0.36	6	0.56
IRF						
SRF	24	4.55	56	10.13	80	7.40
Total grains	528	100.02	553	99.99	1081	100.02

Cement	1		2		Total	
Organics	16	2.20	12	1.67	28	1.94
Calcite	143	19.67	100	13.95	243	16.83
Silica	40	5.50	52	7.25	92	6.37
Total cement	199	27.37	164	22.87	363	25.14

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: Slide from sandstone with lower siltstone contact
Siltstone clasts up to 4mm by 4 mm (rounded)

Slide No. 22 (1), (2)   Rock No. 22   Grain size = 0.10 mm
Location No. 22

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	360	75.00	362	76.21	722	75.60
K-feldspar	1	0.21	1	0.21	2	0.21
Plagioclase	4	0.83	7	1.47	11	1.15
Chlorite	5	1.04	6	1.26	11	1.15
Muscovite	5	1.04	4	0.84	9	0.94
Biotite	4	0.83	3	0.63	7	0.73
Orthopyroxene						
Clinopyroxene	Trace	—	Trace	—	Trace	—
Garnet	1	0.21	2	0.42	3	0.31
Epidote	Trace	—	Trace	—	Trace	—
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques	25	5.21	22	4.63	47	4.92
Altered grains	36	7.50	33	6.95	69	7.23
Rock Fragments	39	8.12	35	7.37	74	7.75
MRF	36	7.50	33	6.95	69	7.23
QRF			1	0.21	1	0.10
VRF						
IRF						
SRF	3	0.62	1	0.21	4	0.42
Total grains	480	99.99	475	99.99	955	99.99
Cement	1		2		Total	
Organics	12	2.33	14	2.72	26	2.53
Calcite						
Silica	23	4.47	25	4.86	48	4.66
Total cement	35	6.80	39	7.58	74	7.19

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes:

Slide No. 23(1), (2)   Rock No. 23   Grain size = 0.25 mm
Location No. 23

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	382	74.76	370	71.02	752	72.87
K-feldspar	2	0.39	2	0.38	4	0.39
Plagioclase	14	2.74	16	3.07	30	2.91
Chlorite	1	0.20	2	0.38	3	0.29
Muscovite	Trace	—	Trace	—	Trace	—
Biotite	2	0.39	4	0.77	6	0.58
Orthopyroxene						
Clinopyroxene			Trace	—	Trace	—
Garnet	Trace	—			Trace	—
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques	10	1.96	9	1.73	19	1.84
Altered grains	57	11.15	62	11.90	119	11.53
Rock Fragments	43	8.42	56	10.74	99	9.59
MRF	36	7.05	45	8.64	81	7.85
QRF	4	0.78	6	1.15	10	0.97
VRF	1	0.20	2	0.38	3	0.29
IRF	2	0.39	1	0.19	3	0.29
SRF			2	0.38	2	0.19
Total grains	511	100.01	521	99.99	1032	100.00
Cement	1		2		Total	
Organics	5	0.89	4	0.70	9	0.80
Calcite						
Silica	47	8.35	43	7.57	90	7.96
Total cement	52	9.24	47	8.27	99	8.76

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: authigenic muscovite is replacing feldspar
Cpx is augite.

Slide No. 24 (1), (2) Rock No. 24 Grain size = 0.143 mm
Location No. 24

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	362	77.19	364	74.59	726	75.86
K-feldspar	3	0.64	1	0.20	4	0.42
Plagioclase	9	1.92	16	3.28	25	2.61
Chlorite	3	0.64	5	1.02	8	0.84
Muscovite	1	0.21	2	0.41	3	0.31
Biotite	3	0.64	6	1.23	9	0.94
Orthopyroxene	1	0.21			1	0.10
Clinopyroxene						
Garnet			1	0.20	1	0.10
Epidote	Trace	—			Trace	—
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques	14	2.99	12	2.46	26	2.72
Altered grains	49	10.45	49	10.04	98	10.24
Rock Fragments	24	5.11	32	6.56	56	5.84
MRF	20	4.26	32	6.56	52	5.43
QRF	1	0.21			1	0.10
VRF	3	0.64	Trace	—	3	0.31
IRF						
SRF						
Total grains	469	100.00	488	99.99	957	99.98
Cement	1		2		Total	
Organics	62	10.90	92	14.67	154	12.88
Calcite						
Silica	38	6.68	47	7.50	85	7.11
Total cement	100	17.58	139	22.17	239	19.99

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes:

Slide No. 25(1), (2), (3)   Rock No. 25.   Grain size = 0.100 mm

Location No. 25

	1		2		3	
Grains	# grains	%	# grains	%	# grains	%
Quartz	358	76.66	367	85.55	358	75.85
K-feldspar	1	0.21	Trace	—	Trace	—
Plagioclase	13	2.78	8	1.86	8	1.69
Chlorite	3	0.64	4	0.93	3	0.64
Muscovite	4	0.86	1	0.23	7	1.48
Biotite	11	2.36	15	3.50	20	4.24
Orthopyroxene					Trace	—
Clinopyroxene						
Garnet	Trace	—	Trace	—	2	0.42
Epidote	Trace	—				
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques	17	3.64	8	1.86	12	2.54
Altered grains	51	10.92	24	5.59	59	12.50
Rock Fragments	9	1.93	2	0.47	3	0.64
MRF	9	1.93	2	0.47	3	0.64
QRF						
VRF						
IRF						
SRF						
Total grains	467	100.00	429	99.99	472	100.00
Cement	1		2		3	
Organics	58	9.72	60	10.91	64	11.05
Calcite						
Silica	72	12.06	61	11.09	43	7.43
Total cement	130	21.78	121	22.00	107	18.48

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: Totals compiled on next page

Slide No. 25(1),(2),(3)

	Total	
Grains	# grains	%
Quartz	1083	79.17
K-feldspar	1	0.07
Plagioclase	29	2.12
Chlorite	10	0.73
Muscovite	12	0.88
Biotite	46	3.36
Orthopyroxene	Trace	—
Clinopyroxene		
Garnet	2	0.15
Epidote	Trace	—
Hornblende		
Sodalite		
Zircon		
Tourmaline		
Opaques	37	2.70
Altered grains	134	9.80
Rock Fragments	14	1.02
MRF	14	1.02
QRF		
VRF		
IRF		
SRF		
Total grains	1368	100.00
Cement	Total	
Organics	182	10.54
Calcite		
Silica	176	10.20
Total cement	358	20.74

MRF=metamorphic rock fragments QRF=quartz rock fragments VRF=volcanic rock fragments IRF=intrusive rock fragments SRF=sedimentary rock fragments

Notes:

Slide No. 26(1), (2) Rock No. 26. Grain size = 0.250 mm
Location No. 26

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	390	76.02	399	79.96	789	77.96
K-feldspar	Trace	—	2	0.40	2	0.20
Plagioclase	5	0.97	5	1.00	10	0.99
Chlorite	Trace	—	1	0.20	1	0.10
Muscovite	1	0.19	5	1.00	6	0.59
Biotite	5	0.97	1	0.20	6	0.59
Orthopyroxene						
Clinopyroxene						
Garnet	Trace	—	Trace	—	Trace	—
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline	Trace	—			Trace	—
Opaques	4	0.78	4	0.80	8	0.79
Altered grains	63	12.28	49	9.82	112	11.07
Rock Fragments	45	8.77	33	6.61	78	7.71
MRF	31	6.04	23	4.61	54	5.34
QRF	4	0.78	1	0.20	5	0.49
VRF						
IRF			2	0.40	2	0.20
SRF	10	1.95	7	1.40	17	1.68
Total grains	513	99.98	499	99.99	1012	100.00
Cement	1		2		Total	
Organics	3	0.54	7	1.32	10	0.92
Calcite						
Silica	36	6.52	24	4.53	60	5.55
Total cement	39	7.06	31	5.85	70	6.47

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: Tourmaline in IRF -> granitic or pegmatitic source

Slide No. 27a (1)
27c (1), (2)

Rock No. 27a, 27c
Location No. 27

Grain size = 0.056mm (27a)
Siltstone 0.050mm (27c)

	1		2		3	
Grains	# grains	%	# grains	%	# grains	%
Quartz						
K-feldspar						
Plagioclase						
Chlorite						
Muscovite						
Biotite						
Orthopyroxene						
Clinopyroxene						
Garnet						
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques						
Altered grains						
Rock Fragments						
MRF						
QRF						
VRF						
IRF						
SRF						
Total grains						
Cement	1		2		3	
Organics						
Calcite						
Silica						
Total cement						

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: Slide 27a (1) - coarse siltstone to very fine-grained sandstone
→ calcite cement ≤ 40 %, high in chlorite, opaques, organics, numerous siltstone clasts
Slide 27c (1) - high in opaques, organics (layering), calcite-cemented
→ elongated shale (mudstone) fragments ; quartz, muscovite grains dominant
Slide 27c (2) - same as (1) only more chlorite

Slide No. 27b(1)   Rock No. 27b   Grain size = 0.100 mm
Location No. 27

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	370	72.27				
K-feldspar	5	0.98				
Plagioclase	4	0.78				
Chlorite	1	0.20				
Muscovite	3	0.59				
Biotite	21	4.10				
Orthopyroxene	Trace	—				
Clinopyroxene						
Garnet						
Epidote						
Hornblende						
Sodalite						
Zircon						
Tourmaline	Trace	—				
Opaques	4	0.78				
Altered grains	68	13.28				
Rock Fragments	36	7.04				
MRF	3	0.59				
QRF						
VRF						
IRF						
SRF	33	6.45				
Total grains	512	100.02				
Cement	1		2		Total	
Organics	60	9.22				
Calcite	55	8.45				
Silica	24	3.69				
Total cement	139	21.36				

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: This sandstone is in proximity to siltstone beds.

Slide No. 30a (1), (2) Rock No. 30a Grain size = 0.100 mm

Location No. 30

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	372	78.81	370	79.06	742	78.94
K-feldspar	Trace	—	1	0.21	1	0.11
Plagioclase	7	1.48	10	2.14	17	1.81
Chlorite	4	0.85	4	0.85	8	0.85
Muscovite	5	1.06	2	0.43	7	0.74
Biotite	8	1.69	8	1.71	16	1.70
Orthopyroxene	Trace	—	1	0.21	1	0.11
Clinopyroxene						
Garnet	Trace	—	2	0.43	2	0.21
Epidote						
Hornblende	Trace ?	—			Trace ?	—
Sodalite						
Zircon						
Tourmaline	Trace	—	Trace	—	Trace	—
Opaques	11	2.33	10	2.14	21	2.23
Altered grains	58	12.29	57	12.18	115	12.23
Rock Fragments	7	1.48	3	0.64	10	1.06
MRF	5	1.06	2	0.43	7	0.74
QRF						
VRF						
IRF						
SRF	2	0.42	1	0.21	3	0.32
Total grains	472	99.99	468	100.00	940	99.99

Cement	1		2		Total	
Organics	33	5.81	58	10.02	91	7.93
Calcite						
Silica	63	11.09	53	9.15	116	10.11
Total cement	96	16.90	111	19.17	207	18.04

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: concentrations (layers) of garnet and other heavy minerals aligned parallel to bedding

Slide No. 30b(1),(2) Rock No. 30b Grain size = 0.091 mm
Location No. 30

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	358	72.76	367	74.59	725	73.68
K-feldspar	Trace	—	1	0.20	1	0.10
Plagioclase	8	1.63	8	1.63	16	1.63
Chlorite	8	1.63	5	1.02	13	1.32
Muscovite	4	0.81	2	0.41	6	0.61
Biotite	2	0.41	9	1.83	11	1.12
Orthopyroxene	1	0.20	Trace	—	1	0.10
Clinopyroxene						
Garnet	1	0.20	Trace	—	1	0.10
Epidote	1	0.20	Trace?	—	1	0.10
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques	18	3.66	12	2.44	30	3.05
Altered grains	78	15.85	79	16.06	157	15.96
Rock Fragments	13	2.64	9	1.83	22	2.23
MRF	12	2.44	8	1.63	20	2.03
QRF						
VRF						
IRF						
SRF	1	0.20	1	0.20	2	0.20
Total grains	492	99.99	492	100.01	984	100.00
Cement	1		2		Total	
Organics	65	10.83	51	8.66	116	9.76
Calcite						
Silica	43	7.17	46	7.81	89	7.49
Total cement	108	18.00	97	16.47	205	17.25

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes:

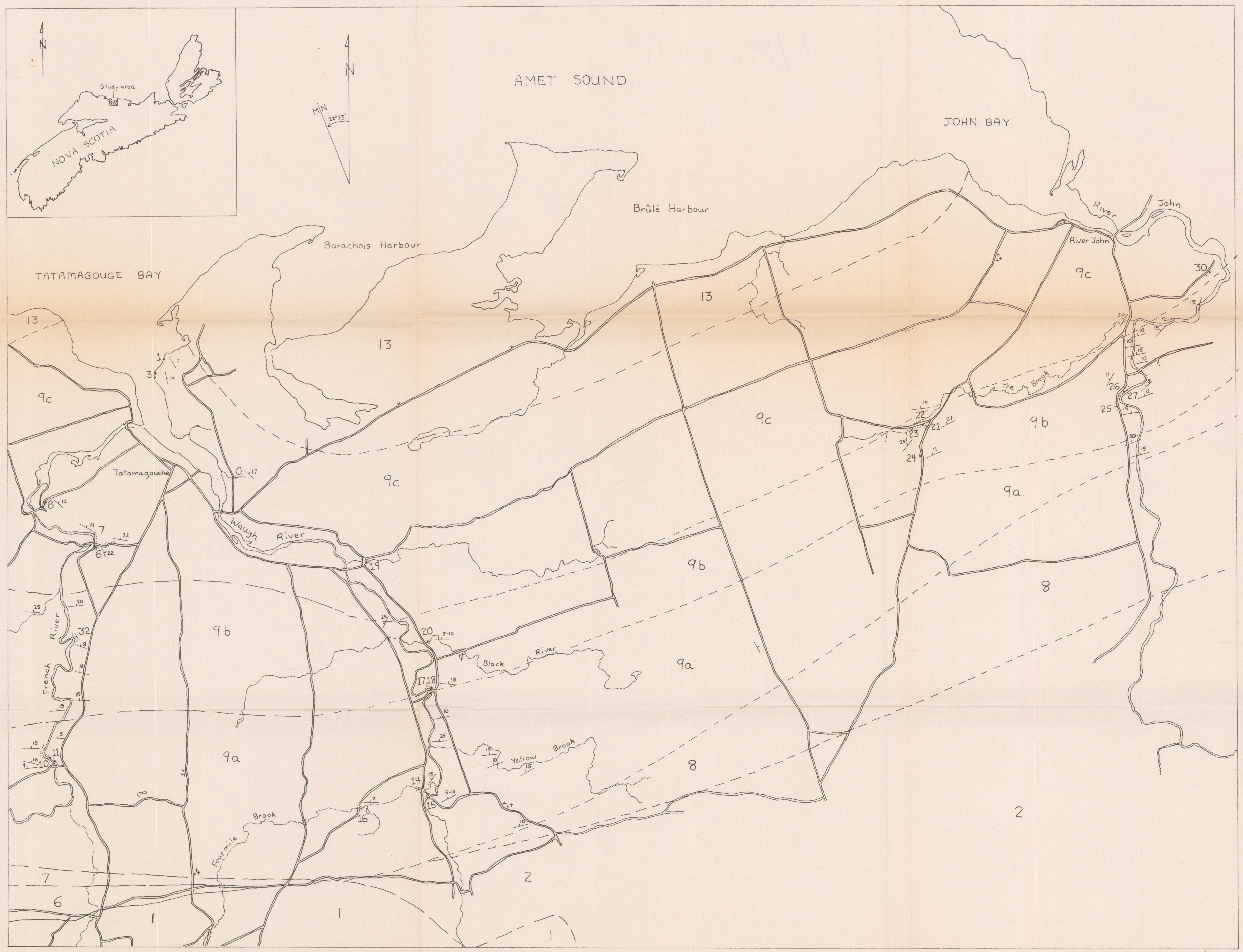
Slide No. 32(1),(2) Rock No. 32 Location No. 32 Grain size = 0.111 mm

	1		2		Total	
Grains	# grains	%	# grains	%	# grains	%
Quartz	372	72.23	375	71.43	747	71.83
K-feldspar	1	0.19	Trace	—	1	0.10
Plagioclase	8	1.55	4	0.76	12	1.15
Chlorite	3	0.58	2	0.38	5	0.48
Muscovite	2	0.39	1	0.19	3	0.29
Biotite	7		2	0.38	9	0.87
Orthopyroxene	Trace	—			Trace	—
Clinopyroxene	1	0.19	Trace	—	1	0.10
Garnet	2	0.39	1	0.19	3	0.29
Epidote	Trace	—	Trace	—	Trace	—
Hornblende						
Sodalite						
Zircon						
Tourmaline						
Opaques	12	2.33	16	3.05	28	2.69
Altered grains	52	10.10	66	12.57	118	11.35
Rock Fragments	55	10.68	58	11.05	113	10.87
MRF	1	0.19	Trace	—	1	0.10
QRF						
VRF						
IRF						
SRF	54	10.49	58	11.05	112	10.77
Total grains	515	99.99	525	100.00	1040	100.02
Cement	1		2		Total	
Organics	32	4.96	34	4.98	66	4.97
Calcite	52	8.06	68	9.96	120	9.04
Silica	46	7.13	56	8.20	102	7.68
Total cement	130	20.15	158	23.14	288	21.69

MRF= metamorphic rock fragments QRF= quartz rock fragments VRF= volcanic rock fragments IRF= intrusive rock fragments SRF= sedimentary rock fragments

Notes: Sandstone in proximity to siltstone beds.
Slide 32(1) - siltstone clasts up to 3 mm by 1 mm elongated parallel to bedding.
Slide 32(2) - rounded siltstone clasts up to 2mm by 2mm as well as elongate clasts up to 4mm by 1 mm.

GEOLOGICAL MAP OF THE WALLACE RIVER FORMATION



STRATIGRAPHIC LEGEND

13	Amet Sound Formation (Pictou Group) – grey to red micaceous sandstone, shale, grit, conglomerate, limy beds
9	Wallace River Formation (Pictou Group) – 9c Waugh River Member; 9b Balfron Member; 9a Wentworth Member
8	Caribou River Formation (Pictou Group) – grey sandstone, grit, shale
7	CUMBERLAND GROUP – red to grey sandstone, siltstone, shale, conglomerate; coal
6	Boss Point Formation (Riversdale Group) – grey sandstone, grit, limestone pebble conglomerate, shale
2	RIVER JOHN GROUP and undifferentiated pre-Pictou strata
1	Pre-Middle Devonian volcanic, sedimentary, metamorphic, intrusive rocks

MAP SYMBOLS

Attitude of strata — inclined 10

Outcrop — broken, rubbly

Contacts
- stratigraphic contact
- approximate position of contact
- arbitrary separation between map units

Sample Locations • 14

1 : 50,000

0 1 2 3 4 5
kilometres

(after Roscoe et al, 1972)