Sedimentology and Tectonic activities in Rawdon Hills Nova Scotia

by

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Abstract

The general Geology and Sedimentology of the Horton sedimentary deposits of Rawdon Hills were studied by using two drill cores and a few outcrops available in the area.

Vitrinite reflectance and fission track method were employed to detect the paleo-tectonic activities of this region. In the case of fission track dating apatite grains were separated, mounted and irradiated. Finally the induced and spontaneous tracks were counted to get an average age of 170 m.y. which locates the samples in the paleo-partial annealing zone.

Vitrinite reflectance rank values revealed the possible maximum depth of burial to be around 4000 metres at the time of coalification. The minimum required temperature for coalification was 90 to 98 de^{o}C for a period of 170 m.y.

Finally, the relation between the ages recovered by fission track technique and the Atlantic ocean rifting during Jurassic and Cretaceous was discussed.

CHAPTER 1 . INTRODUCTION

1. Introduction

The Rawdon Hills, Nova Scotia, lie between latitudes 45°05' and 45° 13' North and longitudes 63° 25' and 63° 50' West in the central part of the province (about 70km noth of Halifax, Figure, 1).

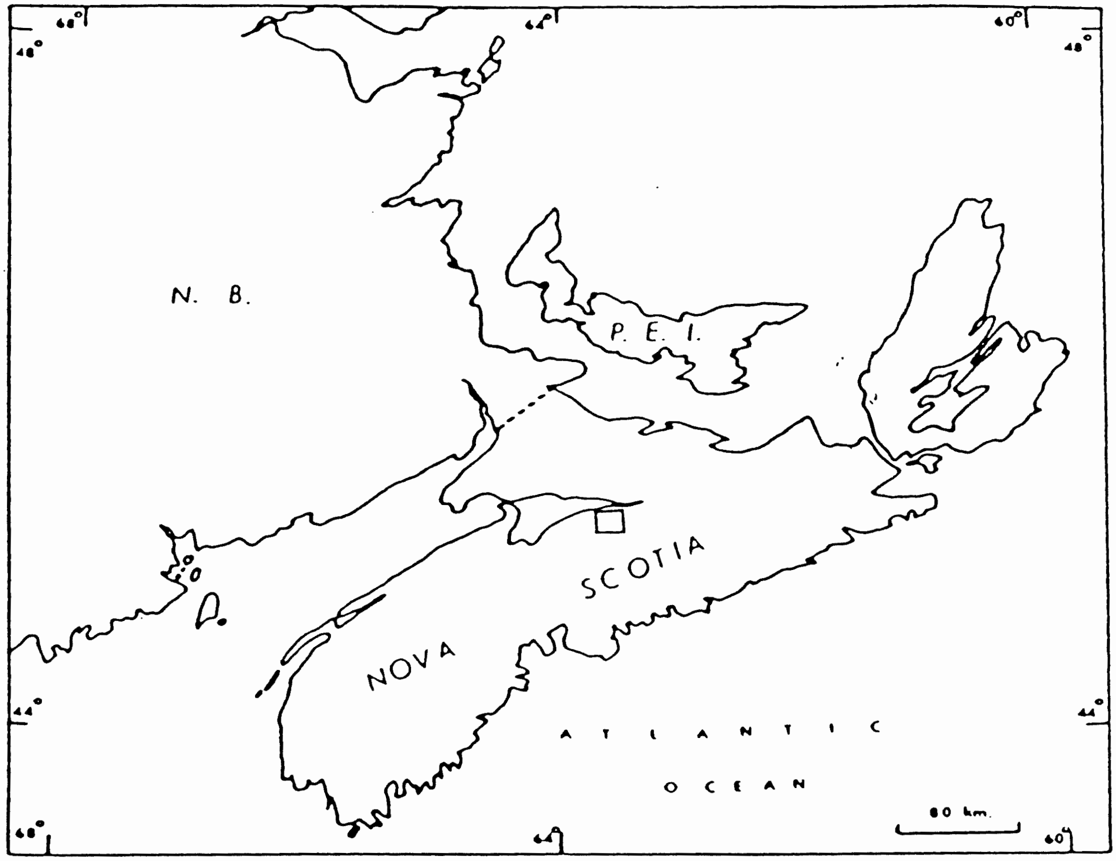


Fig (1.1)- Horton deposits in Nova Scotia, with the location of thesis area in the Rawdon Hills(Cook, 1973).

The Horton Group is the the lowest group of sediments which extend in age from the end of Devonian to the end of the Tournaisian time (352 Ma). Horton strata are now exposed in a wide band from Kings County to northern Cape Breton, lying along the flank of the uplands or forming the rolling highlands through the centre of Nova Scotia. Much of the band is a coarse, resistant sandstone which is very poor in fossils.

Climate during the early part of the Carboniferous period was probably temperate, partly because of the atitude of the land in this region, but mainly because the continents were drifting northward towards the equator (Roland, 1982).

The study area for Horton clastic deposits in this thesis was restricted to the Rawdon Hills area, Fig 2.1 . Due to an overabundance of vegetation, it was difficult to find many districts with visible outcrops. The most complete section of Horton strata was found along (located on the Fig 2.1): (D)- 1 mile west of Barr Setlements. (A)- 3 miles north west of McPhees Corner. (C)- 2.8 miles, west of McPhees Corner. Unfortunately most of the contacts and many strata in these districts are obscured due to abundance of vegetation, drift and faults.

A survey was conducted along the Glen Brook from the bottom to the top of the Horton sediments that are underlain by Halifax Formation slates and overlain by Windsor evaporites (Fig 2.2, Figure is in the envelope provided in the last page of this thesis).

GEOLOGICAL MAP OF
RAWDON HILLS, NOVA SCOTIA

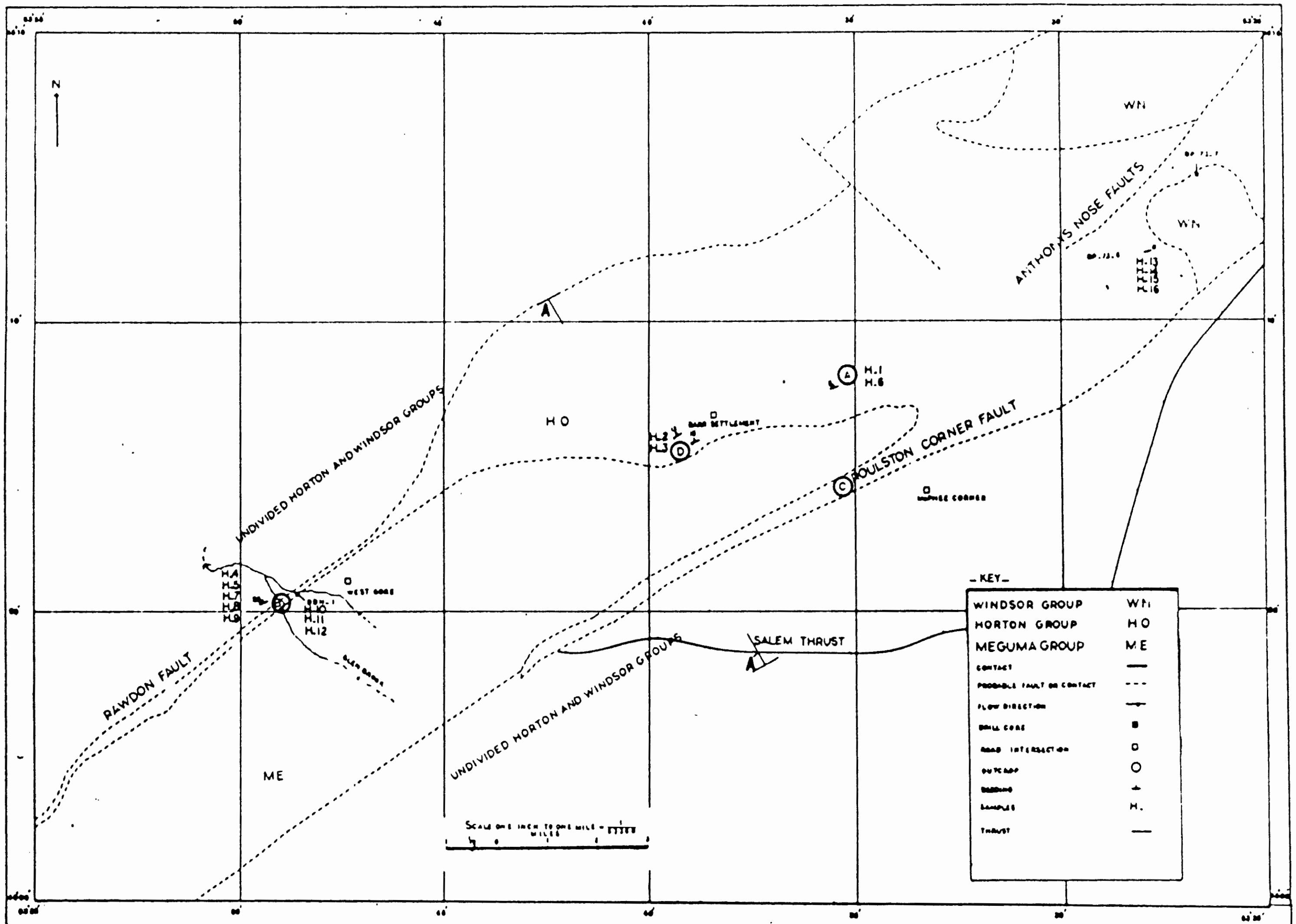


FIGURE 2.1 (MODIFIED FROM STEVENSON, I.M. [illegible] – GILES, A.S. AND BOEHNER, R.C. [illegible])

The tectonics of this area was studied using the fission track technique on apatite grains contained in sediments sampled in drill cores BP-73-6 and BP-73-7, and the vitrinite reflectance of carbonaceous matter from the drill cores BP-73_6 and DDH-1, and from two outcrops.

All the periods, and ages mentioned in this thesis are based on the geological time scale by Harland, and Cox (1982).

1.1. Scope and Purpose

This thesis addresses two questions:

1- When were the Rawdon Hills uplifted and in response to what required tectonic events?

2- How useful are vitrinite reflectance values as a means for establishing the thermal history of this area?

1.2. Method

To answer the above questions Three different methods were employed.

1.2.1. FIELD SURVEY _ A survey was conducted by the author in Glen Brook, during two days of september 1985.

1.2.2. FISSION TRACK DATING _ Three samples from two drill cores in the eastern section the Rawdon Hills were dated, using fission track technique. To date the samples, detrital apatite grains from cores and field samples were separated at Dalhousie University during the summer of 1984. They were mounted, irradiated, and counted during the summer of 1985. Finally, during January 1986 the age of the samples was calculated.

1.2.3. VITRINITE REFLECTANCE - Nine samples chosen from different outcrops and drill cores (Fig 4.1), were analysed for Ro rank values. Samples were analysed in Bedford Institute Of Oceanography by Mr. M. Avery during the winter of 1985.

CHAPTER II. GEOLOGY AND SEDIMENTOLOGY

2.1. Regional Geology

In the Rawdon Hills, located in the NW section of the Shubenacadie Basin (Fig, 2.1), the Horton Formation overlies unconformably on the metamorphosed Halifax Formation of the Meguma Group. The crystalline rocks that have the core of the Rawdon Hills, are folded into a series of parallel, tight anticlines and synclines (Fig, 3.10). East of Gore, the structures plunge to the northeast beneath Horton Group deposits. Around Gore, the hills are high and have steep slopes.

Horton Group sedimentary rocks are mostly composed of siltstone, sandstone, and conglomerate. Beds are folded into gentle broad folds. Generally, Horton beds are steeper in the western side(60 degrees), than in the eastern sections of the Rawdon Hills (5 degrees). In the eastern section beds are dipping less than 5 degrees.

The Rawdon Hills block is bounded by two major faults: Rawdon Fault in the north, and Roulston Fault in the south(Giles and Boehner, 1982).

Giles, (1983) suggested that the Roulston Fault forms part of a major post-Visean sinistral shear zone.

2.2. Previous Works

One of the original studies done on the Horton deposits is by Bell, (1929). He divided the Horton Group into the Horton Bluff and Cheverie Formations. The lower, or Horton Bluff Formation consists of grey feldspathic conglomerate, grit, and sandstones, interbedded with dark grey argillaceous shales. The upper, or Cheverie Formation, consists chiefly of red shale and grey arkosic grits. Bell estimated the two formations to have a maximum combined thickness of more than 1300 metres.

More detailed work was done by I.M. Stevenson in 1956 and 1959. He suggested that a statistical study of primary sedimentary structures and the mineralogical composition of the Horton sedimentary rocks offer conclusive proof that they were derived from the Devonian granitic batholith and associated metasedimentary rocks that lie to the south.

The most recent study on the Horton deposits (Rawdon Hills) was done by P.K. Smith(1985). In this paper he generally describes the stratigraphy of one drill hole conducted 490 metres east of Glen Brook (Fig 2.1).

2.3. Stratigraphy of Glen Brook Area

The stratigraphy of Glen Brook was studied by using data from a single diamond drill hole , and by surveying part of Glen Brook (two miles southwest of Gore) Fig 2.2.

2.3.1. Description For Drill Core (DDH-1)

A single diamond drill hole (DDH-1) was drilled 1.3 km northeast of the West Gore by the Nova Scotia Department of Mines and Energy, in 1985. (Fig 2.3). The vertical drill hole intersected 68.5 m of Horton Group clastic sediments(Fig 2.4a). The hole has been divided arbitarily into three sections.

2.3.1.1. Lithology

At the base, Horton sediments overlie uncomformably the slates of the Meguma Group . Above the contact, Horton sediments consist of a basal coarse polymictic pebble conglomerate, (section 1 of Fig 2.4a). The thickness of this bed is 4 metres, containing rounded white vein quartz and slate boulders of up to 40 cm. Clastic constituents are probably derived from the underlying Meguma Group. Above this bed there are a series of fining upward cyclic patterns (section II) for 52.5 metres. These cyclic patterns each consist of basal fine grained sandstones with an average of 10% organic matter, with occasional black shaly lamination (1-2 cm), slikensides and a minor amount of fault breccia. Each sandstone sequence has a contact with the siltstone or shaly strata which contains a high proportion of organic matter(in some layers >90%). Plant remains are broken up, which is suggestive of their transported nature. Some of the plant fossils identified are <u>Lepidodendropsis</u> <u>Corrugata</u> , and <u>Asterocalamites</u> <u>Scrobiculatus</u>. Alternatively, the upper sections of some of these shale bands roots are visible, which suggest their in situ nature. Shaly beds are dark greyish to black with occasional lighter greyish laminated shaly layers . A few layers

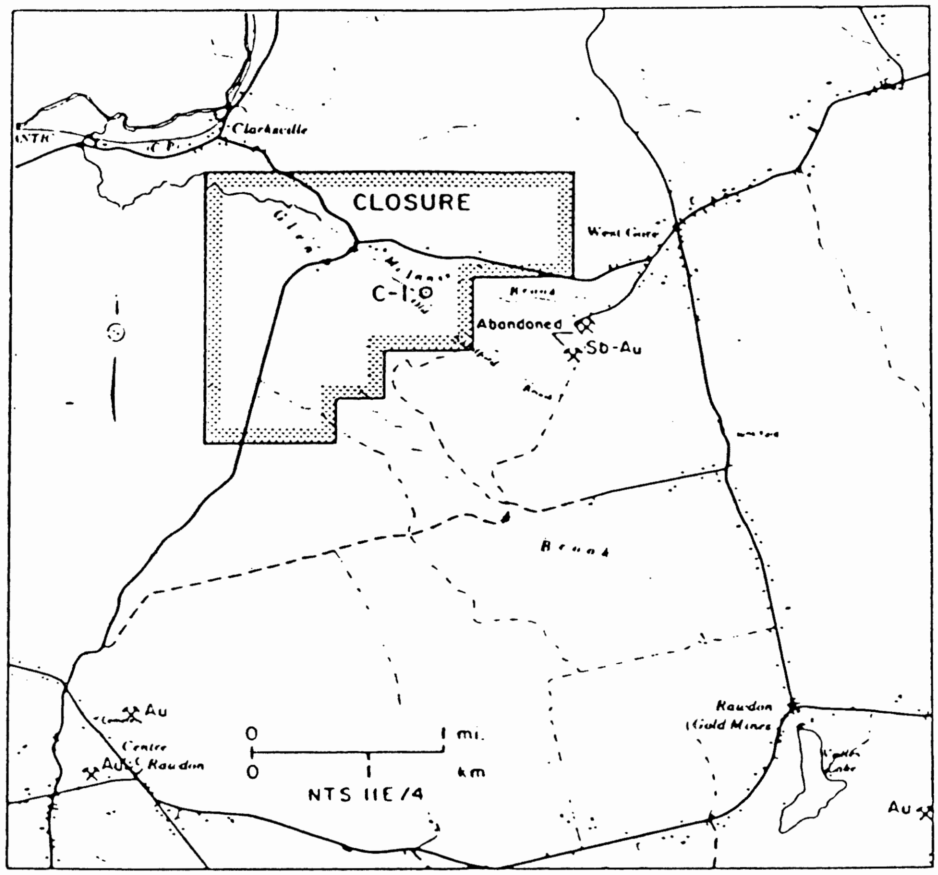


Figure (2.3): West Core, Hants County. The position of drill core DDH-1. (Smith,P.K., 1985).

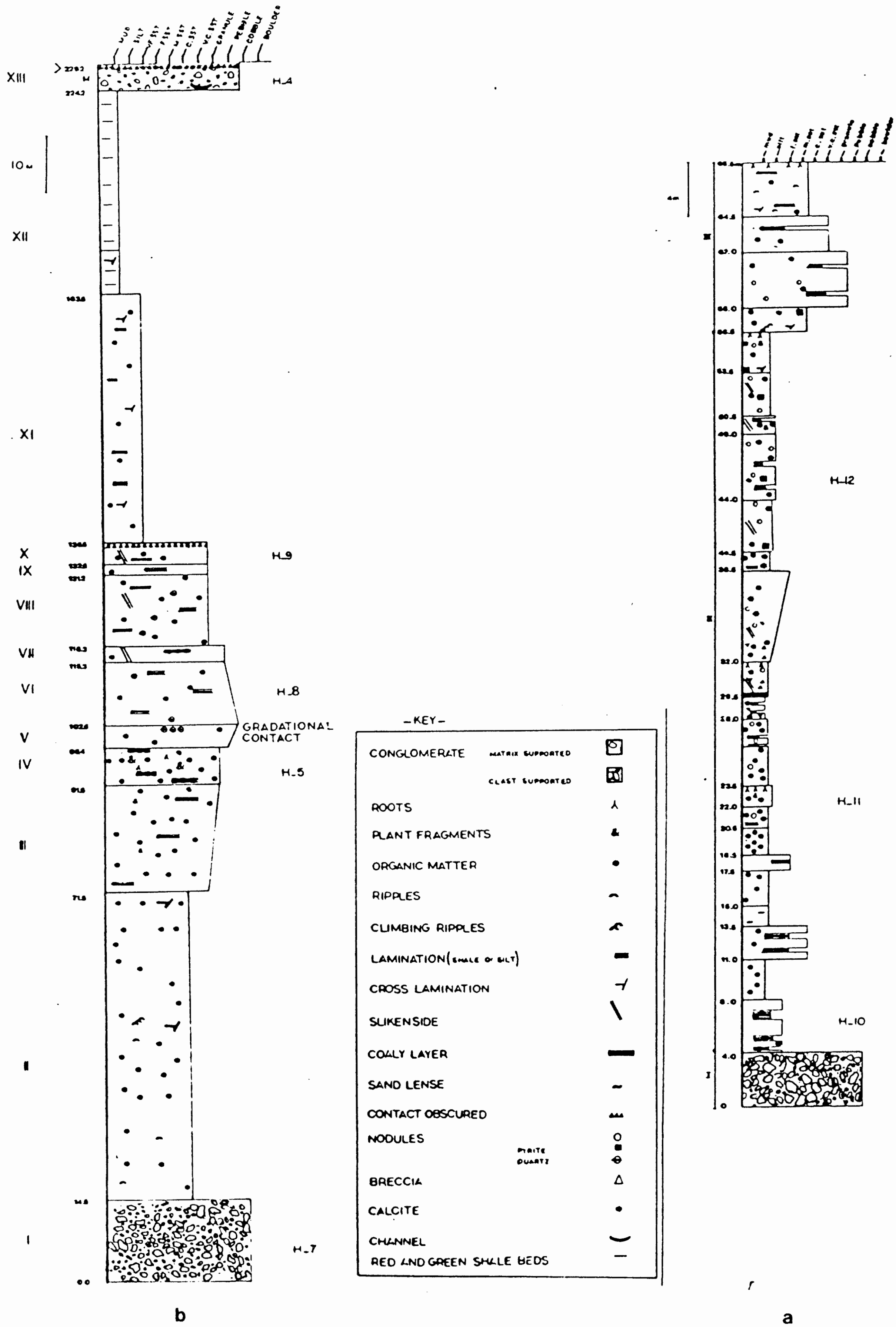


Figure 2.4 : (a) Stratigraphic column from the drill core (DDH-1). (b) The stratigraphic column of Glen Brook.

of low grade coal are preserved in the shaly and siltstone sequences.

Siderite nodules (3 cm in diameter) and Pyrite nodules are common and increase upwards in the sequence. Siderite nodules are normally oxidized on their outer exposure. Both of these nodules are more abundant in the shaly sequences than in sandy strata .

In section III (Fig,2.4a) ,light grey medium size sandstone to light grey coarse arkosic sandstone reflect of definite change of the enviroment from section III. Sandstones are mixed arkosic to clean in appearance.

The lower section of part III is composed of light grey fine sandstone, with the same pyrite and marcasite nodules up to 1.5 cm and a high percentage (80%) of organic matter, which are more abundant in the top of this stratum. Climbing ripples present in this section suggest a high rate of sedimentation. Four metres of very coarse, light grey arkosic sandstone overlying this sequence, which consists of 60% quartz, 35% organic fragments and 5% white mica. Few lamination of fine sandstone with abundant (>85%) organic matters of dark grey to black thinly laminated shales are common in this stratum. Above this coarse sandstone sequence beds start to decrease in grain size with ripple marks, cross bedding, and rooting on the upper sections of the last exposed stratum. Structures like ripple marks, climbing ripples and cross lamination indicate that the section is the right way up.

The most distinctive feature in these beds (especially in the middle of the stratigraphic column) is the abundance of slickensides which indicate selective shearing . Minor amounts of fault breccia, calcite (dolomite) are present along the fractures.

2.3.1.2. Interpretation

Overall, drill hole (DDH-1) consists of a conglomerate grit, sandstone, siltstone, and shale with a predominance of sediments. The sequence shown in Fig 2.4a is indicative of deposition under continental conditions . A marine origin is excluded by the presence of rooting, lamination, crossbedding, gravels containing well rounded pebbles, and angular quartz grits. Furthermore, the absence of the marine fossils, and saline deposits are indications of the nonmarine origin of this stratigraphic section.

In more detail, starting from the bottom up clast supported conglomerate indicates well rounded nonspherical greyish sandstone, black slate and white vein quartz. The clast constituents are characterstic of the underlying Halifax Meguma Group and associated veins. Section II of Fig 2.4a consists of a series of cycles from fine sandstone to siltstone and shaly layers which overly the sandstones. The presence of pyrite, and possibly siderite (oxidized) nodules, rootings, nonmarine flora and the absence of marine fossils are all suggestive of a shallow lacustrine to swampy environment. In fact, a rise in lake level would cause the river channels to be choked in their own detritus, hence the formation of a fining upward sequence. Selley (1980) suggests that a fluvio-lacustrine swamp environment can be suitable for the formation of coal. Lack of well developed coaly layers in Fig 2.4a could be due to the lack of enough vegetation during late Devonian to early Mississippian ,or lack of sufficient water in the lacustrine to swampy environment. Section III starts from fine to very coarse sandstone, climbing ripples, well exposed lamination, cross lamination, an abundance of organic matter in some of the lamination, ripple marks and rooting are suggestive of a higher energy, higher sediment supply and a nonmarine environment. Water levels seem to be sufficiently shallow for wave action to ripple sand occasionally.

2.3.2. Surveying and Stratigraphic Column of Glen Brook (2 Miles Southwest of Gore).

A survey was conducted in Glen Brook (Fig 2.1., Fig 2.2). The section was started from the contact of the Meguma slates to the top of strata which Horton deposits disconformably underlying Windsor gypsum .

2.3.2.1. Stratigraphic Column

The section consists of more than 240 metres of polymictic clast - supported pebble conglomerate (14 metres), grits, sandstones, siltstones, and shales.

2.3.2.2. Lithology

Basal conglomerate (facies I, from 0 to 14.5 m, Fig 2.4b) unconformably overlies the Halifax Formation rocks.The Conglomerate is clast-supported and consists of well rounded white quartz and slates. Some of the clasts are as large as 30 to 40 centimetres in diameter (boulders) . The conglomerate is overlain by a medium grain sandstone (facies II, 14.5 - 71.5 m) . This facies consists of more than 40% organic matter, periodic finer grain sandstone lamination, cross lamination, occasional ripples and a few climbing ripples. This facies is followed by a coarser sandstone bed(facies III, 71.5 - 91.5 m) which is grading upwards. Sandstones are arkosic to clean , with more than 40% organic matter and plant fragments (3 to 4 mm). This bed is succeeded by a very coarse sandstone stratum (facies IV, 91.5 - 98.4m). Fossilized plant fragments with stems and leaves are abundant. Interbeds of fissile dark grey to black , thinly laminated shales are common which contain localized pyrite nodules as large as 3 cm in diameter. In these carbonaceous shaly layers and contain abundant fossilized plant remains. Three types of plant fossils identified:

1. Lepidodendropsis corrugata (abundant).
2. Triletes cheveriensis
3. Asterocalamites scrobiculatus

This sequence is followed by a fine clast supported conglomerate stratum (facies V, 98.4 - 102.6 m) with granule size semi rounded quartz clasts and occasional black shaly fragments. Quartz clasts constitute 60% of this facies. Locally, there are some rounded nodules of quartz. Black fissile shale seems to be transported by the mechanism that formed this facies. From 102.6 metres upward, grain size decreases. The contact is gradational and is fining upwards to very coarse sandstone with a few finer sandy lamination (facies VI, 102.6 - 115.3m). Quartz nodules are locally present , but are fewer than the stratum below. This very coarse sandstone layer is overlain by another very coarse sandstone layer (facies VII, 115.5 - 118.3 m), which has few black shale lamination with more than 90% organic matter.

Above this bed the grain sizes change from very coarse sandstone to coarse sandstone (facies VIII, 118.3 - 131.2 m) with occasional quartz nodules of 2 to 3mm in diameter. More than 60% of the grains are quartz with an abundant proportion of black shaly fragments. Slickensides and fine sandstone lamination are present. There is a red sandstone bed (facies IX, 131.2 - 132.6 m) with at least 10% white mica and light greyish green sandstone lamination. This bed is overlain by a light greyish micaceous sandstone bed(facies X, 132.6 - 136.5 m), its top is obscured and contains 5% organic matter, 45% glassy quartz, 30% feldspar and 20% white mica. Slickensides and lamination are common.

Above 136.5 metres, light greyish sandstone is overlain by a coarse siltstone bed (facies XI, 136.5 - 183.5 m). There is a distinctive increase of white mica compared to previous stratum.

Lamination , cross lamination and organic matter are common. The last sequence (before the conglomerate) is a series of red and green shale sequences (facies XII, 183.5 - 224.2 m). The average of each red bed in this sequence is 60 cm the red beds dip 48 degrees northwest. Red and green shale beds do not exhibit any primary structures, except in the bottom where a few cross lamination were observed.

Finally these strata are overlain by (facies XIII, 224.2 - > 229.2 m) a matrix supported pebble conglomerate (>5 metres thick). The upper and Lower contacts of the conglomerate are obscured. Clasts mainly consist of rounded white quartz,feldspar (approximately 40%) mica, well rounded slates (refer to petrology section) and granites. There is a single channel with a length of 2.5 metres and height of 50 cm in the bottom of the conglomerate bed. Grains in the channel lag deposits are as large as 8 mm in diameter. Generally the conglomerate has bands of coarser (6 to 8 mm) and finer (2 to 3 mm) phenocrysts which are overlain disconformably by marine strata of the Windsor group(Stevenson, 1959).

2.3.2.3. Structures

The first facies in the stratigraphic column, Figure (2.4b) is a pebble conglomerate stratum. This facies strikes 60 degrees west of south and dips 60 degrees northwest. Facies II is striking 51 degrees west of south and dipping 65 degrees northwest. Presence of climbing ripples and lamination in the sandstone bed indicate the section is right way up. Facies IV is striking 73 degrees west of south and dipping 32 degrees northwest. Presence of slikensides in this stratum suggests that minor shearing has affected portions of this stratum. Slikensides are frequently present in facies VIII, IX, and X. Finally, red and green beds in facies XII are dipping 48 degrees northwest.

2.3.2.4. Optical Petrology

The thin section prepared from facies II (Fig, 2.4b) shows K- feldspars (0.8 mm), quartz (0.9 mm), and muscovite (0.01 mm). More than 60% of the rock is quartz. Grains are generally subhedral in character. Grain boundaries are scalloped to sutured shape which is suggestive of a textural disequilibrium in the rock. The quartz grains show minor undulatory extinction. The matrix of the thin section is composed of muscovite, organic matter and quartz. This sample is a sedimentary sandstone rock.

Another rock was prepared from the clast of the conglomerate in facies XIII (Fig, 2.4b). The thin section exhibits a low grade metamorphic rock (slate). It shows a retrograde stage of a relict phorphyroblasts of andalusits produced during thermal metamorphism. Few chiastolite crosses are observed, but most of the andalusites exhibit hydrothermal alteration to sericite. Porphyroblasts are generally 2 to 3 mm in diameter and are subidioblastic to idioblastic in character. The matrix is very fine grained(0.01 mm) and is altered to clay (

muscovite and sericite).

2.3.2.5. Interpretation

Generally, this basal conglomeratic facies (Fig 2.4b) does not have any internal structure, but the presence of well rounded clasts and the absence of clay material are suggestive of a high flux regime in a fluvial type of deposit.

The presence of climbing ripples, cross stratification, periodic shaly lamination, the abundance of plant fragments and organic matter in some of the facies, semi-rounded grains and finally, gradual change from sandstone facies to conglomerate facies are suggestive of some type of fluvial deposit with high flow regime and overload sediment with some short flooding period. The type of fluvial deposit is difficult to distinguish due to the absence of some of the facies and primary structures . It is suggested that such a deposit is some sort of a transition between the typical braided system and the classical meandering system.

Finally, facies XIII is a well rounded, matrix supported pebble conglomerate with channeling and channel lag deposits in the lower proximity of the bed. This facies exhibit some planar stratification of finer sand to granule size clastic sediments. The most probable environment for such a facies is a braided type of fluvial deposit.

2.3.2.6. Correlation

An attempt has been made to correlate the stratigraphic sections of Figure 2.4a and 2.4b. A distance of 490 metres separates these two stratigraphic columns (Fig, 2.2). Even though both of these sections belong to the Horton group clastic deposits, Figure 2.4a, has a total thickness of 68.5 metres and Figure 2.4b has a thickness of more than 229 metres.

Stevenson (1957) estimated a maximum thickness of 914 metres for Horton deposits. In fact, there are no continuously exposed sections in the Rawdon Hills with definite beds delimiting the top and the bottom of any series, nor are there complete sections whereby accurate thicknesses of the series can be measured, because extensive faulting has caused repetition of sequences. Many sections have also been largely obscured by drifting. The only similar facies between Figure 2.4a and 2.4b is the basal polymictic clast supported pebble conglomerate, facies I, which both of these beds have the same rock type showing similar texture. The only difference between the two beds is their thickness which in the stratigraphic column in Figure 2.4b is 14 metres and in Figure 2.4a it is only 4 metres. One possibility for such a difference may arise from different rates of erosion in these locations or difference in sediment load in the transporting fluvial system. Also, it is possible that 2.4a was higher topographically. Therefore, most of sediments were transported toward the lower areas like (2.4b). Other facies in these two stratigraphic columns show definite differences in their depositional environments. Section ii of

Figure 2.4a is a lacustrine type of deposit with a series of cyclic sandstone and fissile dark grey to black ,thinly laminated shales. Section ii shows medium to coarse grained sandstone deposits from the marginal deposits of a lake or near shore depositional environment. In contrast, the stratigraphic column from Glen Brook,Figure 2.4b, has much coarser grains relative to Figure 2.4a, and is identified to be a fluvial type of deposit.

Overall, Figure 2.4b has a coarsening upward pattern and Figure 2.4a exhibit a fining upward pattern. The survey in the Glen Brook area was conducted from the basal Horton deposits (contact between the Halifax Meguma slates and the Horton deposits) to the top of the Horton (contact between Horton and the Windsor gypsum is obscured). In the case of Figure 2.4a, the drill hole was started close to the contact between the Meguma and the Horton sediments. Therefore, a major part of the Horton deposits are missing in the drill hole.

In summary, except for the basal conglomerate bed the rest of these sequences can not be correlated .

2.4. Origin of the Horton deposits in the Rawdon Hills

Stevenson (1956) suggested that the Horton deposits originated from an older upland that lay to the south in Horton time. Based on the few hundred measurements from the flow direction of the primary structures, Stevenson showed that the current ripple marks indicating the dominance of currents were toward northeast.

From the few primary sedimentary structures measured by the author in an outcrop (3 miles north east of McPhees corner),Figure 2.1, the direction of the flow was toward the southeast. Few lineations in sandstone strata showing 130 degrees southeast-northwesterly direction, and several rib and furrow structures were measured to have an average direction of 128 degrees towards the southeast. Obviously, ripples in a stream may exhibit variable direction of flows in different localities, but for instance, presence of slates and quartz clasts in facies I suggest that the sediments are originated from the Meguma slate rocks that lie to the south. In the case of facies XIII (in Glen Brook), the presence of approximately 40% feldspar, granite clasts, and some clasts containing andalusite grains in conglomerate, are not sufficient to decide on the origin of this facies. These detrital sediments could be originated from the south (Meguma Group and granite batholith) or from the north side, Cobequid Highlands.

2.5. Summary

A survey was conducted along the Glen Brook 2 miles southwest of Gore (Fig 2.1, 2.4b, 2.2) In this locality, Horton sediments consist of conglomerate, grit, sandstone, siltstone, and shale with the coarser members predominant. The stratigraphic column constructed from the survey exhibit a general coarsening upward (up to 102.6 metres), and then fining upward(224.2 metres).

At the top, Windsor gypsum is disconformably underlain (Stevenson, 1959) by a pebble size, grey Horton conglomerate containing mainly rounded pebbles of free quartz. At the basal contact Halifax Meguma slates are overlain with marked angular unconformity by a basal Horton conglomerate. The whole section is fluvial in origin.

The Nova Scotia Department of Mines and Energy drilled a hole, located 490 metres east of Glen Brook. This drill hole has upper sandstone facies with lower cyclic thinly laminated shales, and basal conglomerate unconformably deposited on the Halifax Formation Meguma slates. Except for basal conglomerate which is fluvial in origin, the stratigraphic is lacustrine in origin.

Because of lack of enough information, and the contradiction between the flow direction measurements given by the author and those given by Stevenson (1959), the origin of the Horton sediments remains unclear. The results presented by the author show that the sediments were transported from the north, but Stevenson (1959) claims that they were transported from the south.

CHAPTER III. FISSION TRACK STUDY

3.1. Introduction

Fission track dating is a new approach to the interpretation of thermal histories of sedimentary basins. This technique depends on the observations of annealing of fission tracks in minerals. The pattern of apatite fission track ages will yield information on thermal history unobtainable by other methods. The unique advantage of the fission track method is that it can give information not only on maximum palaeotemperatures, but also their variation through time.

The fission track method was employed on two drill cores from east of Rawdon Hills to date the possible uplift event in this area.

3.2. Core Samples

Two diamond drill core samples (BP-73-6 and BP-73-7) were used to date apatites by the fission track technique (Fig 2.1). These cores were drilled by Red Fern Resources. BP-73-6 was 250m long and BP-73-7 was 213m long.

BP-73-6 penetrated an interbedded sequence of siltstones, sandstones and shaly siltstones. The top of the section to 139m consisted of predominantly green siltstones with some beds of red siltstones. Below 178m the sandstones were grey with abundant bands and lamination of black shaly sandstone.

BP-73-7 penetrated a sequence of siltstones and sandstones capped by a thin layer of dolomite limestone. The top section of The siltstones and sandstones measured to 89m was predominantly red with coarser fragments towards the bottom. Below 89m the siltstones and sandstones were predominantly green with some grey beds to the bottom of the hole.

3.3. Fission Track Technique

The principle of fission track analysis was originally developed by Fleisher, Price, and Walker (1963). The method is reviewed in Fleisher, Price, and Walker (1969). This technique was perfected by C.W. Naeser since 1978 .

Fission track dating is one of the newer tools used to identify paleothermal anomalies. Basically, a track is a damaged zone formed as a charged particle passes through a solid (Naeser, 1979) Fig 3.1. The length and the shape of the different tracks is dependent on the type of particle that formed the track. The length of the tracks in the samples is approximately 10 microns long Fig 3.2.

Normally, three naturally occurring isotopes spontaneously fission: ^{232}Th , ^{235}U, ^{238}U. Of these only ^{238}U produces a significant number of fission events. For all practical purposes, all fission tracks can be assumed to have come from ^{238}U. Figure 3.1 shows the general track forming mechanism (MacDougall, 1976). The fragments formed at the time of fission are highly charged

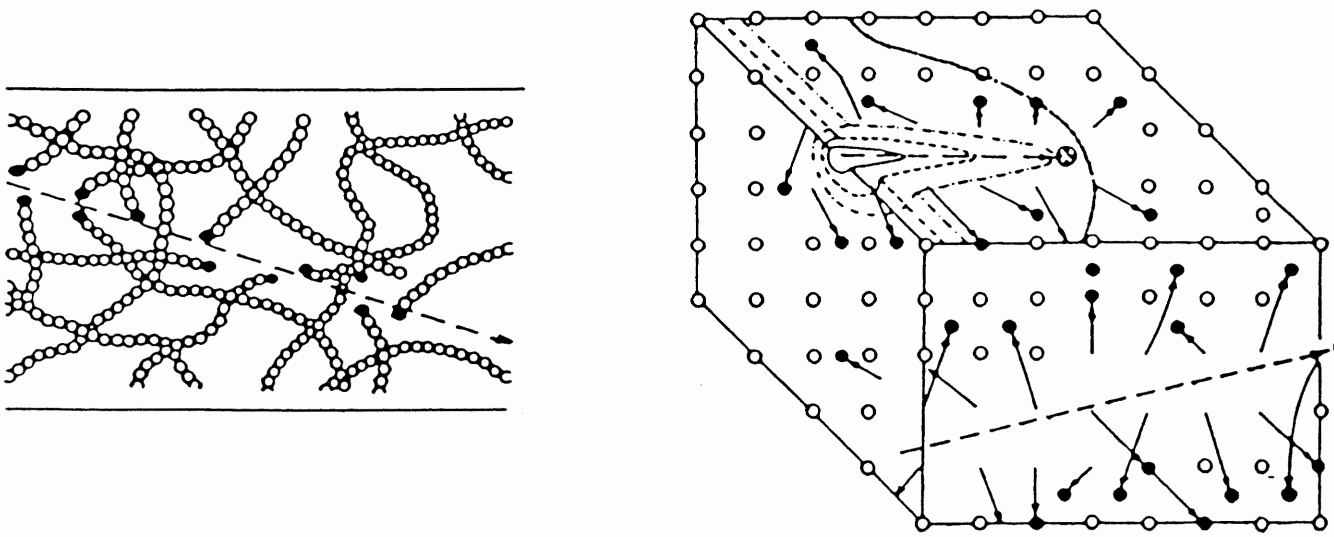
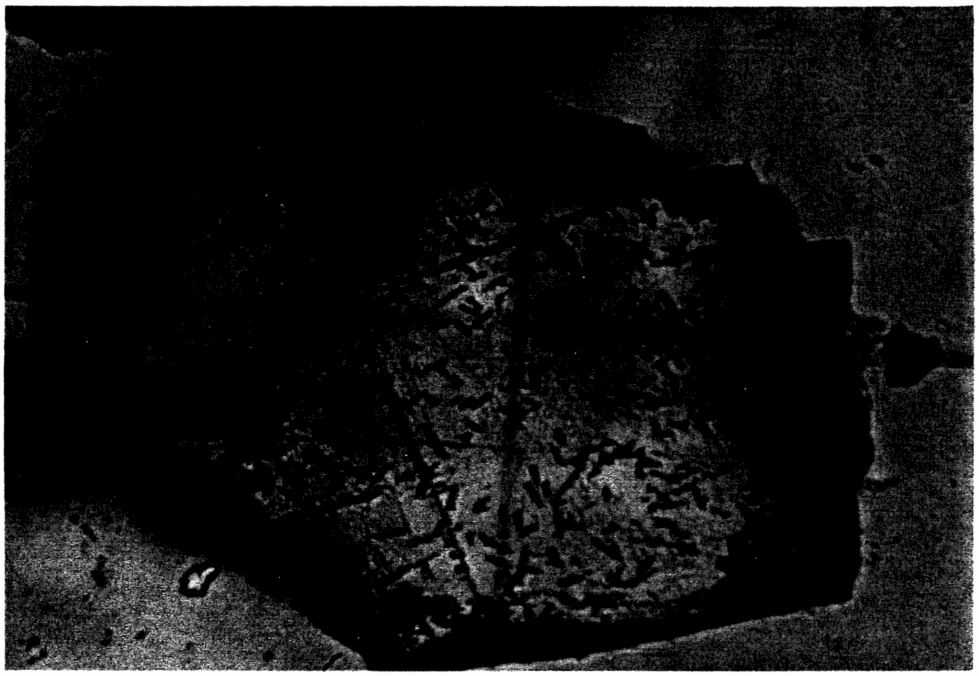


Fig: (3.1) - Fission particle passing trough the crystal lattice of a solid, and forming a damaged zone(Macdagall, J. 1976).



50 μ

Figure 3.2 : Spontaneous tracks in the apatite grain (sample 6-7).

nuclei that disrupt the electron balance of the atoms in the mineral lattice along their path. As the charged particle passes through, it leaves a zone of positive charge in the crystal lattice structure. This causes the positively charged ions in the lattice to repulse each other and force themselves into the crystal structure, forming the track or damaged zone. When the track is formed it is normally stable at temperatures less than 100 ^{o}c. By increasing the temperature, atomic movements of molecules and ions increase, so that positively charged ions move back into the track and cause the damaged zone to anneal until it no longer can be observed.

There are five types of procedures that are used in the fission track dating and for each of them there are some advantages and disadvantages. For this project the EDM procedure was used The schematic representation of each type is illustrated in Figure 3.4. For the various practical purposes the population method (PM), and external detector method (EDM) are used almost exclusively. In the case of the subtraction and repolishing methods, further procedural variations have been used, involving the etching of the external surfaces. Generally, this is unacceptable because of possible contamination. Also in population and subtraction methods necessitate counting many crystals. In the case of both EDM and re-etch method where external surfaces are used, a geometry correction factor is required.

3.4. EDM method

In the EDM the fossil tracks are counted in the etched, mounted grains, and the induced tracks are counted in the exactly the same area on an external detector of low uranium muscovite covered the grain's surface during irradiation and subsequenty etched. Thus fossil and induced tracks are measured from the same planar surface of an individual crystal and inhomogeneous uranium distribution both within and between crystals is of negligible consequence. In EDM method fossil tracks are result from the passage of charged particles across the internal surface of crystal lattice, from both above and below producing a 4π geometry (Hurford, and Green, 1982). The induced tracks, will be formed by passing charged particles from the grain to the mica which is producing a 2π geometry. In the early works by Naeser, and Dodge, (1969), and the more recent works by Hurford, and Green, (1983), it is assumed that a factor of 0.5 would correct the difference in geometry.

One of the major advantages of the EDM is the simplicity of handling required after irradiation. In particular, no grinding, or polishing of radioactive materials is necessary, this is an important safety consideration. This procedure is so designed that sampling problems should be eliminated since both Ns and Ni (all the symbols are explained in Appandix B) ideally originate from the same amount of uranium. In this case, each pair of measurements (Nsj, Nij or Psj, Pij) should give roughly identical ratios.

3.5. Method

3.5.1. Separation Procedure

Apatite crystals were separated and dated, since tracks in apatite fade relatively at a much lower temperature(70 - 125 ^{o}c ,Gleadow, 1983) than zircon and sphene. Apatite is very useful as a low temperature geological thermometer. Since zircon and sphene start to anneal at temperatures above 200 ^{o}C.

From the two drill cores (BP-73-6) and (BP-73-7) seventeen samples were chosen in intervals of 30 metres. Table A a,b in the appendix list the samples in different intervals. Ten samples from BP-73-6 and seven samples from BP-73-7 were dissolved in 15% acetic acid for a period of 48 hours to dissolve the calcite cement of the samples. Samples were sieved and grain sizes between - 70 + 120 mesh were chosen for heavy liquid separation. This separation is done by using tetra-bromoethane to separate heavy minerals from feldspar, muscovite, and quartz grains. Methylene Iodide is then used to separate lighter apatite, fluorite, and other light minerals from heavier minerals like zircon. Those samples with a high proportion of mafic minerals (>50%) were separated by magnetic separation method. In this process apatite, fluorite,pyrite calcite,and barite were separated from the rest of the minerals. The magnetic separator was used with a constant forward slope of 15 degrees, side slope of 15-12 degrees, and a magnet current of 0.8 amp.

Finally, apatites were separated out by the process of hand picking. Apatite crystals were relatively rounded and corroded. The refractive index and reaction by 10% HCl acid were used for some of the doubtful grains to identify the apatites.(Fig3.3).

3.5.2. Section Preparation and Polishing

The separated grains of apatite were mounted in epoxy resin on petrographic (27x45mm) glass slides. Grains were placed on the slides and a large drop of the epoxy was placed on the slide and the grains, then another petrographic slide was placed on the epoxy. After the epoxy hardened the bottom slide was removed. Polishing was then carried out in five steps using 600,30,9,1,and 0.05 micron plates on rotating laps.

After completing the process of polishing, from the original seventeen samples, just five were suitable to continue the process of EDM, and the twelve samples had to be disregarded. Because, either apatite was not present in some of these twelve samples or very small amount of grains recovered by various separation and polishing methods were not sufficient for further procedures.

3.5.3. Etching and Irradiation

In the external detector method (EDM) samples should be etched before irradiation. All samples were etched by 7% HNO_3

FIG (3.3): Mineral separation flow chart.

```
             ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
             ^ 17 Smples from 2 drill cores  ^
             ^ (BP-73-6 and BP-73-7)         ^
             ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
                          :
               ( each approximately 300 gr )
                          :
               *****************************
               * Cement dissolved in 15%   *
               * CH3COOH For 48 hours      *
               *****************************
                          :
                  ^^^^^^^^^^^^^^^^^^^^^^^^^^
                  ^ Sieved -70 + 120 mesh  ^
                  ^^^^^^^^^^^^^^^^^^^^^^^^^^
                          :
 ____________  *****************************
 :LIGHT:feld, :  *      Heavy liquid          *
 :qtz,musco   :__* tetrabromoethane d=2.96    *
 ____________  *****************************
                          :
                      ^^^^^^^^^^^^
                      ^  Heavy   ^
                      ^^^^^^^^^^^^
                          :
 _____________          **************************
 :LIGHT:        :   *     Heavy liquid          *
 :apatite,      :   *                           *
 :flurite,etc   :__* methyleneiodide d=3.32 *
 _____________          **************************
                          :
                      ^^^^^^^^^^^^
                      ^ Light    ^
                      ^^^^^^^^^^^^
                          :
 _____________    ********************     ______________
 :Nonmagnetic: :  * Magnetic seperator*   :  Magnetic :    :
 :apatite,     :  *    15 ,0.8 amp    *__: sphene,etc      :
 :flurite,     :____*                 *    ______________
 :calcite,etc  :  ********************
 _____________            :
                      ^^^^^^^^^^^^^^
                      ^nonmagnetic ^
                      ^^^^^^^^^^^^^^
                          :
  __________          *******************
  :apatite   :_______* Hand picking      *
  __________          *using microscope  *
                      *******************
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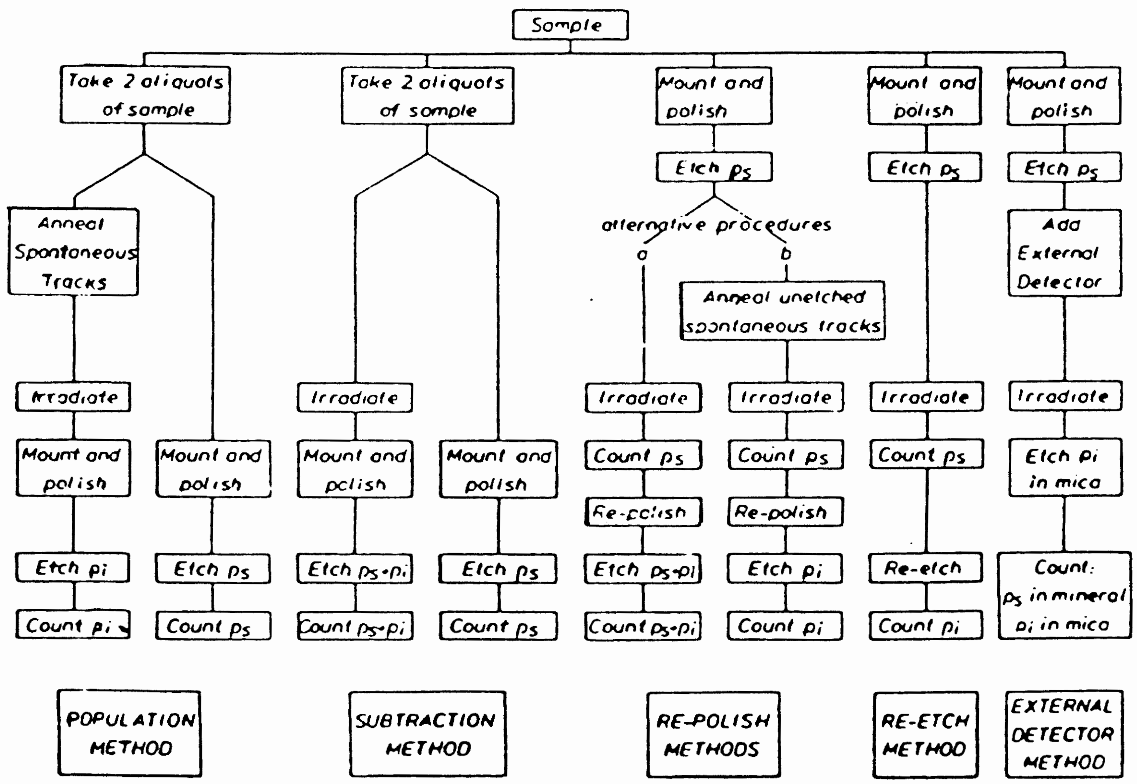

Fig (3.4) - Schematic representation of different fission track dating procedures. The last column is the EDM procedure (Green, 1982).

for 40 seconds to reveal the fossil tracks on the grain surfaces. The reason that a chemical etchant is being used is because tracks in their natural state are too small to be seen except with an electron microscope . By choosing the proper chemical etchant, it is possible to dissolve out the damage zone and not dissolve its crystal (Price and Walker 1962).

Each mount was then covered with a piece of clean, low-uranium muscovite (0.05mm thick). Muscovite was chosen over the lexan polycarbonate sheets because muscovite is able to record the tracks by the same mechanism as that for the common minerals used in dating. Another reason for using a mica detector is that track fading can occur in some organic polymers such as lexan, during neutron irradiation under the environmental conditions found in some reactors.

Finally, samples were packed in a piece of heavy duty aluminum foil with four standard glasses, each covered by a mica sheet,on the bottom, on the top, and two in the middle, with samples on the top and bottom of each of them. In fact standard glasses are used to determine the the neutron dose as acurately as possible. The standard glass had a uniform uranium concentration and were counted for track density.

The package of samples were then sent to McMaster University's nuclear reactor for irradiation. A standard neutron dose of $3.5 \times 10^{15} n\ cm^{-2}$ was used for the apatite samples.

After the process of irradiation the muscovite cover sheets were etched by 48% HF for 12 minutes to reveal the induced tracks. The muscovite sheets covered each of the standard glasses were etched by the same chemical etchant for one hour to reveal the induced tracks.

3.5.4. Fission Track Counting

Induced and spontaneous tracks were counted by Olympus BH-2 microscope , fitted with binocular viewing, transmitted and reflected light and the magnification (1000x). The gride used for counting has 55 by 55 micron size for counted grains and 125 by 125 micron size for the glass dosimeter. Counts for each sample are listed on Table 3.1 . Induced tracks counted on the mica sheets reveals the Pd (the density of induced tracks on the mica). There were four standard glass dosimeters in irradiation package which are plotted on Fig 3.5. This figure illustrates the counted induced track densities in glass dosimeters v.s. the position of samples in irradiation package.

Apatite's fission tracks are readily distinguished by their characteristic tubular shape, and their thicker head and thinner tails, from the other etch pits that result from imperfections in the crystal lattice. Using EDM first the spontaneous tracks were counted from the mounted grains, and then the image of the same location on the mica detector counted(induced tracks). The same location must be counted on both the grain (Nsj), and the mica (Nij), since in the same crystal the concentration of uranium can

TABLE (3.1)- NO OF INDUCED AND SPONTANEOUS TRACKS COUNTED IN DIFFERENT GRAINS.

SAMPLE 6-7		SAMPLE 7-1		SAMPLE 7-5	
FOSSIL	INDUCED	FOSSIL	INDUCED	FOSSIL	INDUCED
54	54	34	20	52	30
72	68	63	50	38	20
17	13	72	59	63	34
96	80	20	13	60	32
46	33	142	118	71	41
38	27	45	34	119	88
9	6	9	5	128	92
14	10	58	38	112	80
23	18	68	50	175	113
98	81	81	62	205	129
91	74			109	86
48	35			116	89
42	30			48	32
55	42			51	33
51	40			99	68
108	91			112	79
101	83			89	42
142	121				
112	94				
102	89				

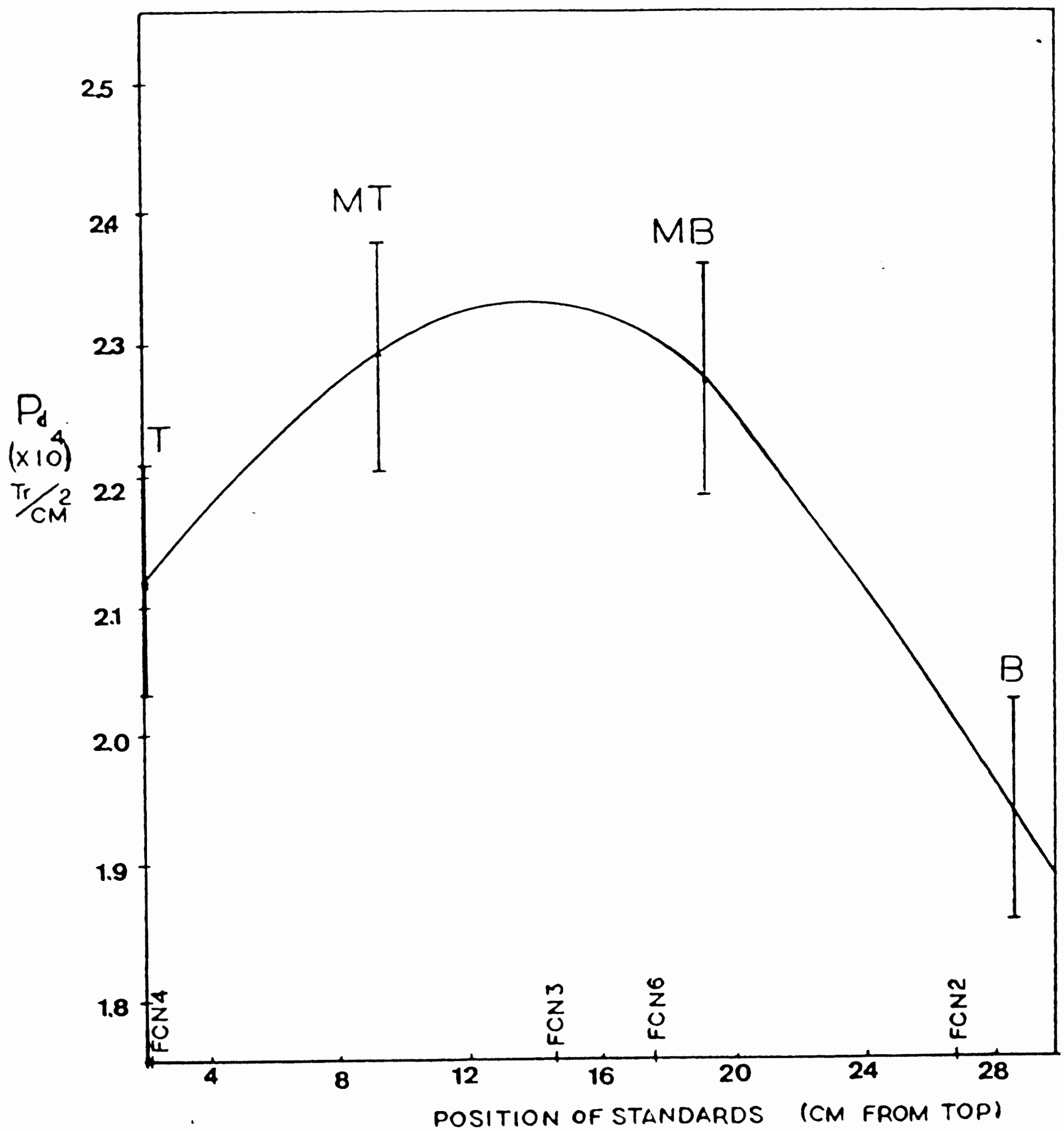

Fig (3,5) - Four standard glass dosimeters (from the irradiation package) are plotted V.S. Pd.

be variable. The observed track density is related to the length of time during which tracks have accumulated, and to the uranium concentration of the specimen.

3.5.5. Age equation

The fission track age equation is of the form (after Price, ... Walker ,and Naeser, 1967).

$$A = 1/\lambda_D \ \mathrm{Ln}\left[1 + \frac{P_S}{P_I}\frac{\lambda_D \varnothing \ \sigma_{235} \ I}{\lambda_F}\right] \qquad 1$$

The values and descriptions for symbols are listed in Appendix B. In the conventional error analysis, normally the common assumption is that the random nature of radioactive decay is the only source of error in the fission track dating method. In this case, derivation of a fission track age is dependent on the measurement of the ratio Ps/Pi. Green, (1981) suggests that the conventional analysis give a suitable estimate of Ps/Pi as long as the observed track counts are acceptable under a X^2 criterian. Values of X^2 may be calculated from equation two by Green,(1981).

$$X^2 = \sum_{j=1}^{n} \frac{(N_{sj} - \hat{N}_{sj})^2}{\hat{N}_{sj}} + \sum_{j=1}^{n} \frac{(N_{ij} - \hat{N}_{ij})^2}{\hat{N}_{ij}} \qquad 2$$

where

$$\hat{N}_{sj} = \frac{N_s}{N_s + N_i}(N_{sj} + N_{ij}) \qquad 3$$

and

$$\hat{N}_{ij} = \frac{N_I}{N_S + N_i} \left(N_{Sj} + N_{ij} \right)$$

The values of X^2 should then be tested at a 5% level, with (n-1) degrees of freedom, which n is the number of crystals counted. If the value of X^2 is acceptable then conventional error analysis can be used. Three samples used for the fission track study in this presentation satisfy the 5% level for X^2, therefore fit the poission distribution. So conventional analyses were employed to find the error in the ratio Ns/Ni which are being listed on Table 3.2 For the conventional analysis (Green,1981) uses values:

$$\sigma(P_s) = \frac{(N_s)^{1/2}}{A}$$

and

$$\sigma(P_i) = \frac{(N_i)^{1/2}}{A}$$

where σ(Ps) and σ(Pi) are errors in Ps and Pi. These errors are combined to give the final uncertainty in Ns/Ni by:

$$\frac{\sigma(N_s/N_i)}{N_s/N_i} \quad \left[\frac{1}{N_s} + \frac{1}{N_I} \right] \qquad 4$$

Referring to equation 1, since the values of the constants

TABLE (3.2) - THE VALUES OF CHI-SQUARE, AND CONVENTIONAL ANALYSIS

SAMPLE	CHI-SQUARE	DEGREES OF FREEDOM	NS/NI	ERROR FOR NS/NI
BCFCN2	14.53	59	.272	.017
BCFCN4	15.14	53	.249	.017
BCFCP1	13.17	11	.242	.033
BSFCN2	25.74	59	.297	.017
BSFCN4	34.36	63	.254	.015
CHFCN2	25.07	40	.238	.019
CHFCN3	11.59	16	.200	.024
CHFCN6	11.31	30	.161	.016
CSFCN2	29.21	45	.217	.016
CSFCN3	13.01	27	.178	.018
CSFCN6	14.26	31	.148	.016

I, and λ_D are well established , only the track densities Ps and Pi, the track constant , λ_F and the thermal neutron fluence ϕ, are required to evaluate the age of unknown samples. Unfortunately the wide disparity of λ_F and ϕ values in different literature has generated a degree of and skepticism towards the track dating method. Recently, Hurford, and Green, (1982), presented an alternative calibration approach for calibration of fission track dating. In this approach , they relate the unknown ages of samples to known ages of standards. This method is a definite way to evaluate and absolute determination of the thermal neutron fluence. In this way, the equation (1), is rewritten with a factor zeta replacing the decay constant λ_F, the neutron fluence ϕ, the ^{235}U thermal neutron fission cross section σ, and the $^{235}U/^{238}U$ isotope abundance ratio I (Hurford , Green. 1983).

$$A\ unk = 1/\lambda_D \ln\left[1 + \left(\frac{P_S}{P_I}\right)_U \lambda_D Z\, g\, P_D\right] \qquad 5$$

where the zeta value is

$$Z = \frac{EXP(\lambda_D A_{STD} - 1)}{(P_S/P_I)_{STD}\, \lambda_D\, g\, P_D} \qquad 6$$

In this process Zeta can be easily calculated by counting Pd, Ps, Pi from the samples. The standard samples adopted in this study were Naeser's apatite samples from Fish Canyon Tuff in the San Juan mountains of southern Colorado. The age of these samples were determined by K-Ar dating method which is 27.79 $\pm$ 0.7 Ma. These standards were used to provide a calibration baseline for the uranium glass dosimeter. The unknown ages of the samples were evaluated by the comparison of the track densities (Pd) measured in the mica detector in contact with the standard glass.

By taking the partial derivative of equation 6 , the error for the zeta can be calculated :

$$\frac{\sigma^2}{Z^2} = \left(\frac{\lambda_D}{1 - e^{(-\lambda_D A_{STD})}} \right)^2 \sigma^2 A_{STD} + \left(\frac{1}{P_s/P_i} \right)^2 \sigma^2 P_s/P_i + \frac{1}{P_D^2} \sigma P_D^2$$

These age standard samples consist of four samples,FCN2, FCN3, FCN4, and FCN6, where FCN stand for Fish Canyon Naeser. Also in a previous irradiation run there were three standard samples which were used to evaluate the best value for the zeta. These samples are FCN2, FCN4, and FCP1, where P stand for Parrish. samples FCN2, and FCN4 which have been used in two different irradiation packages are same samples but the neutron dose used in these irradiation processes are different from each other. As a result the induced track density in the samples will be different.

Figure 3.6 illustrates from the Figure 3.5) are listed in Table 3.2. Figure 3.6 illustrate the plot of zeta values, error bars are 2σ. The reason that an average of zeta should be taken

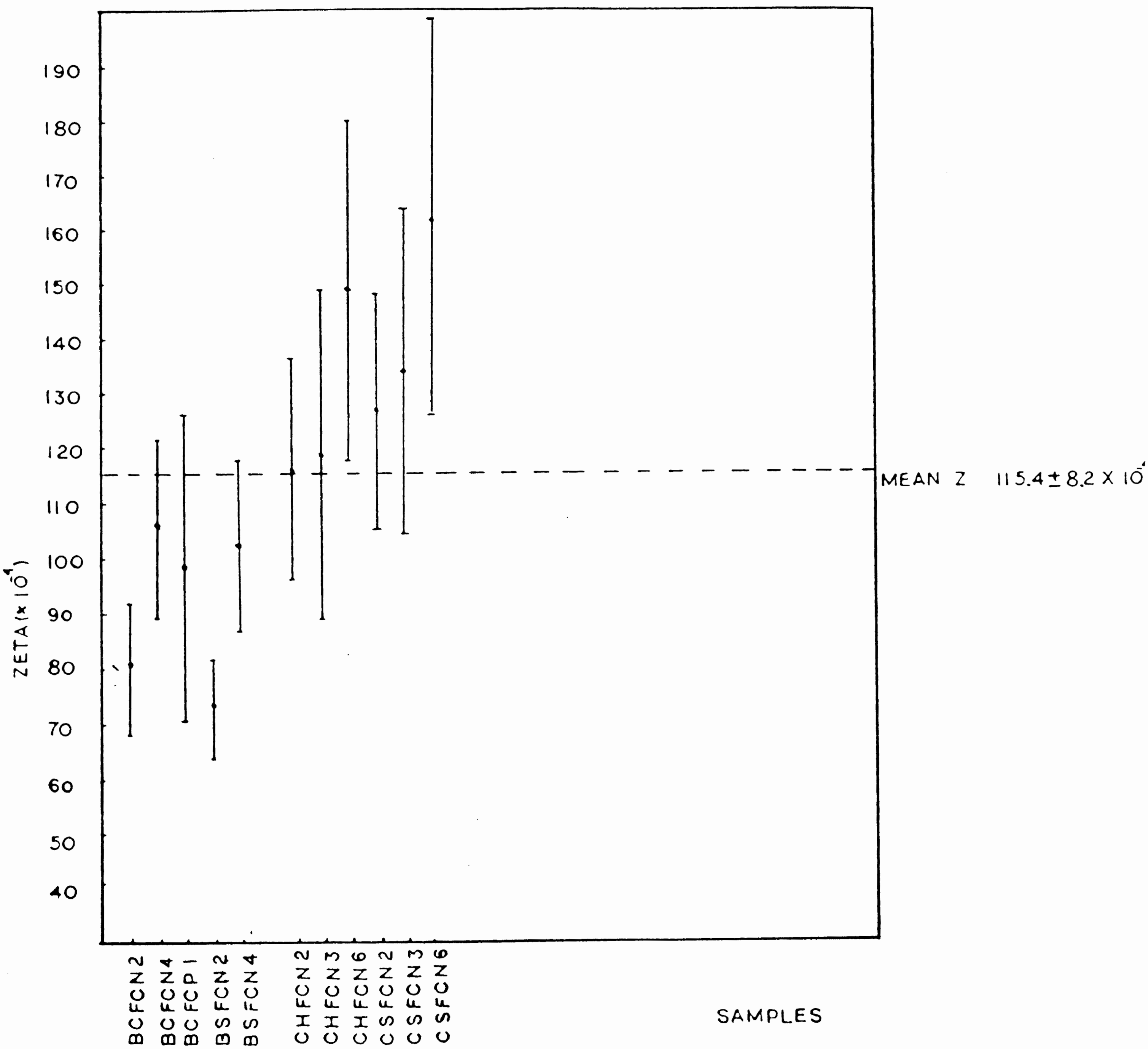

Fig (3.6) - Evaluation of Z values. Dashed lines represents mean. Error bars are 2σ calculated from errors in track densities (Hurford, A.J, and Green P.1983).

is because Z values have variable and large errors, since in each irradiation run the value of Z varies depend on the neutron dose used in the reactor. So, as more zeta values are used the better can be deduced from the average of them. In fact, the Zeta used in equation 5 is an average of all Zetas taken from the standard samples, Table 3.3.

Finally, the age of unknown samples were calculated from the equation 5. The error of the age was calculated from the equation 5 which is :

$$\delta_A^2 = \frac{1}{\lambda_D^2}\frac{(\lambda_D P_s/P_i\, g P_D)^2}{(1+\lambda_D Z P_s/P_i\, g P_D)^2}\delta Z^2 + \frac{(Z g P_D)^2}{(1+\lambda_D Z P_s/P_i\, g P_D)^2}\delta^2 P_s/P_i + \frac{(Z P_s/P_i\, g)}{(1+\lambda_D Z P_s/P_i\, g P_D)^2}\delta P_D^2$$

Age values for the three samples are listed in Table 3.3. Figure 3.7 illustrate the position of the three samples in the two drill cores BP-73-6, and BP-73-7, the length of the drill cores, and the topographic difference of 19 metres between the two drill cores.

Generally, in fission track dating, ages with less than 10% errors are acceptable and are common. Samples 6-7, 7-1, and 7-5 all have errors less than 10% . Samples 7-1 and 7-5 have larger error ($\pm$ 18 and $\pm$17) which resulted from the small number of grains which were recovered and sent to the reactor. There were twelve grains counted in sample 7-1 and 17 grains in sample 7-5.

TABLE (3.3)- ZETA FOR EACH STANDARD SAMPLES, MEAN ZETA, AND THE AGE OF SAMPLES.

* Sample counted by Casey Ravenhurst

** Sample counted by Alex Grist

*** Sample counted by Hadi Mahony

(B) is the first irradiation package

(C) is the second irradiation package

SAMPLES	ZETA	ERRORS OF ZETA	BEST CURRENT ZETA	AGE	ERROR OF AGE
*					
BCFCN2	.0080029	.0005887			
BCFCN4	.0105432	.0008358			
BCFCP1	.0098669	.0014183			
**					
BSFCN2	.0073463	.0005144			
BSFCN4	.0103042	.0007504			
***					
CHFCN2	.0116328	.0010475			
CHFCN3	.0119270	.0014904			
CHFCN6	.0149097	.0015669			
CSFCN2	.0127271	.0010894			
CSFCN3	.0134258	.0014658			
CSFCN6	.0162409	.0018204			
			.01154		
			.00082		
6-7				153.75	14.09
7-1				176.50	18.06
7-5				196.53	17.77

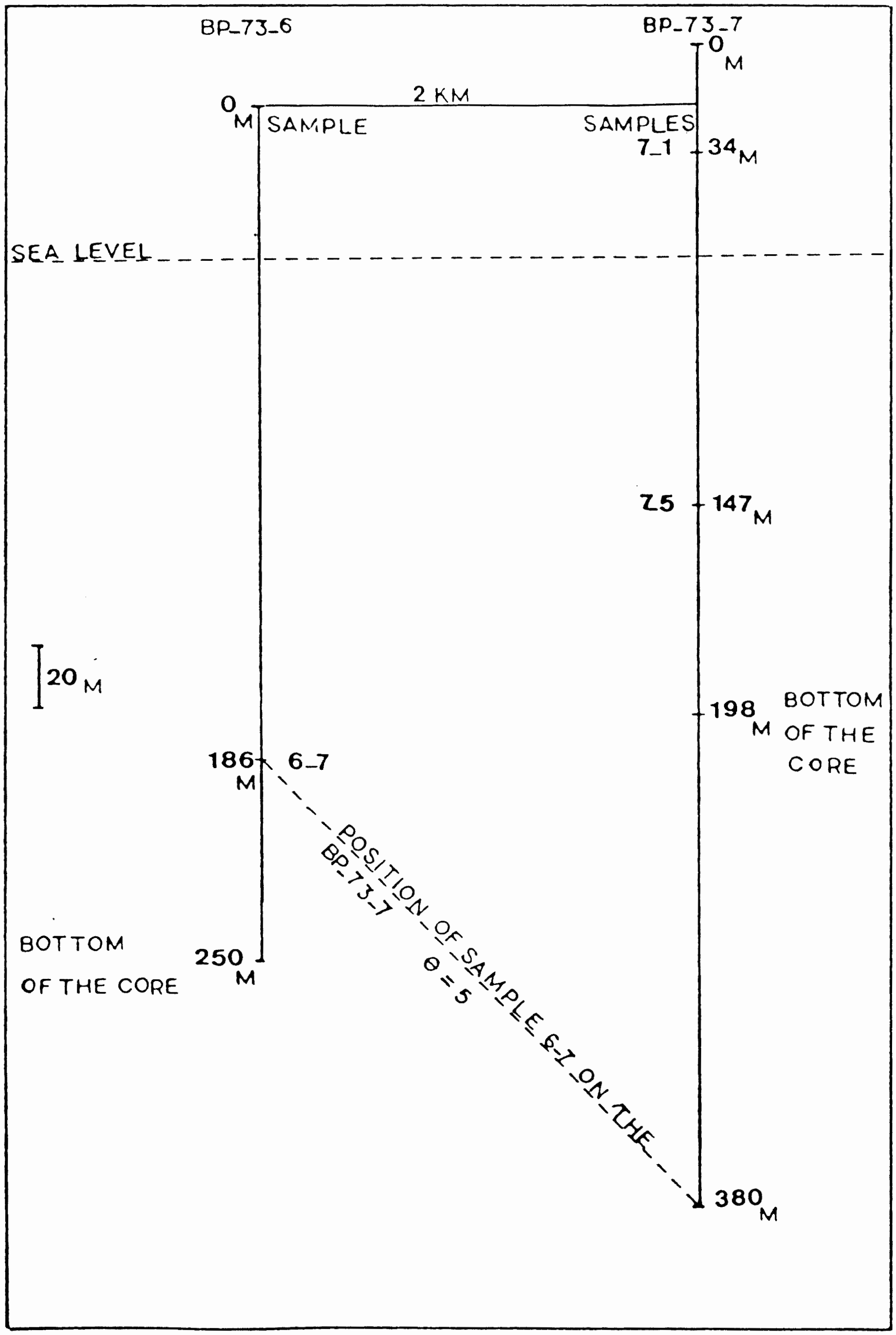

Fig (3.7) - Drill cores BP-73-6 and BP-73-7. The position of samples are located on the drill cores. BP-73-6 is topographically 19m lower than the BP-73-7.

The position of sample 6-7 projected on to the drill core BP-73-7, by using the average bedding dip of 5 degrees East of the North . The position of sample 6-7 will be at the depth of 380 metres. In this manner, sample 7-1 is at a depth of 34 metres in a drill core BP-73-7, and the age of 176.50 ± 18.06 Ma , sample 7-5 is at a depth of 147 metres and an age of 196.53 ± 17.77 Ma and finally, sample 6-7 is at a depth of 380 metres with an age of 153.75 ± 14.09 Ma.

Using the Figure 3.8, the error bars of sample 7-5 and 7-1, almost overlap eachother, an average age of 186.51 ± 17.91 Ma at the depth of 90.5 metres is deduced from the two samples.

3.6. Tectonic uplift in Rawdon Hills

An important assumption involved in fission track dating is that there has been no loss of tracks since the time of formation of the fission track uranium system. The geological interpretation of fission track ages depends intially on understanding the extent to which this assumption is valid for any particular sample. In the cases where loss of tracks has happened this method is able to date not the original formation of the minteral but some later stage in its thermal history.

By far, the most important parameter on the stability of tracks is temperature (Fleischer, 1965). Other factors such as pressure, shock, deformation and fluids have been shown to have no effect or very little additional effect compared to that of

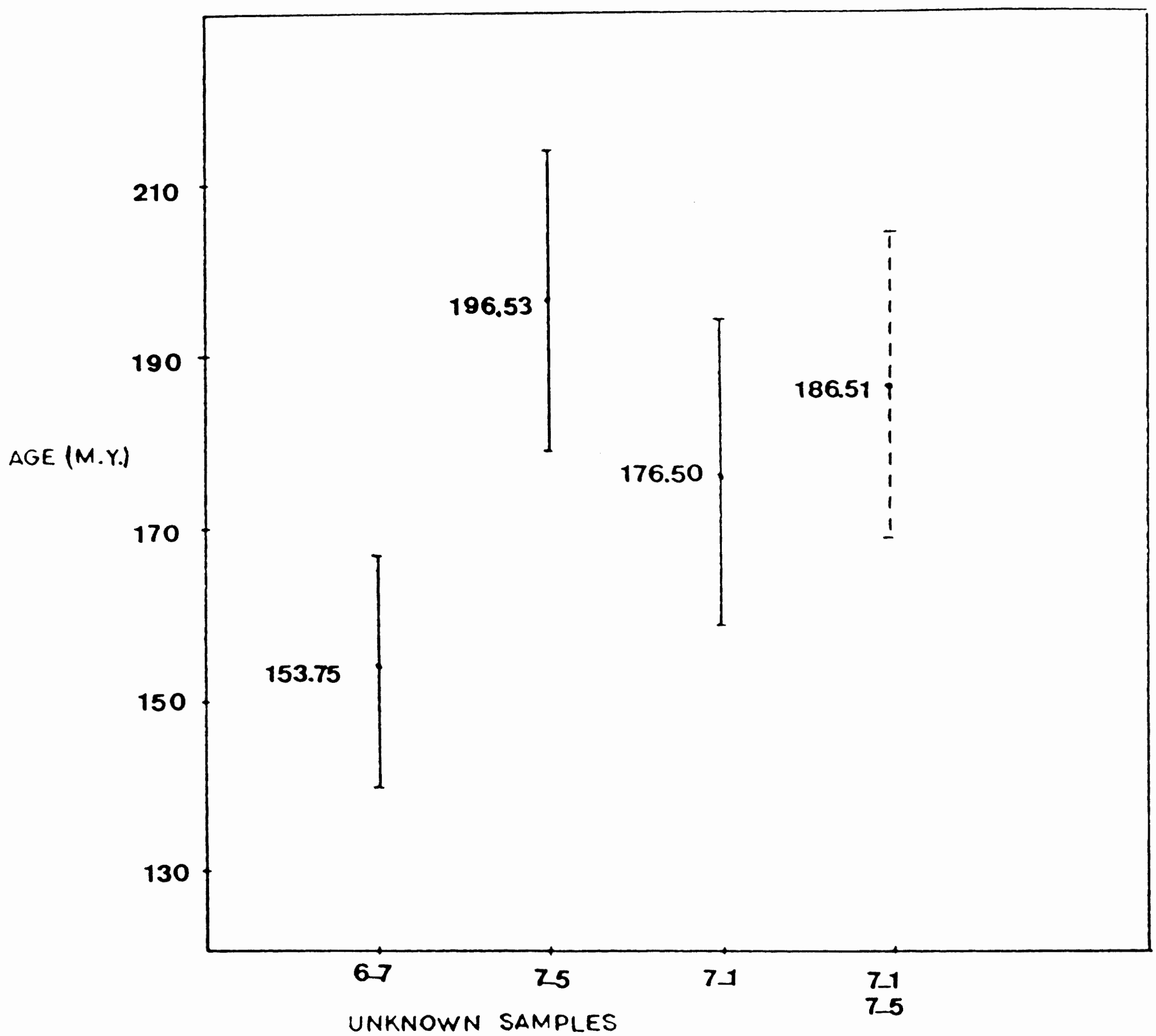

Figure 3.8 : The age of unknown samples and their error bars. The error bar with dashed line is a mean value for the samples 7-1 and 7-5.

temperature (Gleadow, 1983). With increasing the temperature movements of electrons accelerates and gradually neutralizes the ions produced by passing fission fragments. This process is called annealing. In the case of this thesis, the apatite grains were used because they were one of the most easily annealed crystals compared to some other types of minerals used.

Gleadow (1983) has analysed apatite crystals using fission track method, and he suggests that the partial annealing zone for apatite is from 70 to 125 ^{o}C. A hypothetical profile of apatite age with down hole temperature for one deep well is illustrated in Figure 3.9. In this Figure, at 70 ^{o}C apatite starts to anneal, and by the time temperature reaches 125^{o}c tracks are totally annealed and apatite exhibits a zero age. Gleadow (1983), and Naeser (1979) suggest that age of apatite is a function of elevation. In Figure 3.9, apatite between points A and B reflects the rapid uplift with paleotemperatures higher than 125 ^{o}C. The apatite between points B and C are only partially annealed during the burial prior to the uplift.

Using the slope between sample 6-7 and the average age and depth of sample 7-1 and 7-5 a value of 0.11 Ma per metre can be deduced. The inverse of the slope gives the result of 8.8 m/m.y, or 0.0088 km/m.y of uplift. These results have been compared to some other uplift values demonstrated by some of authors in Table 3.4. Compared to those values the rate of uplift from the three samples is very low. From the slope value and the uplift value

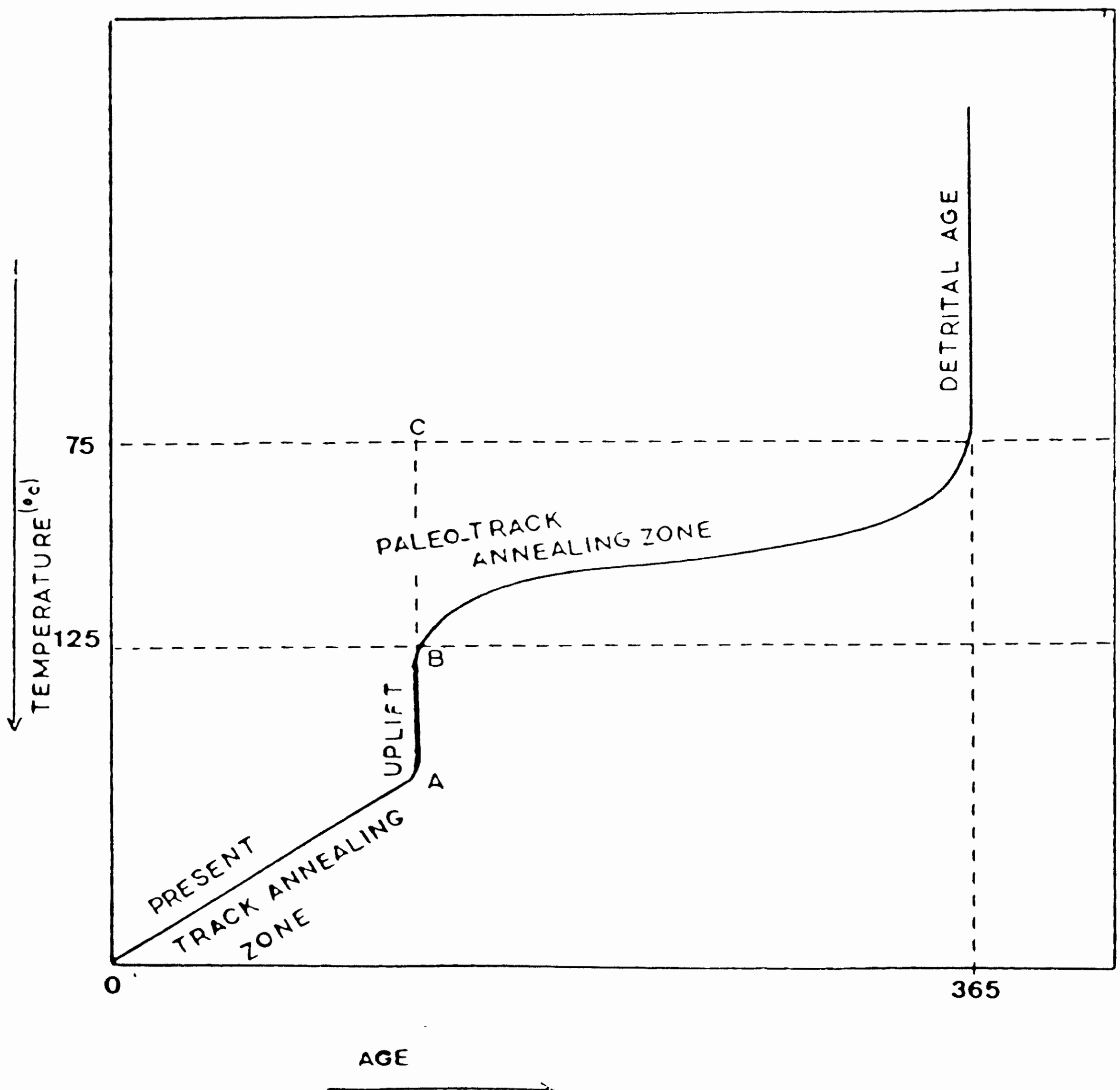

Fig (3.9) - Illustrates the plot for Temperature v.s. age of the samples. The value of 75 to 125°c represent of the paleo- track annealing zone. At this Temperature range the apatite grains were partially annealed(Gleadow, 1983).

Table (3.4): Average uplift rates in tectonically active areas compare to the Rawdon Hills results

Location	Uplift(km/Ma)	References
Williston Basin	.10.15	
Passive Continental Margins	.03-.04	Crowley, etal .1985
Orogenic belts and active continental margins	.10-.90	
Adivondack anorthosite	.03-.05	Miller,and Lakatos,1983
Coast Mountains	.10-.50	Parrish,1983
Rawdon Hills	.0088	

shown in Table 3.4 it can be deduced that these are from the track annealing zone, or in fact 170 Ma is the initial stages of the uplift in the Rawdon Hills.

Another assumption which can be made is that such an age resulted from the general uplift of an extensive area in central N.S. and not just the Rawdon Hills.

Giles, and Boehner, (1982) suggest that in the south of Rawdon Hills the Shubenacadie Basin is traversed by a series of high angle normal faults with generally NE-SW orientations. In the NW section of Shubenacadie Basin the Salem thrust dipping towards North (Fig, 3.10). Above this thrust fault the structure is complicated by presence of Canso Group and Green Oaks Formation (Windsor Group) in which Canso Group is trapped in the Green Oaks Formation. Clearly such a structure resembles a low angle decollement which is believed (Giles, and Boehner, 1982) to post date the high angle faults like Roulston Corner fault. The closest location that these lithologies could be transferred from is the higher elevations of Rawdon Hills. If this assumption be correct then during the deposition of Canso Group, Rawdon Hills block was still subsiding. In this case, the process of uplifting certainly did not start before 319 Ma (the age of Canso Group).

3.7. Confidence limit on the fission track method

EDM is so designed to eliminate the sampling problems in

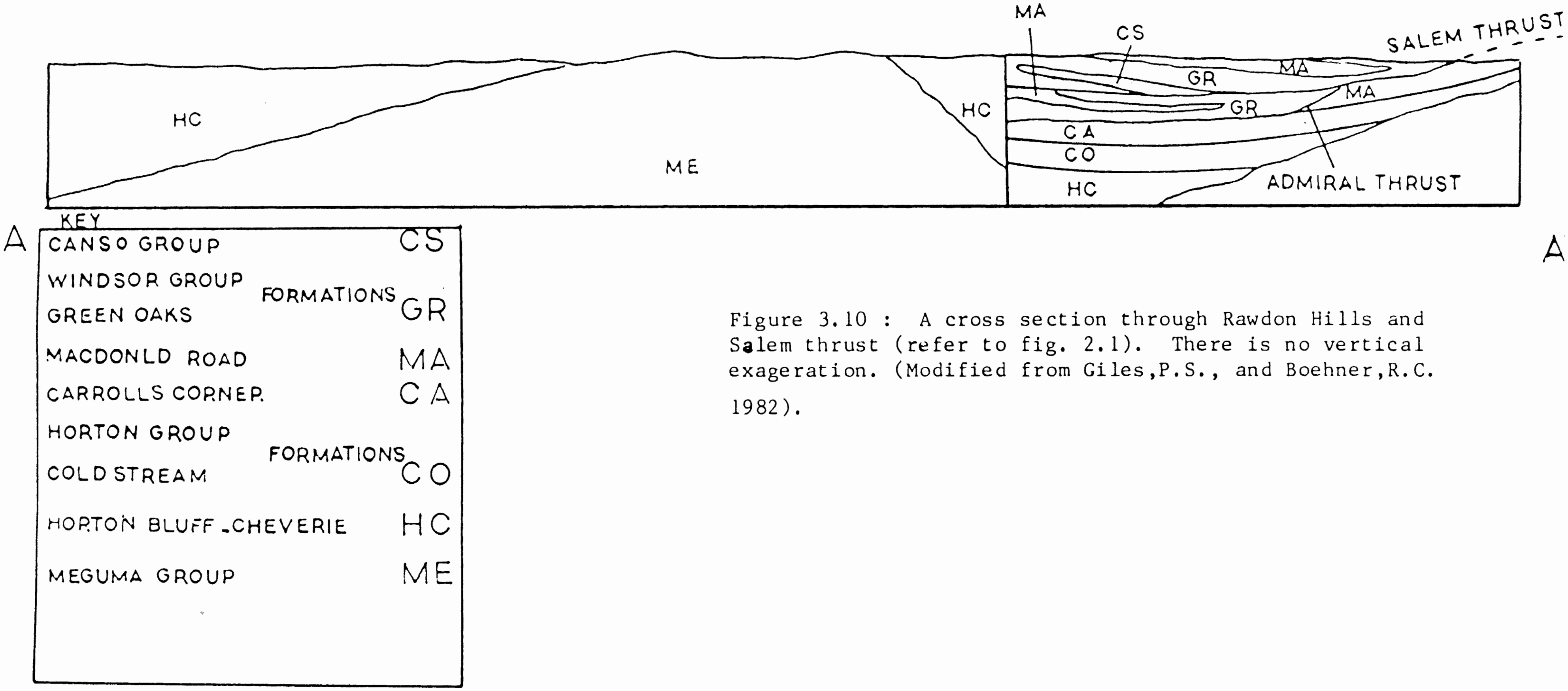

Figure 3.10 : A cross section through Rawdon Hills and Salem thrust (refer to fig. 2.1). There is no vertical exageration. (Modified from Giles,P.S., and Boehner,R.C. 1982).

fission track method. Since, both Nij,and Nsj will give roughly the same ratios. However, there are few difficulties associated with this method. Some of these problems are presented by Green(1981).

1- The presence of track-like defects: It is possible that defects in the mineral be mistaken as a track and be counted which results in over estimation of Pi and even Ps.

2-Varying degrees of contact between crystal and mica: This result in lower counts in induced tracks which lead to higher ratio of Ps/Pi.

3- High track densities: Abundance of Psj or Pij may yield incorrect counted values.

4- Wrong identification of Nij: In cases where few grains are mounted close to each other, the exact position of these tracks (Nij) may be mistaken which lead to count an area other than Nij.

5_ Vertical inhomogeneity of uranium: Induced tracks are counted in a mica exposed to fissions occurring below the sample surface, While in the case of fossil tracks originate from fissions occurring both above and below the sample surface. So it is assumed that the amount of uranium below and above the sample surface is uniform. In the case of counting small number of grains the idea of uranium uniformity may not be met.

6- Under-etching the grains: If the time duration of etching is not enough then lower values of Pi and/or Ps may be counted.

In the case of the standard and the unknown samples analysed by the author, each sample was counted twice to minimize the possibility of counting the defects in stead of the tracks.

In the case of the problem 3, samples had medium range of densities. The average of Ps was approximately 80 to 100 tracks in each grain.

The mounted grains were separated far enough from each other. So, the Pij for each grain did not overlap on each other.

Finally, the time duration of etching for each sample was sufficient enough to reveal the tracks.

3.8. Extensional Tectonism

The evaluated ages from FTD coinside with the middle and late Jurassic time. Royden and Keen (1980) suggest that Nova Scotia underwent extension during rifting in the early Jurassic and late Cretaceous, and has since subsided passively due to conductive cooling of the lithosphere. Their proposed mechanisms for the rifting stage include: extension and thinning, uplift and erosion, partial melting and thinning, magmatic intrusion, and other tectonic processes which alter the pre-rift fabric of the continent. These tectonic processes lead to collapse or uplift during rifting and also alter the thermal structure of the lithosphere. After the completion of rifting, conductive cooling of the lithosphere toward thermal equilibrium can best explain the subsequent subsidence and sedimentation of this margin.

Figure 3.11 illustrates the conceptual model of the tectonic episodes from initial crustal thinning and rifting to sea floor spreading (Manspeizer, 1980). In this figure episode IVb shows the collapsed continental margins, with the fragmented pieces of crust, producing local basins and uplifted areas. Rawdon Hills uplift, Schubenacadie and Musqodoboit basins could have been formed with such a processes.

3.9. Summary

Two drill cores in distance of two kilometres from each other (in the Figure 2.1) were used to date the possible tectonic uplift in the Rawdon Hills. From these two drill cores seventeen samples were chosen in an average of thirty metres intervals. To date the samples EDM of fission track technique was employed, which is a useful, practically convenient, and potentially precise method of geochronology compared to other methods.

Magnetic and heavy liquid separations were employed to separate the detrital apatite grains from rest of samples. Samples were mounted in epoxy and polished to 0.05 microns. Mounted grains were etched(7% HNO_3) and covered by mica

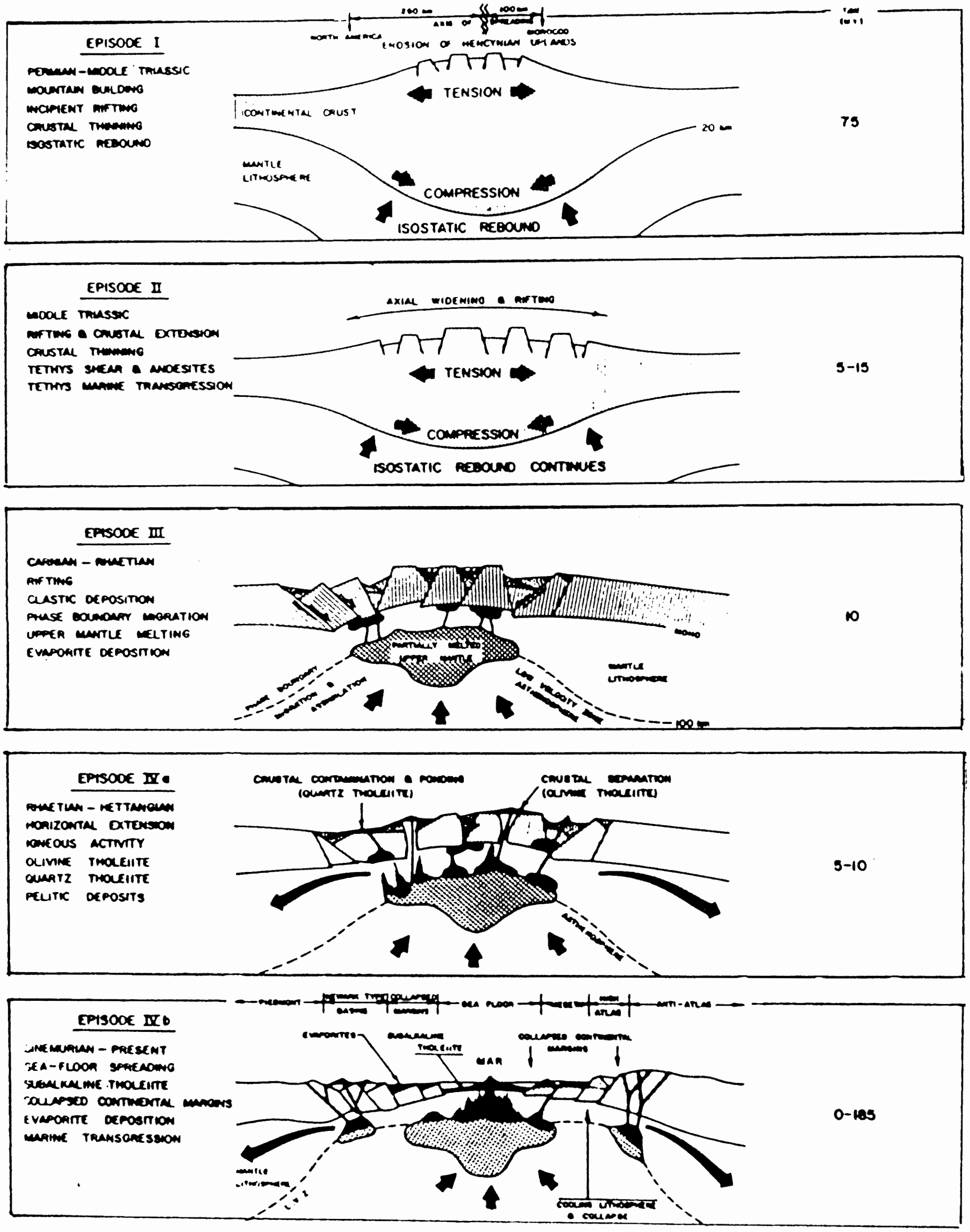

Fig. 3.11. Conceptual model illustrating tectonic episodes from initial crustal thinning and rifting to sea-floor spreading (Manspeizer and others, 1980).

detectors, after packing and irradiation in the MacMaster University reactor, they were counted, and used the age equation which has been explained in detail, the age of apatites were calculated. Finally, using models presented by A.J.Gleadow, I.R. Duddy, and J.F. Lovering, 1983, samples 6-7, 7-1, and 7-5 found out to be in track annealing zone, or atleast in later stages of the uplift. The rate rate of uplift is 0.0088 km/m.y.

Finally, using the stratigraphy of Rawdon Hills, Shubenacadie Basin and the presence of decollement structure above the Salem thrust, it was concluded that Rawdon Hills block was still subsiding during the deposition of Canso Group sediments (319 m.y.ago).

CHAPTER IV. VITRINITRE REFLECTANCE STUDY

4.1. Introduction

Vitrinite is one the three main groups of the coals macerals. It is the most abundant constituent of banded coals, and generally comprises more than 70% of the total maceral composition (Hacquebard, 1985).

Vitrinite reflectance (Ro) has been used as a rank parameter in this study. Basically, vitrinite reflectance increases progressively with increasing coalification and it can be used as a maximum reading thermometer.

4.2. Method

Nine samples were chosen for vitrinite reflectance analysis. These are listed in table 4.1 . Measurments were carried out by M. Avery in Bedford Institute of oceanography(Avery, 1986). The vitrinite reflectance measurements were done on lucite plastic mounts with coaly material, crushed to an average of 850 microns (20 mesh). Samples were polished and analysed immedietly to prevent oxidation of the polished surfaces. The magnification of 640x was employed with normal white incident light using a Zeiss photometer III system .The photometer was calibrated by using glass standards with a reflective index of 1.856. After placing the sample on the revolving microscope stage it is slowly rotated

TABLE (4.1) - VITRINITE REFLECTANCE VALUES.

SAMPLES	V.R. (S.D.) MEAN	NO OF READINGS	V.R. MAX	LOCATION ON THE FIG 2.1	COMMENTS
H.13	1.23(±.13)	63	1.31	BP-73-6	NO BANDING
H.14	1.10(±.12)	95	1.17	BP-73.6	VERY DISTINCTIVE BANDING
H.15	1.21(±.17)	79	1.28	BP-73-6	NO BANDING
H.16	1.25(±.19)	56	1.33	BP-73-6	NO BANDING
H.1	1.06(±.10)	40	1.12	A	SOME BANDING
H.10	.98(±.12)	61	1.04		DISTINCT BANDING
H.11	.91(±.08)	86	.96	DDH-1	MINOR BANDING
H.12	.87(±.09)	88	.92	DDH-1	NO BANDING
H.5	.98(±.10)	53	1.04	B	NO BANDING

through 360 degrees and the highest reading on the recorder is noted. This reading represents the maximum reflectance of the vitrinite under observation (Hacquebard, 1985) Table 4.1. The total number of readings were variable but on the average 50 reliable readings have been recorded. The mean maximum reflectance is calculated as the mathematical average, and is shown as percent reflectance, Table4.1. The standard deviation of the samples is approximately ± 0.1 of the Ro value.

4.3. Description

The results of reflectance readings for each sample is shown by Reflectogram in Appendix C. The position of each sample is spotted on Figure 4.1.

There are few factors which can affect the value of the vitrinite reflectance. The first of these factors is temperature. The increase in rank values in the drill core BP-73-6 (from 1.23 to 1.25 Ro) could be related to the rising of the temperature with the depth. Hacquebard (1985) suggest that correlation between Ro and depth of burial follows Hilts low, not in a linear , but in an asymptotic relationship. The rank increases, i.e. the rank gradient is dependent on the geothermal gradient and also on the heat conductivity of the rock. Time during which the heat is applied and the pressure are two other variables affecting the Ro values.

Coaly matter from the west section of the Rawdon Hills

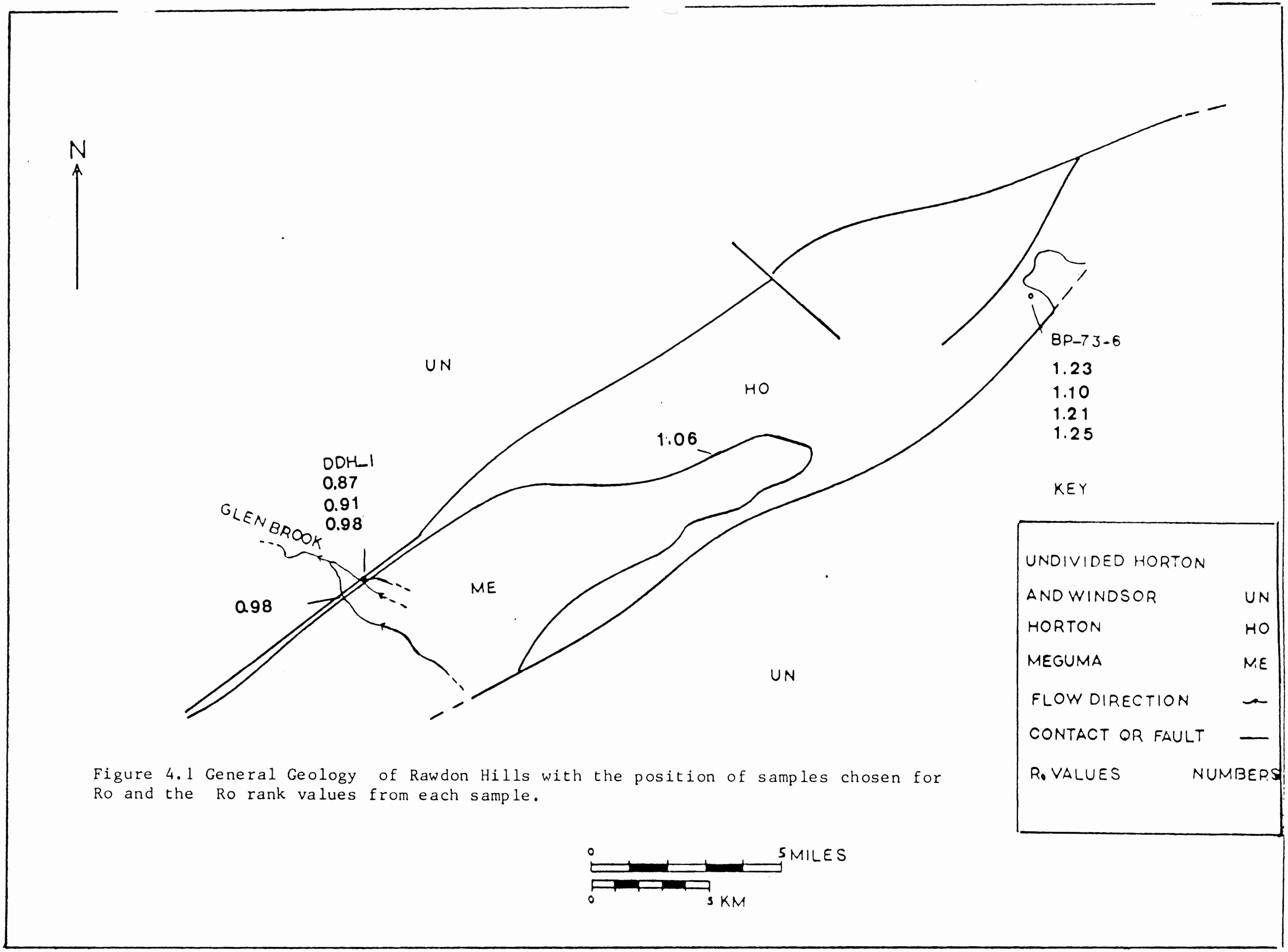

Figure 4.1 General Geology of Rawdon Hills with the position of samples chosen for Ro and the Ro rank values from each sample.

(MODIFIED FROM. PENSFORD, M. 1984)

(drill core DDH-1) has higher Ro values in the lower section of the core(0.98 Ro, sample H.10) relative to the upper section (0.87 Ro, sample H.12) with vertical difference of 40 metres. Due to the presence of numerous slikensides in this area and knowing that the earthquakes may occasionally cause a local rise of the rank, probably due to concentrated fractional heat (Kantsler, 1978). It is unlikely that such a variation in Ro is related to the temperature because these three samples are just 40 metres apart from each other.

Ro values for BP-73-6 show an overall increase with increasing depth. Samples H.13 and H.15, which do not have banding, have higher vitrinite reflectance values as compared to H.14. The reason for such a difference in the vitrinite reflectance value arises from the fact that the vitrinite reflectance measurements should be done on telinite (banded vitrinite) and not on collinite (groundmass vitrinite). In fact within the same coal these two constituents have a persistent difference in reflectance. In the case of samples H.13 and H.15 there is no telinite present. As a result of the vitrinite reflectance values in these samples are slightly higher as compared to H.14 and H.16.

The most important reason for such a difference is the variation in the depth. For example, the samples chosen from drill core BP-73-6 were from 144 to 250 metres depth, but samples from drill core DDH-1 were chosen from a depth of 7 to 90 metres.

In this case the Ro values in BP-73-6 should be expected to be higher than DDH-1.

4.4. Correlation of Vitrinite Reflectance With Depth of Burial

Figure 4.2, shows the composite coalification curve of Mesozoic and Carboniferous coal sequences in the Maritime region from Hacquebard 1985). Comparing the vitrinite reflectance results from Table 4.1 (with Ro values ranging from 0.87 to 1.25) the Maritime coalification curve (if one assumes this plot is correct) shows that an average depth of 4000 metres is necessary for coalification of coal in the Horton Group of the Rawdon Hills. However, the curve plotted in Fig 4.2, assumes a constant geothermal gradient, same time of coalification, and data are obtained from the offshore region of Maritimes.

Originally, Stevenson(1959) from stratigraphic evidence, estimated a maximum thickness of 914 metres for the Horton deposits in this area. If his estimate is accurate then an approximate overburden of 3000 metres of sediments has been eroded away from this region.

4.5. Correlation between Rank, Rock Temperature, and Duration of heating

Figure 4.3 from Hacquebard, (1985) has been used to evaluate possible rock temperature and time of coalification. This figure can be used to illustrate the correlation between coal rank, rock temperature, and duration of heating, where the

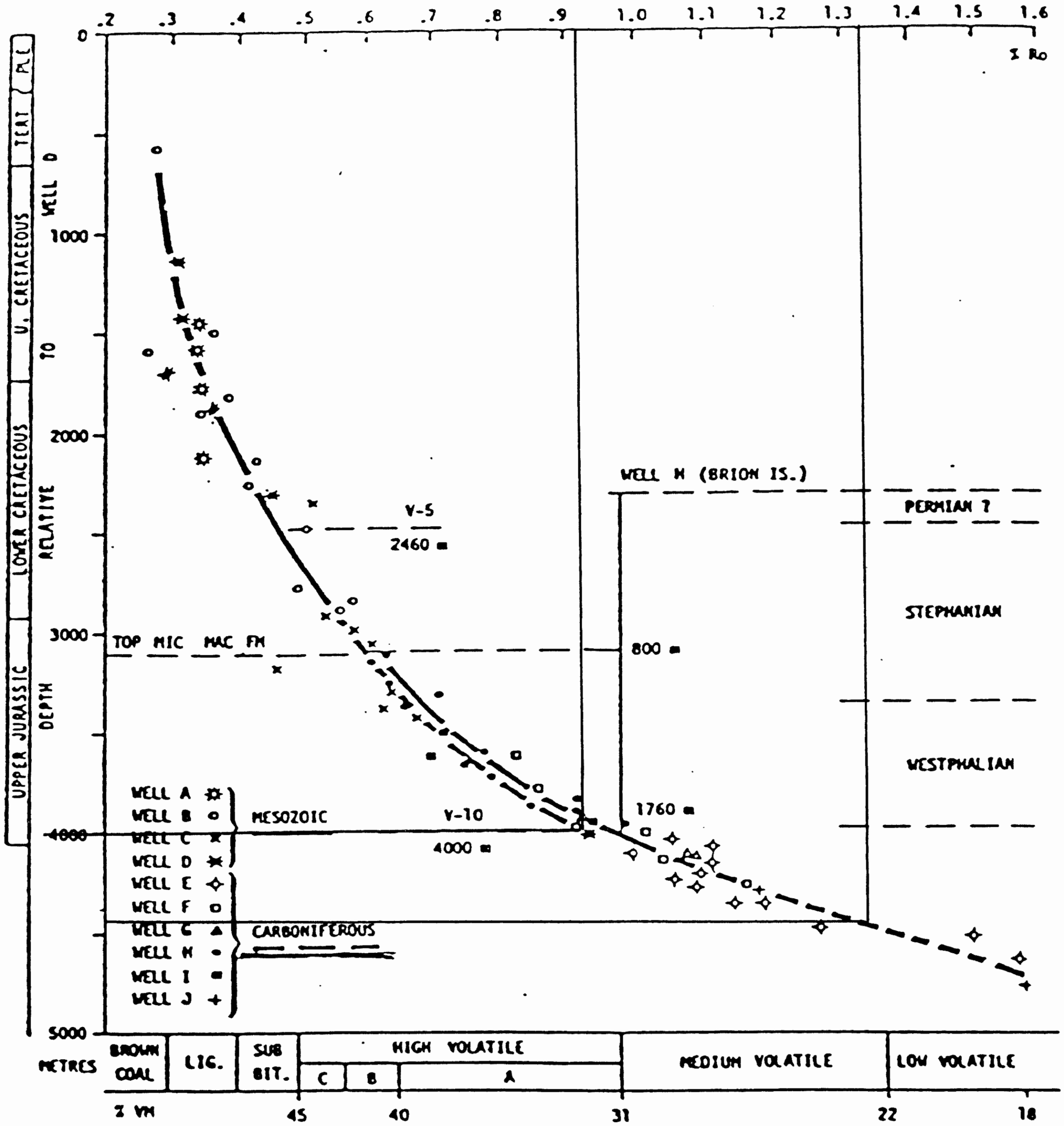

Figure 4.2: The composite coalification curve of Cenozoic and Carboniferous coal sequences in the Maritimes. (Hacquebard, 1985)

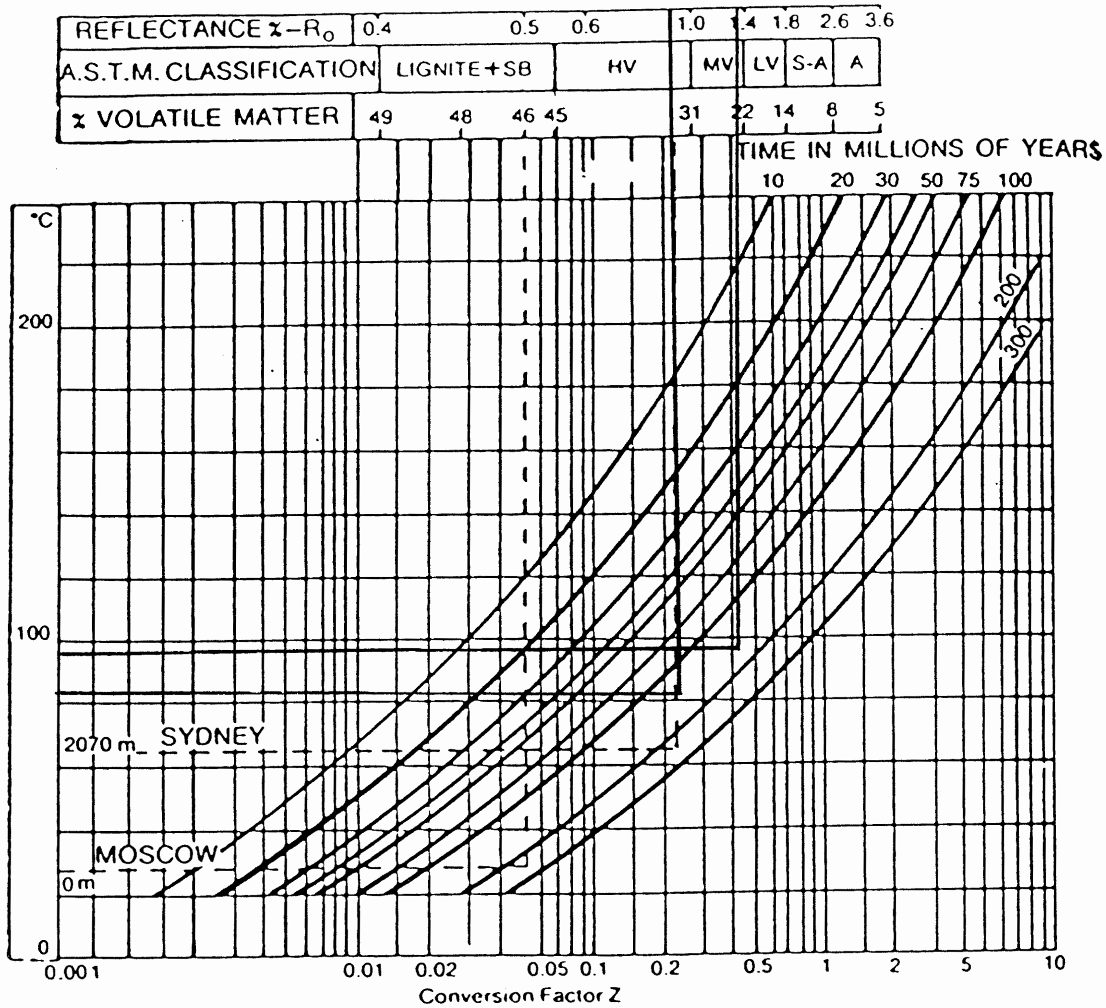

Figure 4.3. The Relationship between rank, temperature, and time of coalification (Hacquebard,P.A., 1970).

rank is plotted on the abscissa as a factor Z. The rock temperature is shown on the ordinate in de^{o}C and the duration of heating is shown by the successive curves in million of years. Using the results from the fission track studies in this thesis, and assuming that apatites were at the paleo-partial annealing zone at approximately 170 Ma.ago , the rock temperature at the time of coalification was in order of 90 to 100 ^{o}C. It should be concluded that such a temperature is the minimum temperature necessary for coalification. Coals could form by higher temperature at a shorter time period.

4.6. Summary

Nine samples were used to evaluate the Ro values for some carbonacous lamination in the different facies of Horton clastic rocks in the Rawdon Hills. The Ro is a suitable maximum reading geothermometer, which is able to detect the maximum burial temperature occurred in an area.

The higher Ro values of drill core Bp-73-6 are the result of deeper peneteration of this core compared to DDH-1. Other factors related to such a difference could be due to the local faulting in the area, pressure gradient, or the time during the heat applied. The evaluated rank values in this study were compared to the Maritime Coalification curve (from Hacquebard, 1985), and to the coal rank, rock temperature, and duration of heating in the Maritimes.

CHAPTER V. CONCLUSION

5.1. Conclusion

From the surveying and the three drill cores employed in this presentation, it is apparent that the Horton Clastic rocks in Rawdon Hills are continental deposits, fluvial in origin, and relatively undisturbed from metamorphic processes(Refer to the section on optical petrology and structures in chapter two).

Using fission track technique, from two drill cores in the eastern section of the Rawdon Hills, three ages from apatite grains were evaluated. The mean of samples 7-1 and 7-5 is 186.51 ± 17.91 ma at 90.5 metres and the sample 6-7 with an age of 153.75 ± 14.09 ma at 380 metres.

Vitrinite reflectance was used for further investigation of the thermal history of the Rawdon Hills. In chapter IV from Figure 4.2, the depth of burial was estimated to be approximately 4000 metres. The value of 4000 metres is the maximum possible depth of burial estimated for this area. Since, the subsidence history of the Nova Scotia indicates that this region underwent extension during rifting in the Jurassic and Cretaceous, the Geothermal gradient would be higher than the present values in the offshore regions. From Figure 4.3 a minimum temperature of 90 °C necessary for coalification was estimated for the Rawdon Hills.

As it was mentioned in chapter III, there has not been any uplift prior to 319 m.y. ago(upper boundary of Canso group). Also, from the slope taken from the apatite samples, they were identified to be from the partial annealing zone, Fig3.9. If these assumptions are correct then the uplift occurred sometime before 153 m.y.ago.

Another assumption which can be deduced from these ages is the upward movement in part of Nova Scotia due to active rifting processes during the Jurassic and Cretaceous time. In fact, the procsses of rifting could have affected a much larger area than just the Rawdon Hills. So, the ages recovered from this area could have been from such a large scale tectonic activities.

The ages recovered from the fission track method are from middle and upper Jurassic, which coincide with the continental rifting of Jurassic time. There are many sedimentary basins formed along the Atlantic continental margin during the tectonic activities initiated in Jurassic and Cretaceous time (Bally, 1981) . During such processes, continents began to rift apart and such a rifting were accompanied by a swelling of the mantle underneath and the resulting elevation extends to a distance of several hundred kilometers on each side (Keen, 1979).

The Atlantic passive margin is formed in two stages (1) Continental breakup and (2) Drifting. The breakup occurred within a plate interior by wrench tectonics and transform faulting associated with a thinned continental type transitional crust that now lies adjacent to the continental and oceanic crusts. Subsided areas formed basins like Shubenacadie and Musqodoboit basins and some places uplifted. The uplift in Rawdon Hills probably happened by such a process during Jurassic or Cretaceous time.

5.2. Recommendations

Fission track dating is a useful method to identify the paleothermal anomalies. This technique can be used more extensively in the Rawdon Hills to answer many questions related to tectonic activity in this region. Particularly, this technique may be used in the surveyed area in Glen Brook. By taking samples from different facies mentioned in chapter II, different strata can be dated. Eventhough Glen Brook Horton sediments are more tilted than the same sediments in eastern parts of Rawdon Hills, but due to presence of a complete section of Horton sediments , a great deal of information can be extracted by using such a dating method.

Apatite is a suitable indicator of the cooling history of a rock because it retains fission track only at temperatures that are significantly less than the blocking temperatures for Rb-Sr or K-Ar geochronometers. It is advisable that another mineral like sphene or zircon be used during the process of fission track dating to give the paleogeothermal gradient of Rawdon Hills. Sphene and zircon have higher thermal closure themperatures.

Fission track dating should be applied to some other deposits in the vicinity of Rawdon Hills to compare the ages calculated from these sediments with others and if the ages are similar it may be concluded that these ages are related to a general upward movement of central Nova Scotia during the Jurassic and Cretaceous Atlantic rifting processes.

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APPENDIX (A)

TABLE (Aa): Samples chosen in approximately 30 meters intervals from drill core BP-73-6.

SAMPLES (meters)	DESCRIPTION
18	Fine Sandstone, with some muscovite and biotite flackes.
46	Green fine grain Sandstone
81	Very fine Siltstone, reddish to greenish colour, with fine shaly laminations
109	Fine Siltstone, some pinkish mineralization along the fractures(calcite or dolomite). Dark grey shaly laminations
144	Greyish green fine Sandstone
160	Fine Sandstone with black shaly laminations
186 (6-7)	Fine Sandstone with black shaly laminations
200	Sandstone with black shaly laminations and muscovite flackes. Some coaly banding.
218	Greyish Sandstone with some shaly laminations. Some pinkish color mineralization along the fractures(probably calcite or dolomite).Whith mica present.
243	Fine greish Sandstone. Small scale cross bedding

TABLE (Ab): Samples chosen in approximately 30 meters intervals from drill core BP-73-7.

SAMPLES (meters)	DESCRIPTION
34 (7-1)	Fine Sandstone, poorly cemented. 10% muscovite.
59	Reddish Sandstone, calcite present
93	Very coarse Sandstone
125	Very fine Sandstone, greish color
147 (7-5)	Fine grain grenish color Sandstone
176	Fine grain greenish color. 10% muscovite
198	Fine grain greyish color Sandstone

APPENDIX (B): SYMBOLISM.

Symbol	Meaning	
Ns	# of spontaneous tracks	
Ni	# of induced tracks	
NsJ	# of spontaneous tracks in the area J	
NiJ	# of induced tracks in the area J	
PsJ	Density of spontaneous tracks in the area J	
PiJ	Density of induced tracks in the area J	
Pd= P_D	Density of the tracks in the glass dosimeter	(Green,P.1982)
λ_d	Total decay constant of ^{238}U, 1.55125×10^{-10} 1/yr	(Green,P.1982)
λ_f	Spontaneous fission decay constant of ^{238}U	(Green,P.1982)
σ	Thermal neutron fission cross section for ^{238}U $580.2\times10^{-24}\,cm^2$	(Green,P.1982)
ϕ	Thermal neutron fluence	(Green,P.1982)
g	Geometry factor for the induced counts, 0.5 for EDM	(Price,etal.1967)
Ps/Pi	Spontaneous/induced track ratio in the sample	(Green,P.1982)
I	Isotopic ratio $^{235}U/^{238}U$ in sample 7.2527×10^{-3}	(Green,P.1982)
σ(Ps)	Errors in Ps	(Green,P.1982)
σ(Pi)	Errors in Pi	(Green,P.1982)
A	Age of unknown	
A std	Age of standard	
X	Chi square	
Z	Zeta (equation 6)	

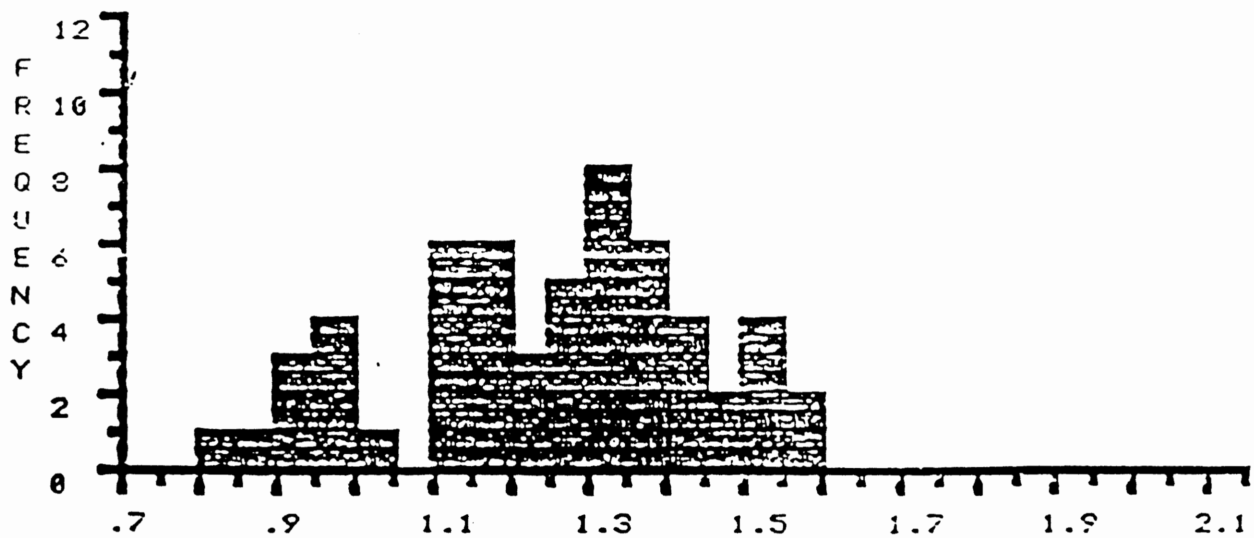
Appendix C: R_o Reflectograms, number of counts and the mean value of R_o counting with standard deviation.

H.16

COL>	0	1	2	3	4	5	6	7	8	9
ROW		.84	.89	.92	.94	.94	.95	.95	.97	.99
1	1	1.1	1.12	1.13	1.13	1.14	1.14	1.15	1.17	1.17
2	1.17	1.18	1.19	1.2	1.23	1.24	1.26	1.26	1.27	1.27
3	1.28	1.3	1.3	1.31	1.31	1.31	1.32	1.33	1.34	1.37
4	1.38	1.38	1.39	1.39	1.39	1.4	1.41	1.42	1.44	1.45
5	1.45	1.51	1.51	1.52	1.54	1.56	1.57			

	SUM	NUMBER	MIN	MAX	MEAN	STAND.DEV.
TOTAL >	69.79	56	.84	1.57	1.25	.19

% REFLECTANCE

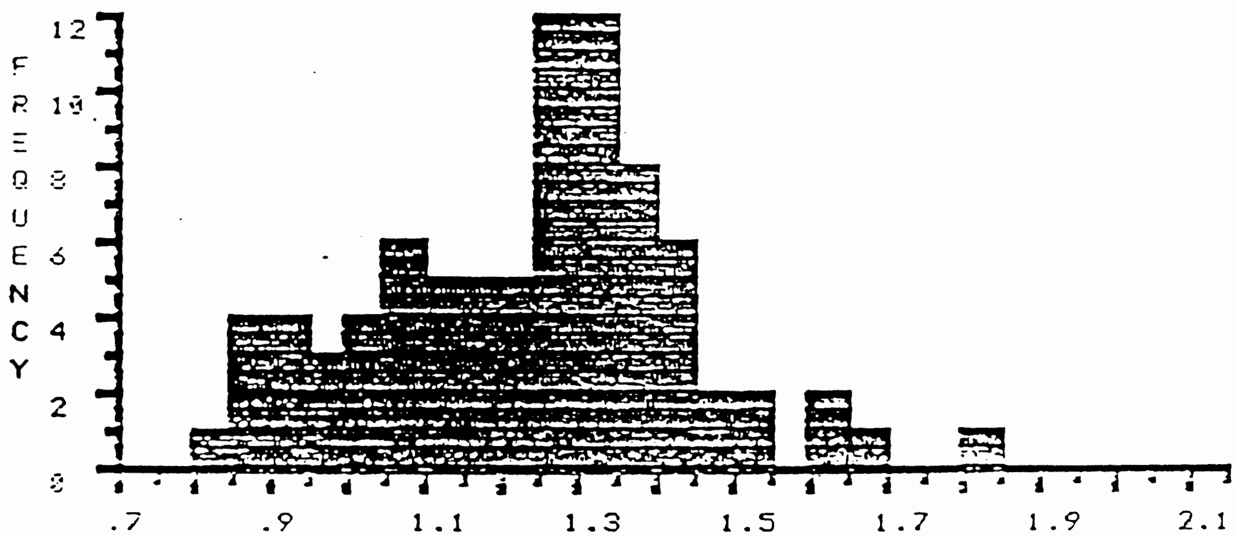


H.15

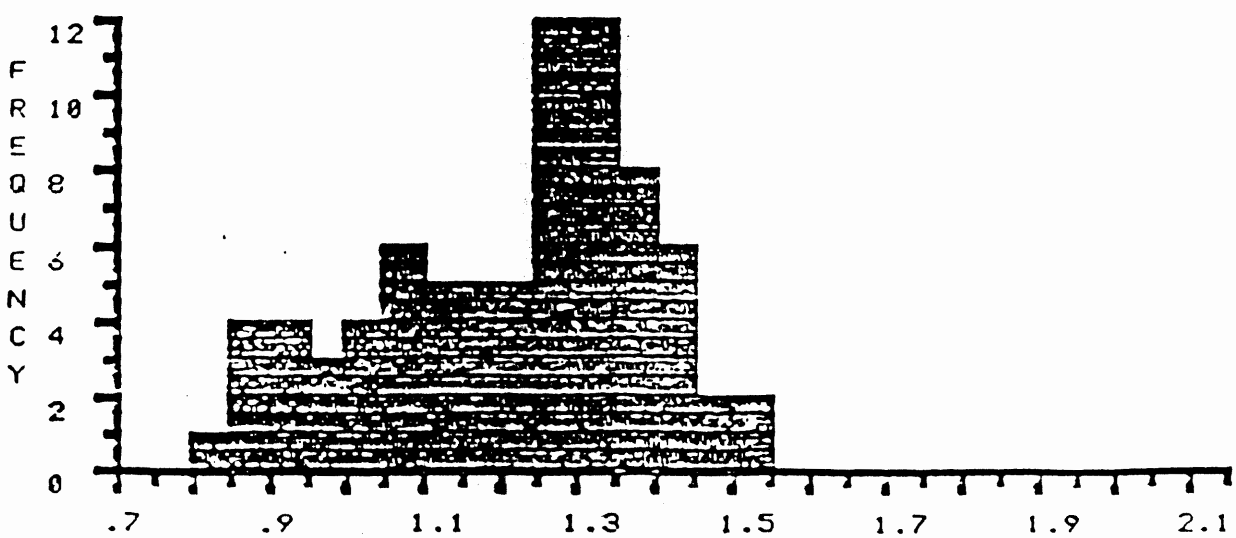
COL>	0	1	2	3	4	5	6	7	8	9
ROW		*.81	*.85	*.87	*.89	*.89	*.93	*.93	*.94	*.94
1	*.95	*.98	*.98	*1.02	*1.02	*1.03	*1.04	*1.05	*1.07	*1.08
2	*1.08	*1.08	*1.08	*1.11	*1.12	*1.13	*1.14	*1.14	*1.15	*1.16
3	*1.17	*1.17	*1.18	*1.21	*1.21	*1.21	*1.21	*1.24	*1.25	*1.25
4	*1.25	*1.27	*1.27	*1.27	*1.27	*1.27	*1.27	*1.28	*1.28	*1.29
5	*1.3	*1.3	*1.3	*1.31	*1.31	*1.31	*1.32	*1.33	*1.34	*1.34
6	*1.34	*1.34	*1.35	*1.35	*1.35	*1.36	*1.37	*1.37	*1.39	*1.39
7	*1.4	*1.41	*1.41	*1.42	*1.43	*1.44	*1.48	*1.48	*1.51	*1.54
8	1.6	1.63	1.69	1.82						

	SUM	NUMBER	MIN	MAX	MEAN	STAND.DEV.
TOTAL >	102.31	83	.81	1.82	1.23	.2
*EDIT >	95.57	79	.81	1.54	1.21	.17

% REFLECTANCE



% REFLECTANCE * * EDITED * *

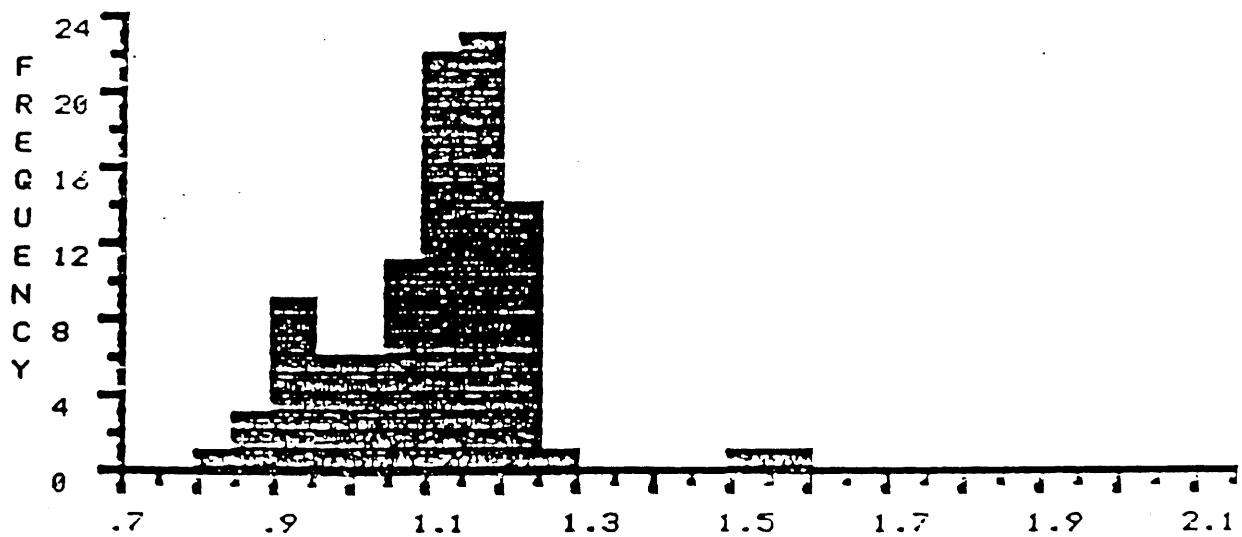


H.14

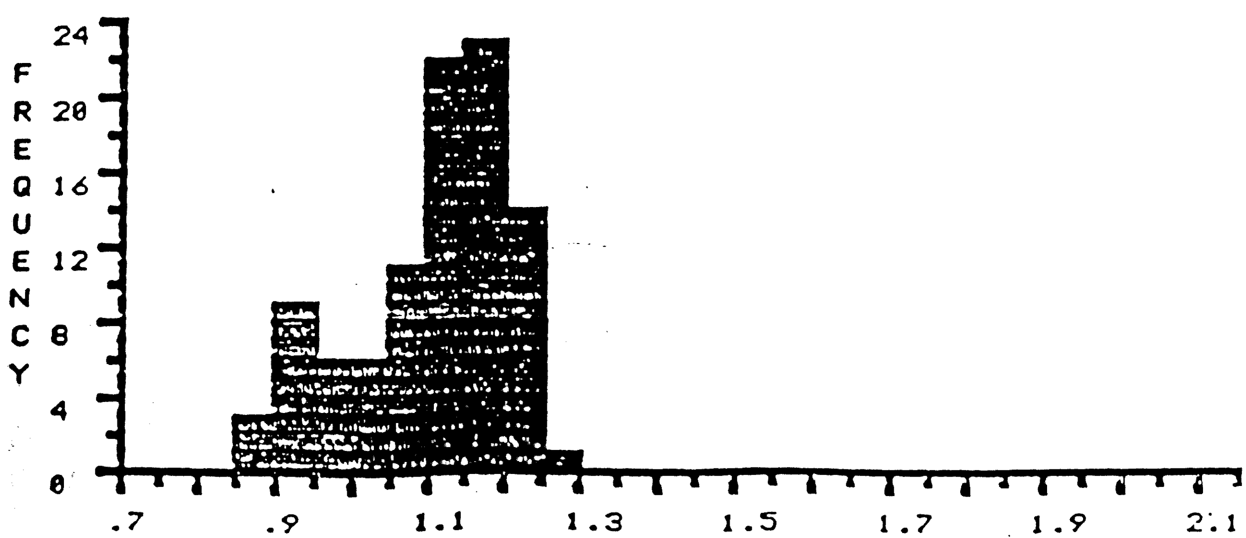
COL>	0	1	2	3	4	5	6	7	8	9
ROW		.81	*.87	*.88	*.89	*.9	*.9	*.9	*.9	*.91
1	*.91	*.93	*.93	*.94	*.96	*.97	*.97	*.97	*.98	*.98
2	*1	*1.02	*1.02	*1.03	*1.04	*1.04	*1.05	*1.05	*1.05	*1.06
3	*1.06	*1.06	*1.07	*1.07	*1.08	*1.08	*1.09	*1.1	*1.1	*1.1
4	*1.1	*1.1	*1.11	*1.11	*1.11	*1.12	*1.12	*1.12	*1.12	*1.13
5	*1.13	*1.13	*1.13	*1.14	*1.14	*1.14	*1.14	*1.14	*1.14	*1.15
6	*1.15	*1.15	*1.15	*1.15	*1.15	*1.16	*1.16	*1.16	*1.16	*1.16
7	*1.17	*1.17	*1.17	*1.17	*1.17	*1.18	*1.18	*1.18	*1.18	*1.18
8	*1.18	*1.19	*1.2	*1.2	*1.2	*1.2	*1.2	*1.2	*1.2	*1.2
9	*1.2	*1.21	*1.22	*1.22	*1.24	*1.24	*1.28	1.52	1.55	

	SUM	NUMBER	MIN	MAX	MEAN	STAND.DEV.
TOTAL >	108.14	98	.81	1.55	1.1	.12
*EDIT >	104.26	95	.87	1.28	1.1	.1

% REFLECTANCE



% REFLECTANCE * * EDITED * *

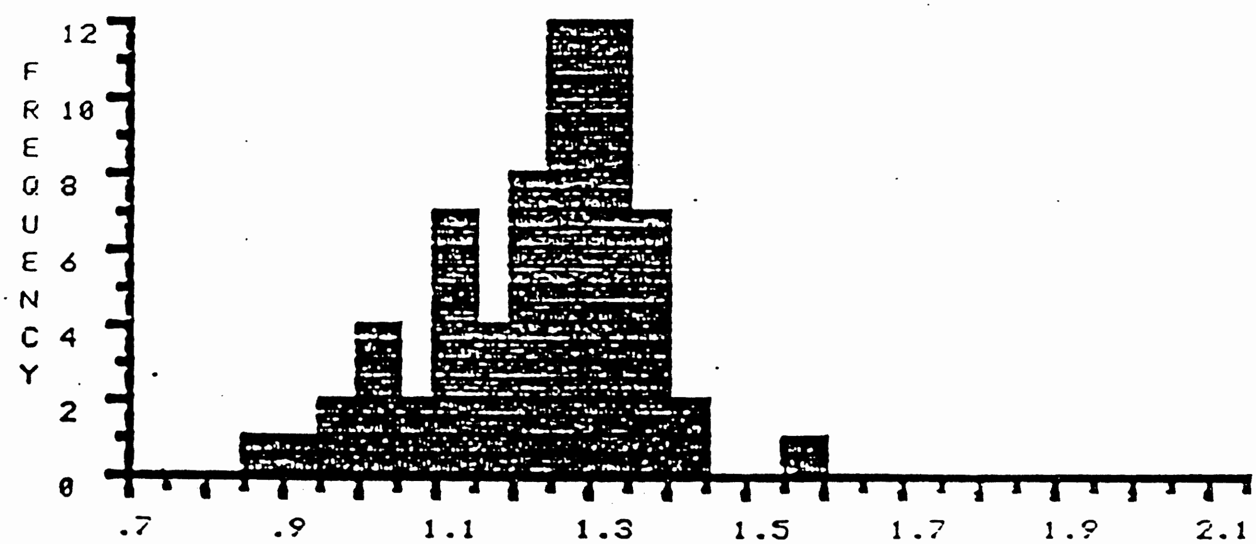


H.13

COL>	0	1	2	3	4	5	6	7	8	9
ROW		.85	.92	.97	.97	1	1.01	1.03	1.03	1.09
1	1.09	1.11	1.11	1.11	1.11	1.13	1.13	1.14	1.15	1.16
2	1.16	1.17	1.2	1.21	1.21	1.21	1.23	1.23	1.24	1.24
3	1.25	1.26	1.26	1.26	1.26	1.26	1.27	1.28	1.28	1.28
4	1.28	1.28	1.3	1.3	1.3	1.31	1.31	1.31	1.32	1.32
5	1.32	1.33	1.34	1.34	1.35	1.35	1.36	1.36	1.37	1.37
6	1.39	1.41	1.43	1.55						

	SUM	NUMBER	MIN	MAX	MEAN	STAND.DEV.
TOTAL >	77.17	63	.85	1.55	1.23	.13

% REFLECTANCE

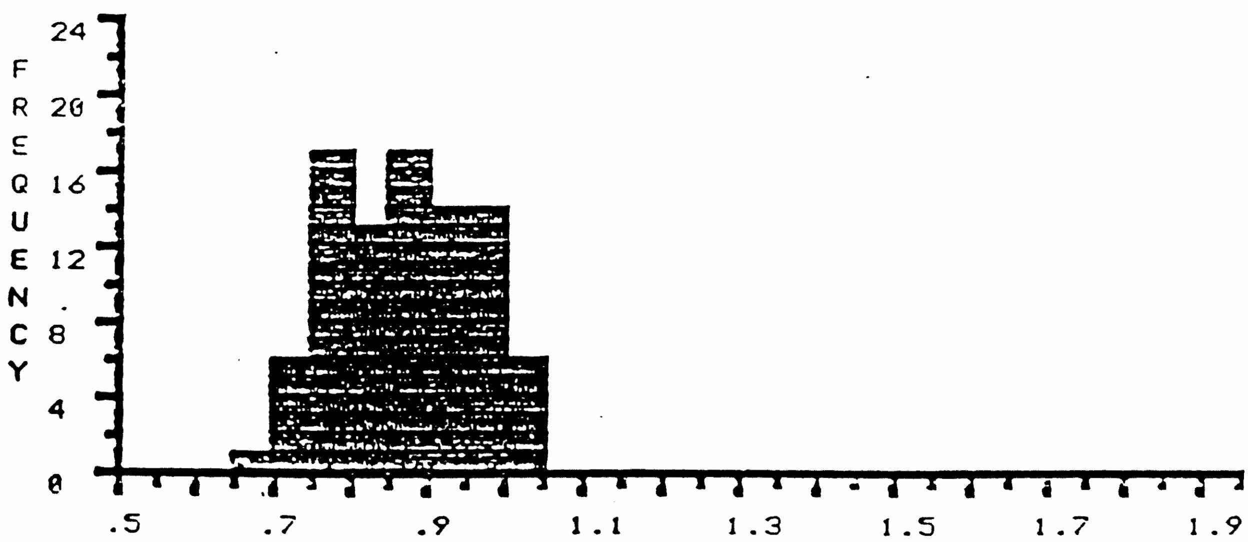


H.12

COL>	0	1	2	3	4	5	6	7	8	9
ROW		.66	.7	.7	.7	.73	.74	.74	.75	.75
1	.75	.76	.77	.77	.77	.77	.78	.78	.78	.79
2	.79	.79	.79	.79	.79	.8	.8	.8	.81	.81
3	.83	.83	.83	.83	.84	.84	.84	.84	.85	.85
4	3	.86	.86	.86	.87	.87	.87	.88	.88	.88
5	.88	.89	.89	.89	.89	.9	.9	.9	.91	.91
6	.92	.93	.93	.93	.93	.93	.93	.93	.94	.95
7	.95	.95	.95	.96	.97	.97	.97	.97	.98	.98
8	.98	.98	.99	1	1	1.01	1.01	1.01	1.03	

	SUM	NUMBER	MIN	MAX	MEAN	STAND.DEV.
TOTAL >	76.14	88	.66	1.03	.87	.09

% R E F L E C T A N C E

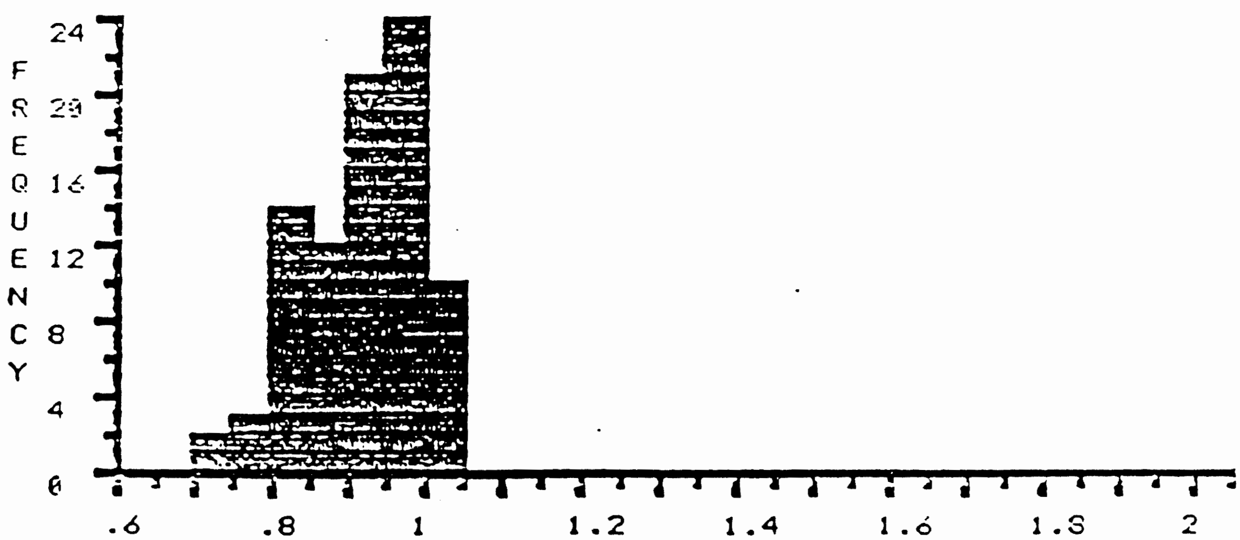


H.11

COL>	0	1	2	3	4	5	6	7	8	9
ROW		.7	.74	.75	.78	.79	.8	.8	.8	.8
1	.81	.81	.81	.81	.83	.83	.84	.84	.84	.84
2	.85	.85	.85	.85	.85	.85	.86	.86	.86	.87
3	.88	.88	.9	.9	.9	.91	.91	.91	.91	.92
4	.92	.92	.93	.93	.93	.93	.93	.93	.94	.94
5	.94	.94	.94	.95	.95	.95	.95	.95	.96	.96
6	.96	.97	.97	.97	.97	.97	.98	.98	.98	.98
7	.98	.98	.99	.99	.99	.99	.99	1	1	1.01
8	1.01	1.02	1.02	1.02	1.03	1.03	1.04			

	SUM	NUMBER	MIN	MAX	MEAN	STAND.DEV.
TOTAL >	78.4	86	.7	1.04	.91	.08

% REFLECTANCE

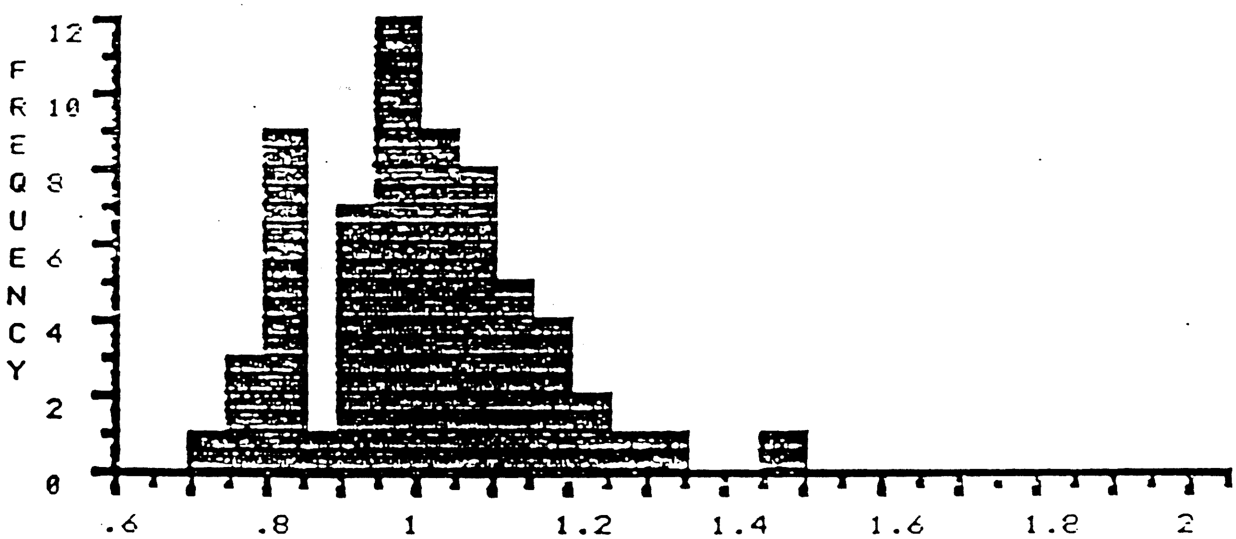


H.10

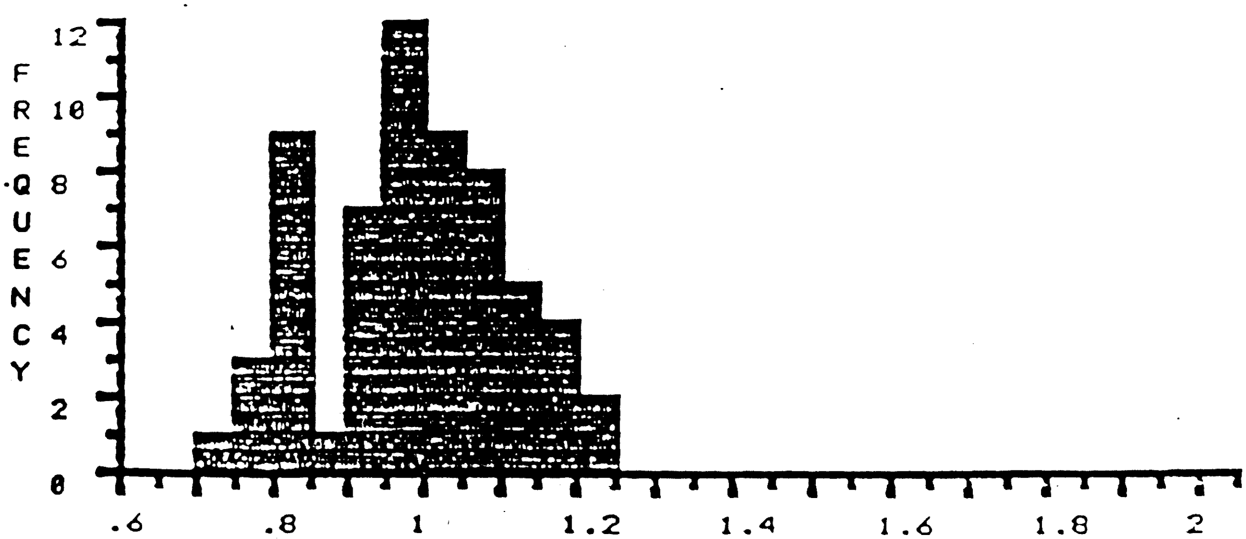
COL >	0	1	2	3	4	5	6	7	8	9
ROW		*.71	*.75	*.76	*.76	*.8	*.8	*.82	*.82	*.82
1	*.83	*.84	*.84	*.84	*.88	*.91	*.91	*.92	*.93	*.93
2	*.93	*.94	*.95	*.95	*.95	*.95	*.96	*.96	*.96	*.97
3	*.97	*.98	*.98	*.99	*1	*1.01	*1.01	*1.02	*1.03	*1.03
4	*1.03	*1.03	*1.04	*1.06	*1.06	*1.07	*1.07	*1.08	*1.08	*1.09
5	*1.09	*1.11	*1.11	*1.11	*1.13	*1.14	*1.15	*1.16	*1.18	*1.18
6	*1.2	*1.21	1.29	1.3	1.45					

	SUM	NUMBER	MIN	MAX	MEAN	STAND.DEV.
TOTAL >	63.83	64	.71	1.45	1	.14
*EDIT >	59.79	61	.71	1.21	.98	.12

% REFLECTANCE



% REFLECTANCE * * EDITED * *

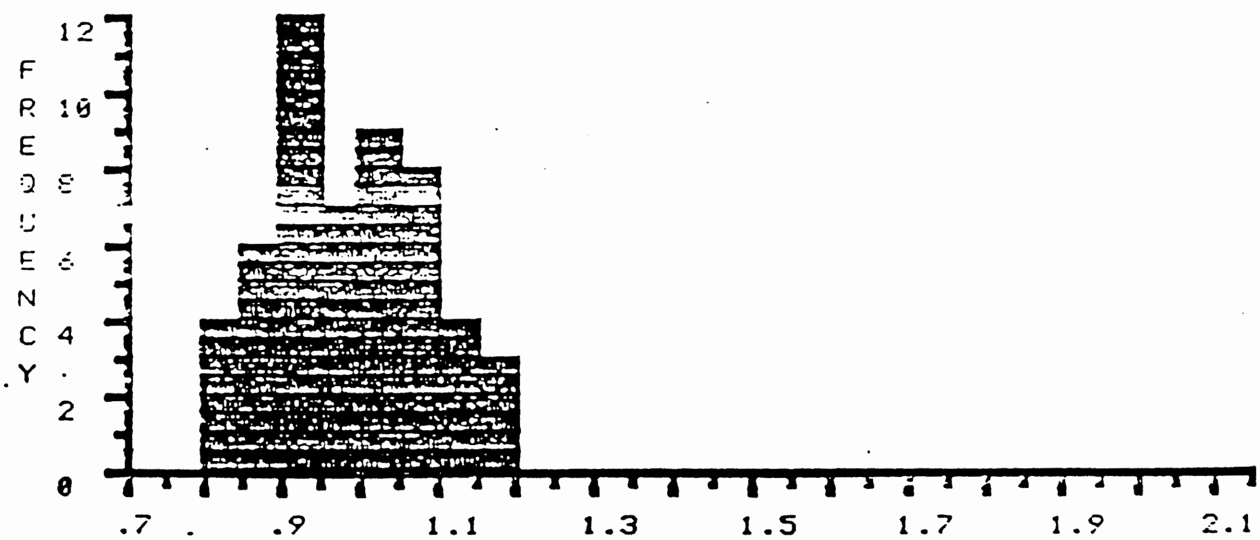


H.5

COL>	0	1	2	3	4	5	6	7	8	9
ROW		.8	.81	.82	.83	.86	.87	.88	.88	.89
1	.89	.9	.91	.91	.92	.93	.93	.93	.93	.93
2	.93	.94	.94	.95	.95	.98	.99	.99	.99	.99
3	1	1	1.01	1.02	1.02	1.02	1.02	1.02	1.04	1.05
4	1.05	1.05	1.05	1.06	1.07	1.08	1.09	1.1	1.13	1.13
5	1.13	1.16	1.17	1.19						

	SUM	NUMBER	MIN	MAX	MEAN	STAND.DEV.
TOTAL >	52.13	53	.8	1.19	.98	.1

% REFLECTANCE

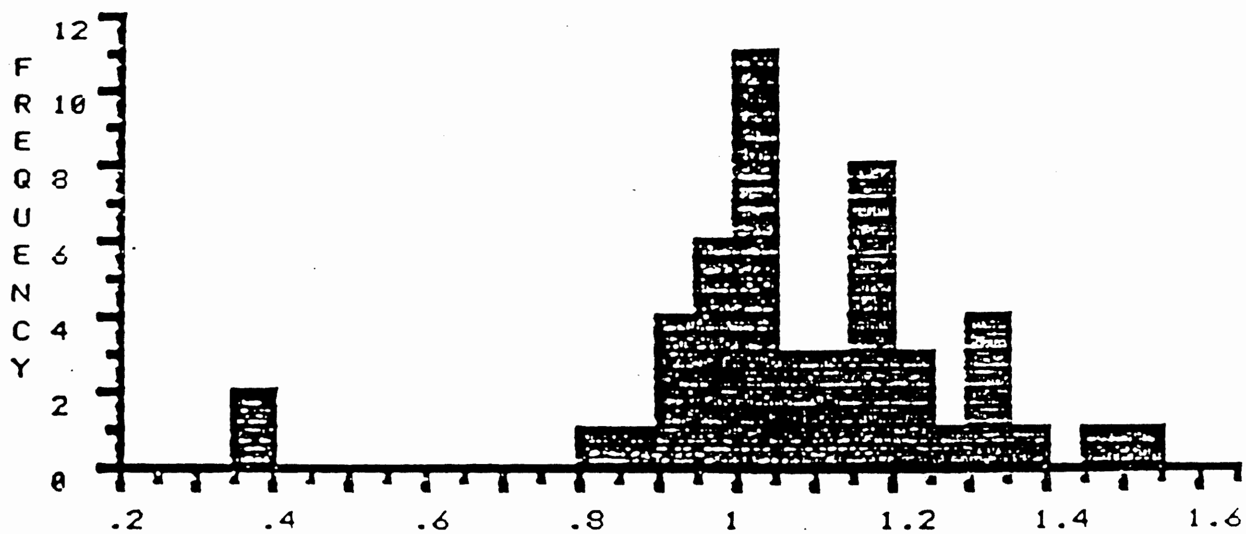


H.I

COL>	0	1	2	3	4	5	6	7	8	9
ROW		.35	.37	.8	*.89	*.9	*.9	*.93	*.93	*.95
1	*.95	*.96	*.98	*.98	*.99	*1	*1	*1	*1	*1.01
2	*1.02	*1.02	*1.03	*1.03	*1.03	*1.04	*1.05	*1.06	*1.09	*1.13
3	*1.13	*1.14	*1.15	*1.16	*1.16	*1.18	*1.18	*1.19	*1.19	*1.19
4	*1.21	*1.21	*1.22	*1.25	1.3	1.31	1.32	1.33	1.39	1.45
5	1.51									

	SUM	NUMBER	MIN	MAX	MEAN	STAND.DEV.
TOTAL >	53.56	50	.35	1.51	1.07	.21
*EDIT >	42.43	40	.89	1.25	1.06	.1

% REFLECTANCE



% REFLECTANCE * * EDITED * *

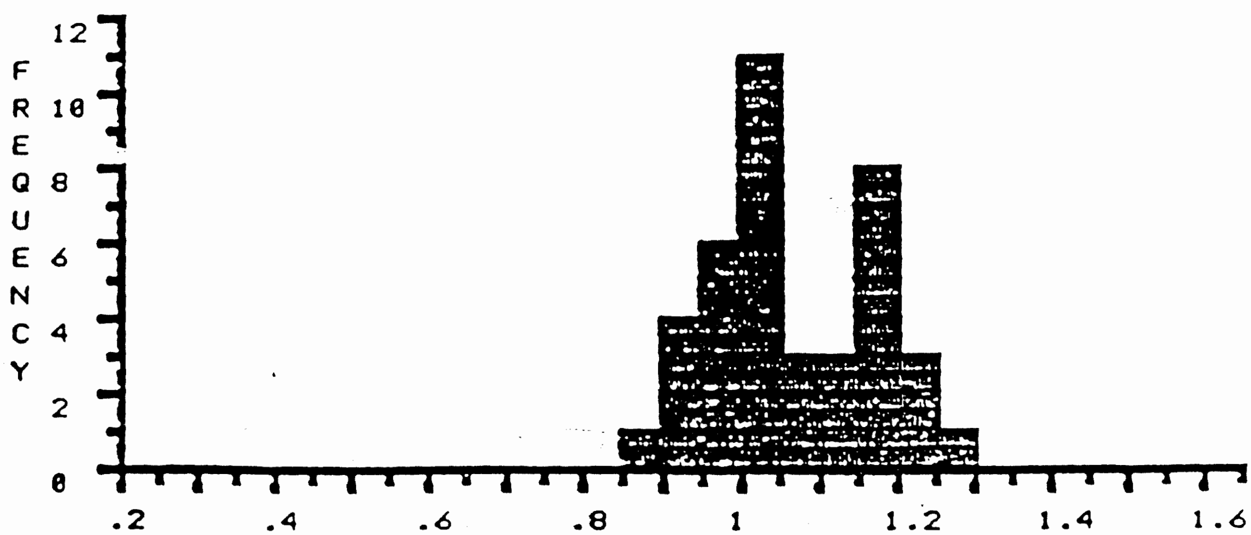
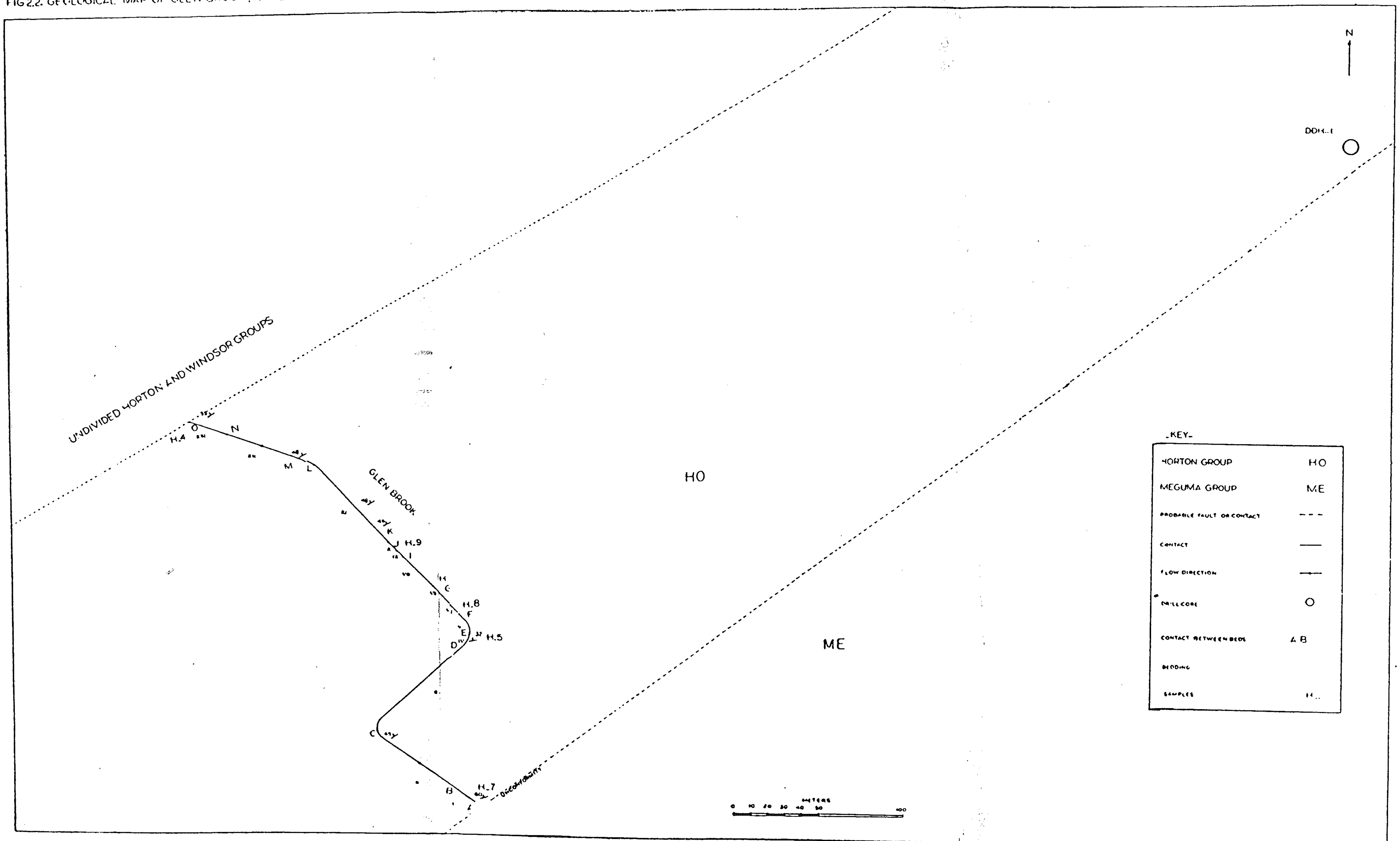


FIG 2.2. GEOLOGICAL MAP OF GLEN BROOK, RAWDON HILLS NOVA SCOTIA



APPENDIX (D)

Follwing are the sample descriptions from vareous outcrops described in this presentation from Rawdon Hills, (refering to fig 2.1).

SAMPLES		3 miles north west of Mcphee corner Location (A) on the figure (2.1).
H-1	Sample is 12 cm. long, 6 cm. wide, 6 cm. thick. Composed of greish siltstone with greyish shaly laminations. Sandstone mainly composed of quartz feldspar, and abundance of plant fragments. One type of this floras identified as Lepidodendron cf. Corrugatum fragments. This sample is being analysed for Ro.	
H-6	Sample is 21cm. long, 14 cm. wide, 1.5 cm. thick. Fine grey sandstone with organic fragments. The most caracteristic point in this sample is presence of the plane view of trough cross bed(Rib and Furrow structure, each 7 cm. wide, and 1.5 cm. long.	
		One mile west of Bar Settelment and 500 metersSSE Location (D) on the figure (2.1).
H-2	Sample is 4 cm.long, 8 cm. wide, 1cm. thick. Very fine grain dark grey sandstone with 5% muscovite 30% organic matter, and fine fragments of plant fossils.	
H-3	Sample is 15 cm. long, 9 cm. wide, 4 cm. thick. Medium grain sandstone with black shaly laminations. Plant fossil fragments are slighly larger than sample H-2 (around 0.5 cm).	
		2 miles south west of Gore (Glen Brook). Location (B) on thefigure (2.1).
H-4	Sample is 24cm. long, 7 cm. wide, 3 cm. thick. Conglomerate is matrix supported close to 40% feldspar clasts and in the matrix ,30% quartz some of the larger clasts 5 cm in diameter are extremely weathered slates, granites, quartz and feldespars. this sample is from facies XIII.	
H-5	Sample is 17 cm. long, 12 cm. wide, 2.5 cm. Thick. Coarse grey sandstone, with some shaly laminations and pyrite nodules as large as 3 cm long in the shaly layers. abundance of organic matter. this sample is from facies IV and it is analysed for v	

vitrinite reflectance.

H-7 Samples are from conglomerate clasts,which are mostly either white quartz or slates. Samples are rounded and smooth. This sample is from facies I

H-8 Sample is 7 cm. long, 5 cm. wide, and 5 cm. thick. It is composed of granule size conglomerate with more than 50% quartz, one visible quartz nodule (1.5 cm in diameter). Some organic matter. This sample is from facies VI.

H-9 Sample is 4 cm. long, 3 cm. wide, 1 cm.thick. It is composed of reddish coarse grain sandstone with quartz, feldspar, and 10% muscovite. Sample is from facies IX.

Drill core DDH-1 (west of Gore).

H-10 Sample is 6 cm. long, 4 cm. wide, 2 cm. thick. Greyish siltstone with shaly laminations which contain organic material, and muscovite. Sample is analysed for vitrinite reflectance.

H-11 Composed of greyish siltstone with brocken fragments ofplant fossils. Sample is being analysed for Ro.

H-12 Siltstone bed with coaly laminations, some pyrite nodules present. Sample is analysed for Ro rank value.

Drill coreBP-73-6 (N.E. of Rawdon Hills).

H-13 Sample is taken from the depth of 144 meters. Siltstone with fine carbonaceous laminations. It is being analysed for Ro value.

H-14 Sample is taken from the depth of 186 meters. Fine sandstone with carbonaceous laminations. It is being analysed for Ro value.

H-15 Sample is taken from the depth of 243 meters. Fine sandstone with carbonaceous laminations. Sample is being used for Ro analysis.

H-16 Sample is being taken from the depth of 250 meters. Fine sandstone with carbonaceous laminations. Sample is being used for Ro analysis.
