

## *Mineralogy and genesis of saprolite and strongly weathered soils in the Appalachian region of Canada*

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The mineralogy and genesis of three recently discovered saprolite sites of the Appalachian region of Canada were compared. The sites are near Mont Jacques-Cartier (Quebec), Big Bald Mountain (New Brunswick), and Cape Breton (Nova Scotia). Although in all three sites the bedrock has been strongly weathered, the degree of weathering varied widely. There were no weatherable minerals left in the clay fractions of the Mont Jacques-Cartier site down to a depth below 3 m, but large amounts of weatherable minerals still remain in the clay fraction of the Chorizon of the Big Bald Mountain site less than 50 cm below the surface. Even for the least weathered Big Bald Mountain site, chemical alterations of the bedrock were detected 17 m below the rock surface. Three probable reasons are discussed for the wide range of degree of chemical weathering among the saprolite sites. There are: the rate of erosion, the nature of the bedrock, and the degree of modification by glacial ice sheets.

On compare la minéralogie et la genèse de trois saprolites récemment découvertes dans la région des Appalaches du Canada. Les sites se trouvent près du mont Jacques-Cartier (Québec), sur le mont Big Bald (Nouveau-Brunswick) et au Cap Breton (Nouvelle-Ecosse). Le degré d'altération varie sensiblement entre les trois sites bien que partout la roche en place ait subi une altération profonde. Au site du mont Jacques-Cartier, jusqu'à une profondeur de 3 m, on ne trouve pas de minéraux altérables dans la fraction argileuse. Au site du mont Big Bald par contre, de grandes quantités de minéraux altérables sont présentes dans la fraction argileuse de l'horizon C, à moins de 50 cm de profondeur. Même dans le cas du site du mont Big Bald, où le degré d'altération était le moindre, on a détecté à 17 m de profondeur des signes d'altération chimique de la roche en place.

On examine trois causes qui pourraient expliquer cette importante variation du degré d'altération entre les trois sites: le taux d'érosion, la nature de la roche en place et le degré de modification apporté par les glaciers.

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### INTRODUCTION

Based upon the Greek word "sapro" (rotten) proposed by Becker (1895), saprolite refers to rock rotted *in situ*, i.e. chemically altered, but coherent and not texturally disintegrated. Saprolite is commonly found in non-glaciated areas, but rarely in the glaciated Appalachian Region of Canada.

In recent years, the finding of the strongly weathered bedrock (saprolite) and residual soils near Quebec City, Quebec (LaSalle and Ledoux, 1975) and Big Bald Mountain, New Brunswick (Wang et al. 1981a) has generated some interest among geologists and pedologists. In the last few years, a number of saprolite and strongly weathered soil sites have been discovered in Canada. For the Appalachian Region of Canada the most notable sites are Cape Breton, Nova

Scotia (McKeague et al. 1982) and Mont Jacques-Cartier, Quebec (Payette et al. 1981).

From published as well as new information on the Big Bald Mountain site and from preliminary findings of the Cape Breton and Mont Jacques-Cartier sites, one can note certain similarities between some of the studied sites on one hand but also certain differences which reveal the great range in degree of weathering of saprolite on the other.

The purpose of this paper is to compare the various saprolite and strongly weathered soil sites, their similarities as well as their differences. The geomorphological and pedological significance in relation to the finding of saprolite in the Appalachian Region of Canada are also discussed.

Brief Description of the Sites (Fig. 1)

1) Mont Jacques-Cartier, Quebec (Lat.

49°05'N; Long. 65°57'W. Elevation about 1150 m AMSL).

The site is on a moderately inclined southeast facing slope about 0.5 km east of the summit of Mont Jacques-Cartier. It is situated in an Alpine meadow in the transitional zone between Krummholz and tundra zones. The site is a critical one as far as glacial reconstructions are concerned. There is a distinct absence of readily identifiable glacial landforms at and above this elevation. Strongly weathered soil and saprolite samples were taken from a trench about 5 m wide and 3 m deep. Semi-weathered bedrock of dominantly fine-grained feldspars and smaller amounts of mica and hornblende was found below 3 m depth. The areal extent of the saprolite of this site is not clear.

cm) over granitic bedrock. Most of the tors were found on or near the crest of the slope. Soil samples were taken from a residual profile; several rock samples were taken from the surface of a tor to a depth of 17 m into the more or less consolidated bedrock. The residual soil covered an estimated area of 20 km<sup>2</sup>.

3) Cape Breton, Nova Scotia (Lat. 46° 28'N; Long. 60°49'W. Elevation: 457 m AMSL).

The general landform is undulating to rolling with relatively smooth ground surface. The site is near the crest of a 10% southwest facing slope. A thin layer of till (less than one meter) covers the saprolite developed on granite. Both till and saprolite samples were taken from a profile about 3m wide

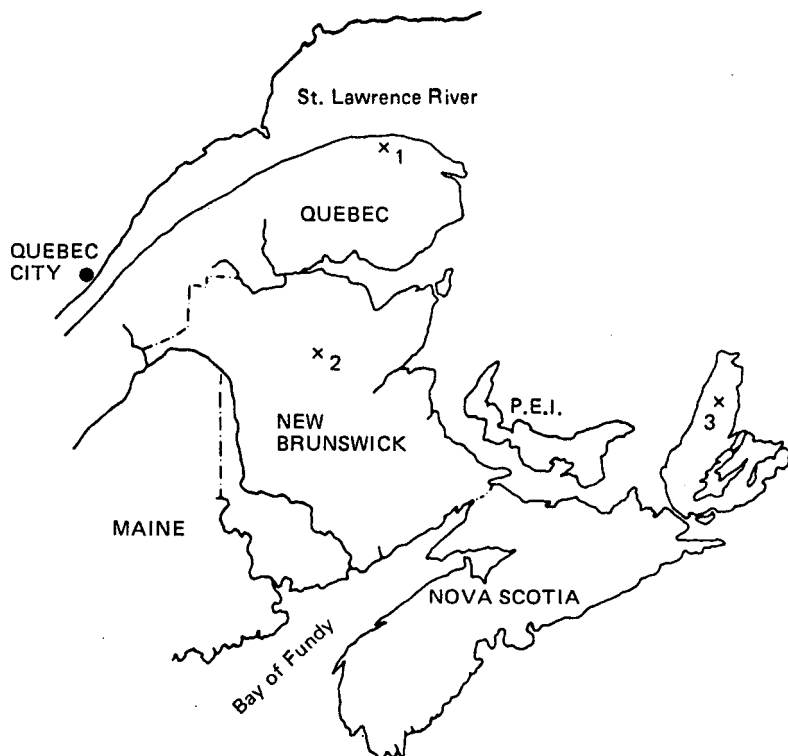


Fig. 1 - Site locations: Mont Jacques-Cartier (1); Big Bald Mountain (2); and Cape Breton (3).

2) Big Bald Mountain, New Brunswick (Lat. 47°11'N; Long. 66°24'W. Elevation: 550-600 m AMSL).

The site was on a gently rolling landscape with thin residual soil (about 50

and 2.5 m deep. Saprolite occupied an estimated area of 100 km<sup>2</sup> of the central Cape Breton Highland. Additional information of the sites can be obtained elsewhere: Mont Jacques-Cartier (Gray

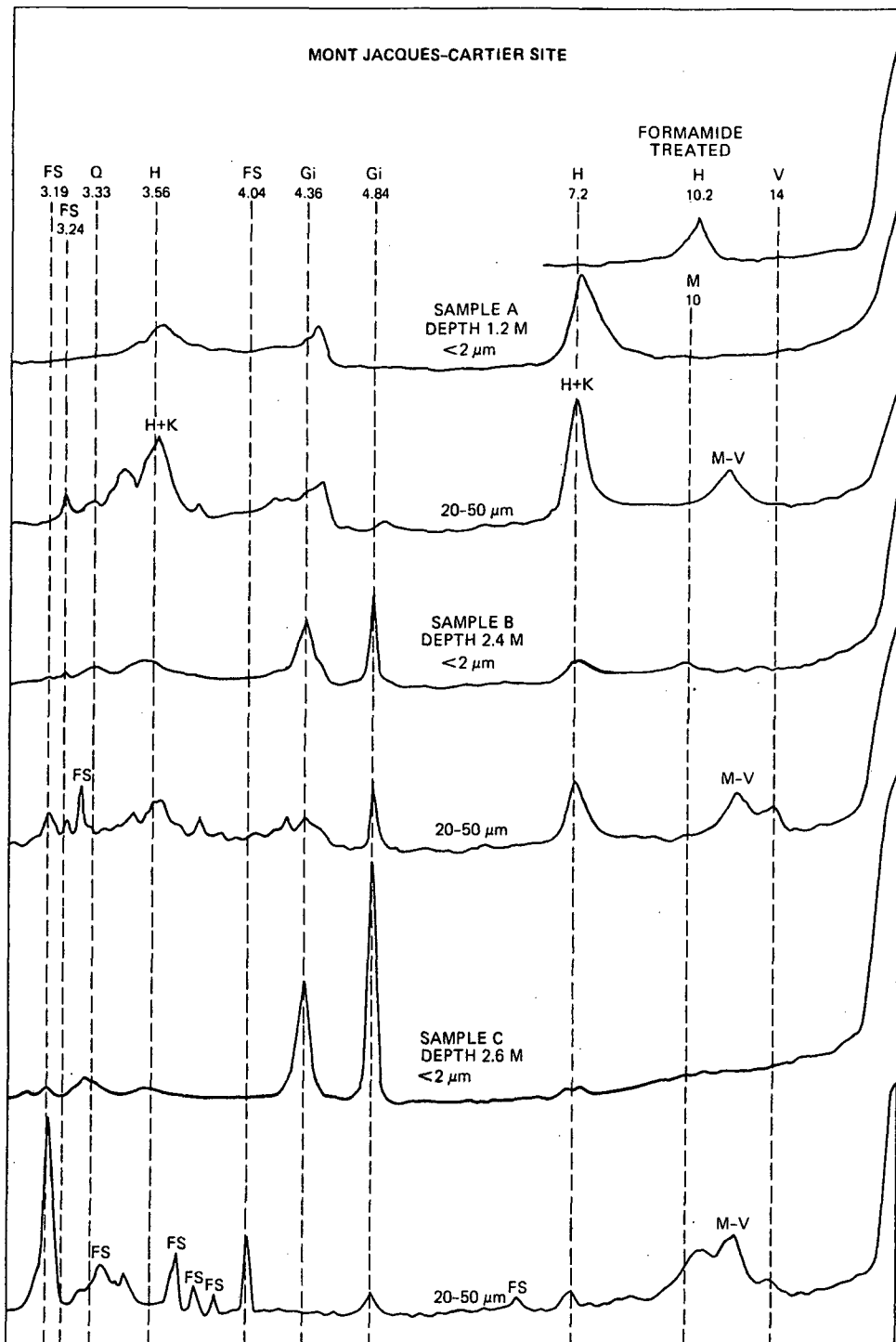


Fig. 2 - X-ray diffraction patterns of clays of the samples of Mont Jacques-Cartier site. V vermiculite; M-V interstratified mica-vermiculite; M mica; H halloysite; H+K halloysite and kaolinite; Gi gibbsite; FS feldspars; Q quartz. Spacings are in angstrom units.

ed. 1981); Big Bald Mountain (Wang et al. 1981a); and Cape Breton (McKeague et al. 1982).

#### METHODS

All samples were treated with hydrogen peroxide prior to particle size separation. The clay fractions ( $<2\mu\text{m}$ ) from the residual soil of Big Bald Mountain and from the saprolite of Cape Breton were treated with tiron (Wang et al. 1981b) to remove amorphous material prior to preparing oriented specimens for X-ray analysis.

Mineral identification was done mainly by X-ray diffraction techniques using Fe-filtered Co-radiation. A Philips diffractometer provided diffractograms of oriented aggregates of clay and silt sizes. The sand size particles were ground to finer particles before X-ray analysis. Mineral quantifications were based on X-ray diffraction peak intensity (Kodama et al. 1977) and by thermogravimetric data (McKeague et al. 1982). For some clay samples, infrared analysis (KBr pellet) was also used to support the identification of kaolinite and gibbsite. To differentiate halloysite from kaolinite, formamide treatment was used. (Personal communication with Mr. J. S. Whitton, Soil Bureau, DSIR, Lower Hutt, New Zealand, and Dr. A.S. Campbell, Soil Science Department, Lincoln College, Canterbury, New Zealand). This treatment consists of adding a few drops of formamide to the air-dry specimen on a glass slide which is then x-rayed from 5 to 10 min. after formamide addition. Formamide-treated halloysite expands from 7 to 10 Å within few minutes whereas formamide-treated kaolinite takes several days to expand. The identification of halloysite was also substantiated by its tubular morphology observed under the electron microscope.

For the rock samples of Big Bald Mountain, rocks were first gently crushed to fine gravel size and then treated with dilute hydrogen peroxide to loosen the fine particles that were

then collected for X-ray and infrared analysis.

#### RESULTS

##### Mont Jacques-Cartier Site

Three kinds of samples were analyzed:

A. Samples just below an upper solifluction layer rich in organic matter (at approx. 100 cm below the surface) - In these samples only halloysite was found in the clay fraction (Fig. 2).

B. Samples from three high chroma layers (7.5 YR 5/6, moist), each about 6 to 10 cm thick occurring between 190 and 280 cm - All the three samples had practically identical x-ray diffraction patterns. The clay fractions were dominantly gibbsite, with some halloysite and a trace of quartz. The coarse silt fractions contained considerable amounts of halloysite plus kaolinite, gibbsite and altered mica (Fig. 2). Small amounts of quartz and feldspars were also present in the silt fractions.

C. Samples from several lower chroma (10YR 5/4, moist) layers which occurred alternately with B samples described above. These samples were obtained between 130 to 300 cm - All the C samples has similar x-ray diffraction patterns. The clay fractions were practically all gibbsite with only trace amounts of halloysite, quartz and feldspars. In the coarse silt fraction, however, feldspars and altered mica were dominant with smaller amount of kaolinite and gibbsite (Fig. 2).

##### Big Bald Mountain Site

The clay fraction of the shallow residual soil contained mainly vermiculite and smectite near the surface. In the subsoils the vermiculite and smectite gave way to interstratified mica-vermiculite and chlorite (Fig. 3). Quartz and small amounts of feldspar were found throughout the residual soil. A significant amount of gibbsite was found in the subsoil horizons (Fig. 3). Kaolinite and gibbsite were detected in the rock powder down to 3.1 m below

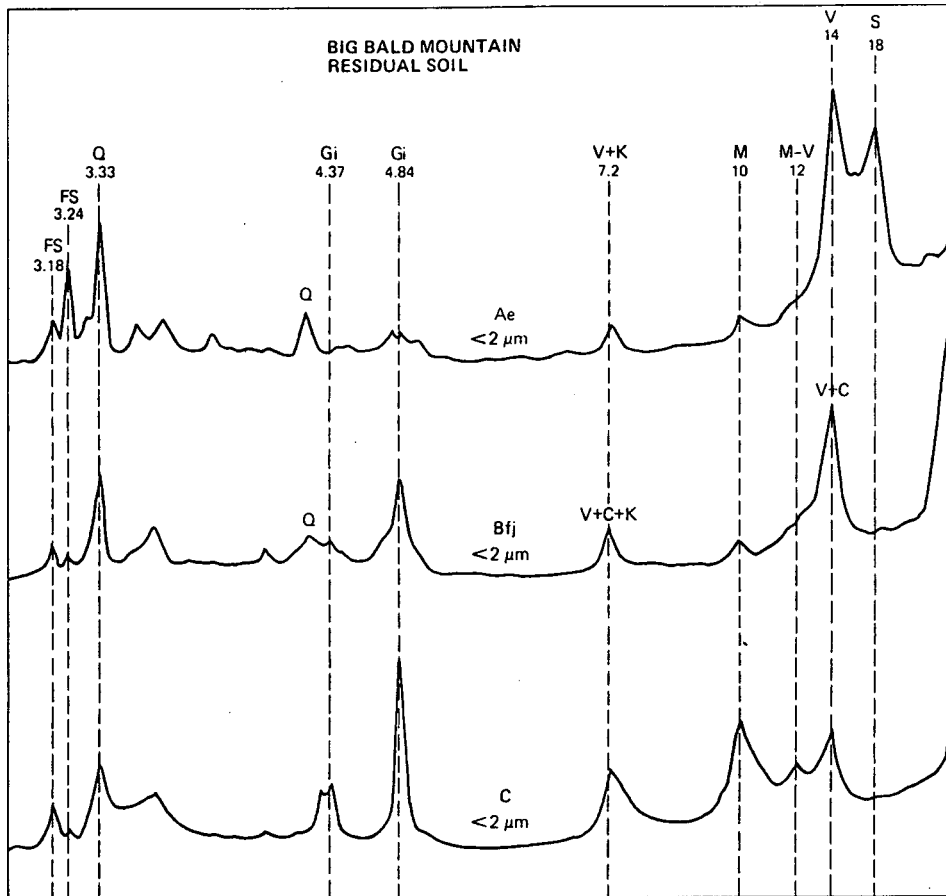


Fig. 3 - X-ray diffraction patterns of clays of the samples of Big Bald Mountain residual soil. S smectite; V vermiculite; V+C vermiculite and chlorite; M-V interstratified mica-vermiculite; M mica; V+K vermiculite and kaolinite; V+C+K vermiculite and chlorite and kaolinite; Gi gibbsite; Q quartz; FS feldspar. Spacings are in angstrom units.

the bedrock surface, while kaolinite was detected 17.1 m below the bedrock surface (Fig. 4). The presence of gibbsite and kaolinite in the rock powder were also confirmed by infrared patterns (Fig. 5).

#### Cape Breton Site

The mineralogy of the saprolite is summarized in Table 1. The amounts of kaolinite, gibbsite and amorphous materials increased as the particle size decreased from sand through silt to clay. Amounts of quartz and feldspars decreased as the particle size decreased. Virtually no amphiboles and interstratified vermiculite-mica were found.

#### DISCUSSION

It is a common practice of pedolo-

lists to assess the degree of chemical weathering of soils by examining the mineralogy of various size fractions of soil particles. Based on such analyses, a weathering sequence of soil minerals was established by Jackson *et al* (1948). In their weathering sequence, gibbsite, kaolinite, halloysite and anatase were considered to be stable minerals in the soil environment. Geothite can also be added to the list of the stable soil minerals (Schwertmann and Taylor 1977). On the other hand soil mineral groups such as olivines, pyroxenes, amphiboles, chlorites, smectites, vermiculites, micas, feldspars were considered to be weatherable minerals.

The clay fraction is most commonly examined in soil weathering studies because it has the largest surface area

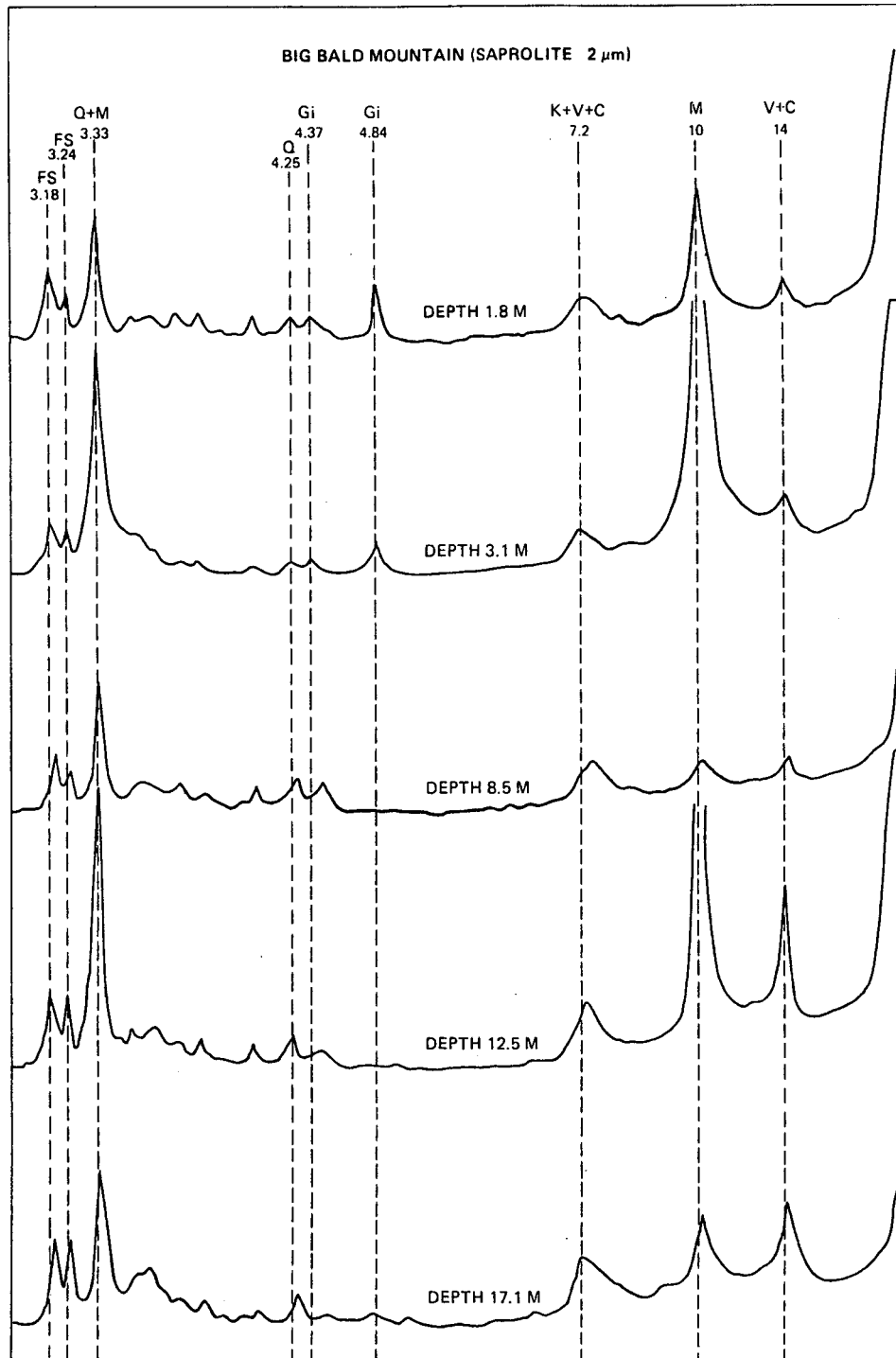


Fig. 4 - X-ray diffraction patterns of clays of the bedrock powder of Big Bald Mountain. V+C vermiculite and chlorite; M mica; K+V+C kaolinite and vermiculite and chlorite; Gi gibbsite; Q quartz; Q+M quartz and mica; FS feldspar. Spacings are in angstrom units.

per unit weight and, as a consequence, is the most active mineral fraction of soils. In strongly weathered soils, it is also useful to examine minerals of coarser fractions (silt and sand).

At the three saprolite sites studied, there is a wide range of chemical alteration. The C horizon of the Big Bald Mountain residual soil represents the least weathered saprolite, because it still had considerable amounts of weatherable minerals such as interstratified mica-vermiculite and chlorite in clay fraction (Fig. 3). No weatherable minerals were found in the clay fractions of the Mont Jacques-Cartier site and the saprolite of Cape Breton. But significant amounts of weatherable minerals remained in the silt and/or sand fractions (Fig. 2 and Table 1). Nevertheless, for even the least weathered saprolite site (Big Bald Mountain) strong chemical alteration of bedrock was evident, as gibbsite and/or kaolinite were detected at a great depth below the bedrock surface (Fig. 4 and 5).

The reasons for the wide range of chemical weathering within the saprolite is not clear. Some possible explanations are listed:

1) The rate of erosion - The site with the higher rate of erosion by which the more exposed and weathered material is removed, will have more weatherable minerals in the saprolite; on the other hand, the protected site (the site with little or no erosion) will have less weatherable minerals in the saprolite.

The Big Bald Mountain site is a good example of a site with high risk of erosion. It is on or near the crest of a rolling landscape with sparse vegetation coverage. It is subject to both wind and water erosion. The thin residual soil (about 50 cm thick) on a landscape not affected by glaciers (Wang *et al* 1981a) is good evidence for supposing that the residual soil is thin because of a relatively high erosion rate and that, consequently, this site has the highest amount of weatherable minerals. For the other sites

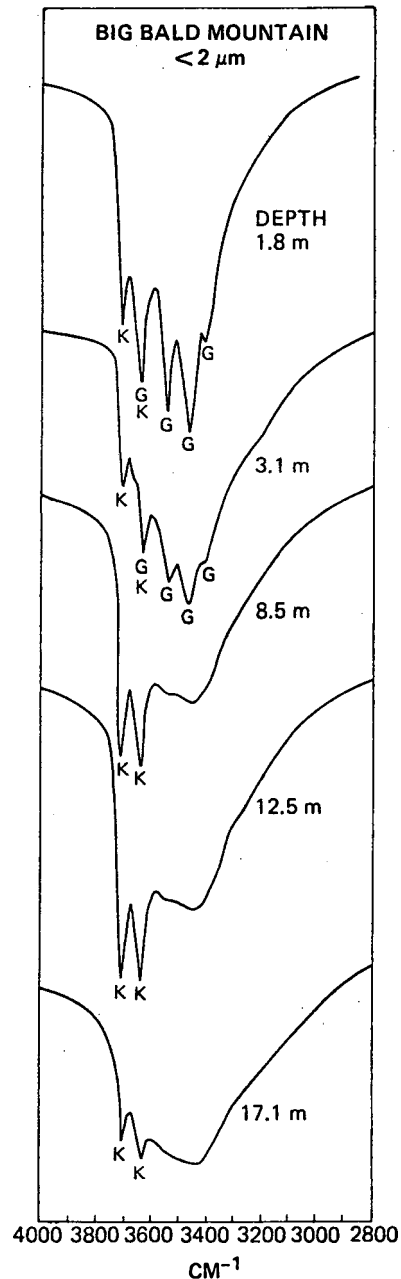


Fig. 5 - Infrared patterns of clays of the bedrock powder of Big Bald Mountain. G gibbsite; K kaolinite.

there are reasons to believe that the erosion rates were slower: the Cape Breton saprolite is overlain by a thin layer of till, which protected the saprolite from post-glacial erosion (McKeague *et al.* 1982); the Mont Jacques-Cartier site, situated on the south-east flank of the summit dome, is protected from the prevailing westerly winds and a protective solifluction lobe between

0.7 and 1 m thick overlies the saprolite. As a result, little or no weatherable minerals were found in the clay fractions of these two sites (Fig. 2, Table 1).

2) The nature of the parent rock minerals - Parent rock containing easily weatherable mineral groups such as olivines, pyroxenes, amphiboles, biotite, Ca-feldspar, etc. can be weathered to stable minerals such as kaolinite, gibbsite, goethite faster than those parent rocks containing mainly more resistant minerals such as K-feldspar, quartz, muscovite, etc. For the Big Bald Mountain and Cape Breton sites, the parent rocks are granite. It contains mainly K-feldspar, quartz, albite and small amounts of biotite. But for the Mont Jacques-Cartier site, the parent rock is monzonite which contains much more weatherable minerals such as Ca-feldspar. This could also account for the more advanced stage of weathering in the Mont Jacques-Cartier saprolite.

3) The degree of modification by glaciers - The Cape Breton site was clearly modified by glaciation (till was found above the saprolites). However, the extent of modification or the amount of saprolite which had been shaved off by glaciation was not clear. Generally, the saprolite near the surface is more strongly weathered than that deeper down. Therefore, the thicker the layer of saprolite removed by glaciation, the greater the amount of weatherable minerals remaining in the saprolite.

#### GEOMORPHOLOGICAL AND PEDOLOGICAL SIGNIFICANCE

The discovery of these saprolite sites

in several areas of the Appalachian Region of Canada indicates that the existence of saprolite in the glaciated Appalachian Region is not confined to a few isolated cases. They are more wide spread than has been believed.

It is also demonstrated that saprolite can be preserved in different geomorphological situations: Preservation on Mont Jacques-Cartier may be indicative of relatively thin and cold based ice. Cold based ice (Gauthier 1978) and/or a permafrost condition may have been responsible for survival of the saprolite on Big Bald Mountain and Cape Breton. LaSalle and Ledoux (1975) suggested that the protection by a fault-line was responsible for the preservation of the saprolite site near Quebec City.

Pedologically, the finding of saprolite in several areas of the Appalachian Region of Canada suggests that residues of ancient weathering rocks have a much greater influence on the parent material of this region than was previously thought. For instance, the common occurrence of kaolinite in many soil parent materials of the Appalachian Region (Kodama 1979) may now be attributed to the probable widespread occurrence of saprolite in preglacial time. A more detailed discussion on the significance of finding saprolite occurrences in Cape Breton can be found in McKeague et al. (1982).

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Table 1

SUMMARY OF MINERALOGY OF SAND, SILT AND CLAY FRACTION OF THE NOVA SCOTIA SAPROLITE

| Particle Size | Vermiculite-Mica interstratification | Mica | Kaolinite | Gibbsite | Quartz | Feldspar | Amphibole | Amorphous |
|---------------|--------------------------------------|------|-----------|----------|--------|----------|-----------|-----------|
| Sand          | tr                                   | *    | **        | tr       | *      | ***      | -         | *         |
| Silt          | -                                    | **   | ***       | tr       | tr     | **       | -         | *         |
| Clay          | -                                    | *    | ***       | *        | -      | tr       | -         | **        |

\*\*\* abundant >30%

\*\* moderate 15-30%

\* minor 5-15%

tr trace 0-5%

- not detected



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