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DETERMINATION OF SOIL CREEP IN THE SOIL PROFILES OF MONT ST. HILAIRE, QUEBEC, CANADA

K. A. MALLICK*

Department of Geological Sciences, McGill University, Montreal, Quebec, Canada

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Abstract. Soil profiles developed on six slopes from five different areas of various rocks of Mont St. Hilaire, Quebec, Canada were selected for the determination of soil creep. Marbles were preferred as compared to plastic cylinders and metal pegs for the determination of soil creep in the area of the present project.

The determination of soil creep on these different rock types and slopes shows variable movement in the soil profiles: an average of 9 in per year has been determined for the upper 6 to 8 in of the soil profile. The movement of soil in the B-horizon ranges between 2–4 in.

Maximum movement rate indicate that under present conditions down slope movement is in the order of 312.5 yards since 12,500 years ago in the upper 6–8 in of the soil profile.

The purpose of the investigation was to determine the rate, distance and time of the movement of slope material at six different slopes developed on varying types of rocks such as syenite, igneous breccia and hornfels etc. This study also seeks to obtain information about the intermixing of soils developed from different types of rocks in contact on their down slope movements under varying topographic conditions.

In the present investigation a quantitative determination of soil creep on varying slopes has been made by putting marble columns in the soil profiles. It has been found that the movement is the highest in the upper 6–8 in of the soil profile. The movement in the soil appears to be related to slope angle, rate of disintegration and decomposition of the rocks underneath the soil profile, vegetation and moisture content of the soil profile.

Geological Description

Mont St. Hilaire is situated in Rouville county, Quebec, 20 miles east of Montreal in the St. Lawrence Lowlands.

Mont St. Hilaire is one of the Monteregian Hills which extends from Oka in the west to Shefford in the east. The hills vary in relief from 620 to 1300 ft above the St. Lawrence Lowlands and are separated from each other by a distance of about 8–10 miles. On the evidence of more or less gradational change in rock types, petrographic similarities, and areal distribution, the hills tend to form a well defined petrographic province.[1]

Mont St. Hilaire is an intrusive plug (?) bordered by a rim of hornfels and is believed to be of Cretaceous age.[2] It covers an area of about 6.76 square miles above the 200 ft contour. The east-west diameter of the core is 2½ miles and about 2 miles from north to south.[3] According to Dresser and Denis the igneous core spreads over an area of 3.37 square miles. The surrounding sedimentary rocks are Ordovician shales of Richmond and Lorraine Groups.[4] Syenite and essexite are the two main rock types of the area and divide the mountain into western and eastern areas respectively (Fig. 1). Essexite is believed to be older than the syenite which has been emplaced as a seperate intrusive. Igneous breccia with fragments of essexite and syenite in a syenitic and trachytic porphyry matrix are also found. Large inclusions of limestone and hornfels occur in the eastern area.

Topography

The height of the mountain is about 1200 ft above the surrounding plain. Broadly the mountain is divided into eastern and western halves which differ topographically and petrologically. Between the two halves is a valley that trends in a north-south direction. Sugar Loaf (Plain de Sucre) the highest peak on the western side has an elevation of 1363 ft and the highest point on the east is about 1200 ft. The main drainage of this area coming to the lake Hertel is along the valleys mostly from the north and west side of the lake. The general level all around the lake is 600 ft. All the mountains around the lake slope gently towards it (Fig. 2).

Division of Areas of Study

Five areas representing different rock types have been selected from the mountains of Mont St. Hilaire. The areas selected have been named after the dominant rock types of the localities. In the syenite area, essexite and calcareous rocks are the adjacent rocks of syenite. Slope no. 1 is developed on syenite in syenite area. Slope no. 2 and 3 represent calcareous and essexite contact zones of the same area. Slope no. 4 is on igneous breccia. Slope no. 5 represents the contact zone between the igneous breccia and

*Now at Department of Geology, University of Karachi, Karachi 32.

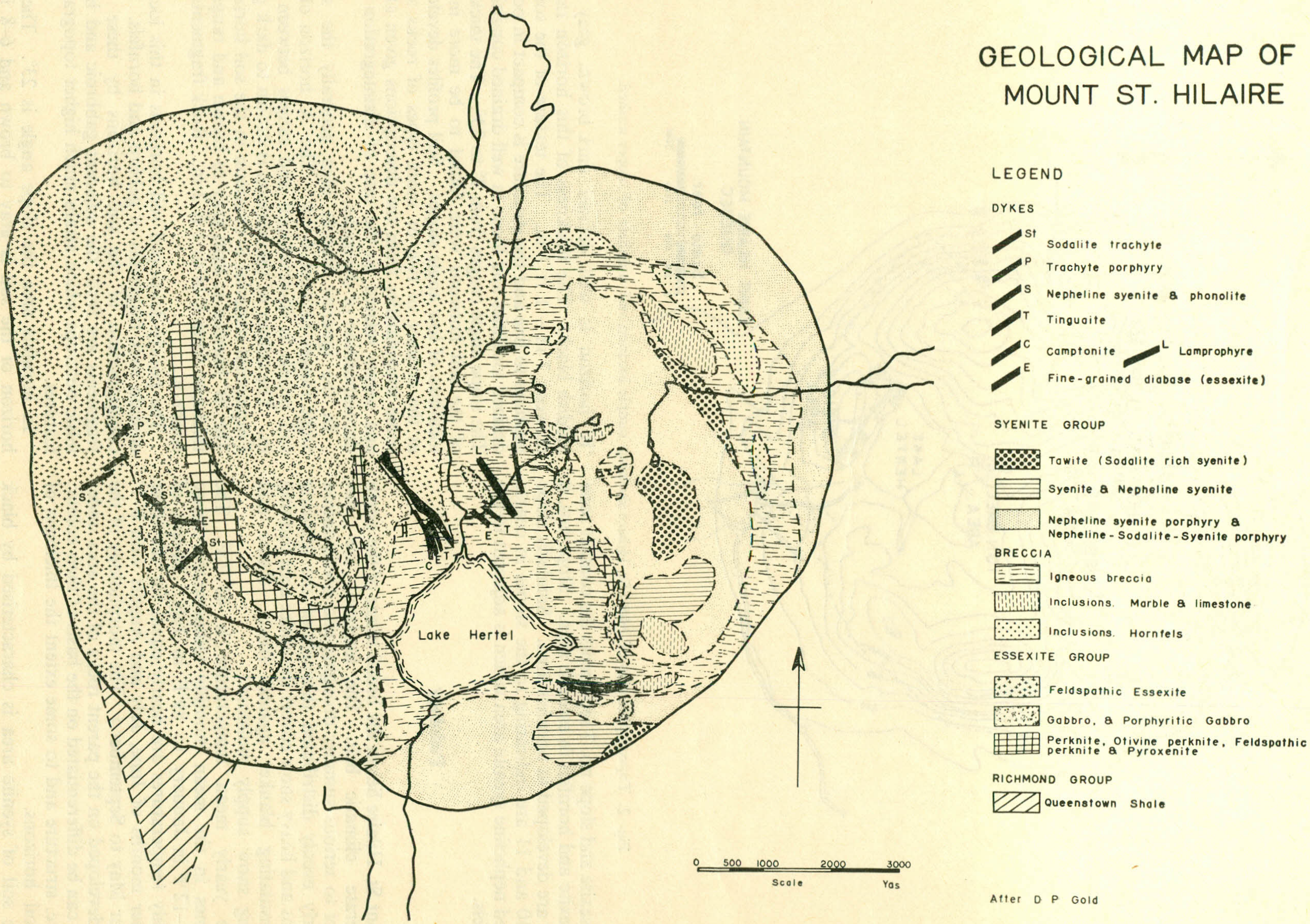
GEOLOGICAL MAP OF
MOUNT ST. HILAIRE
LEGEND
DYKES
St Sodalite trachyte
P Trachyte porphyry
S Nepheline syenite & phonolite
T Tinguaite
C Camptonite
L Lamprophyre
E Fine-grained diabase (essexite)
SYENITE GROUP
Tawite (Sodalite rich syenite)
Syenite & Nepheline syenite
Nepheline syenite porphyry & Nepheline-Sodalite-Syenite porphyry
BRECCIA
Igneous breccia
Inclusions. Marble & limestone
Inclusions. Hornfels
ESSEXITE GROUP
Feldspathic Essexite
Gabbro, & Porphyritic Gabbro
Perknite, Olivine perknite, Feldspathic perknite & Pyroxenite
RICHMOND GROUP
Queenstown Shale
Lake Hertel
0 500 1000 2000 3000
Scale
Yds
After D P Gold

Fig. 1

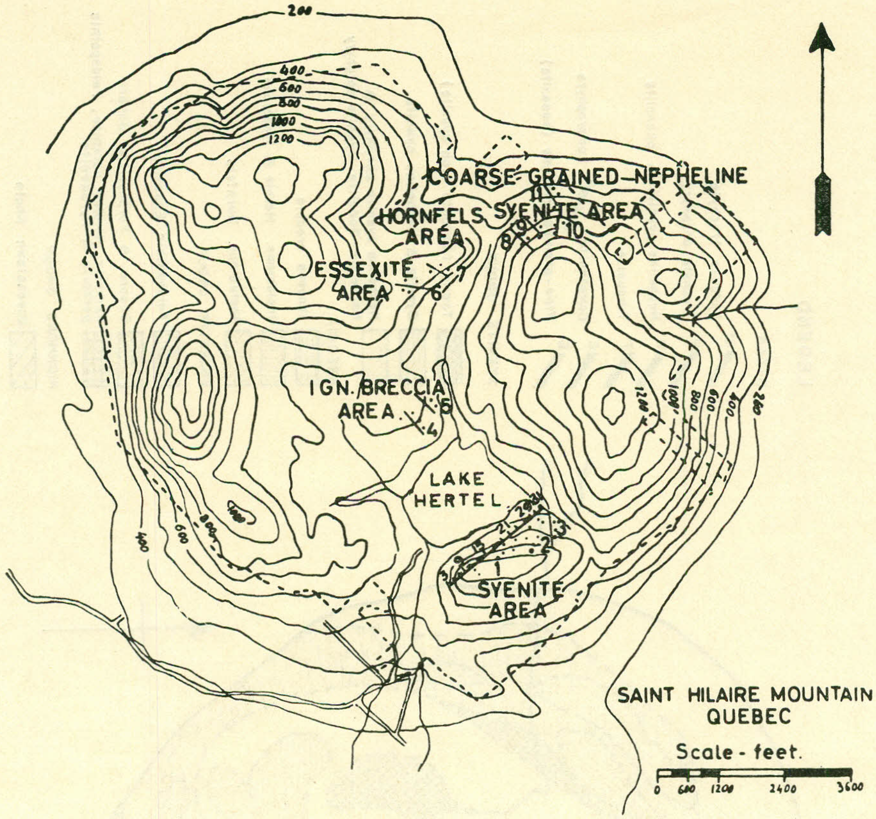

Fig. 2. Topographic map of Mont St. Hilaire showing sample location and numbers of slopes studied.

the essexite and slope no. 7 represents the contact zone of essexite and hornfels in essexite area. Slope nos. 8 and 9 are developed in hornfels area. Similarly slope nos. 10 and 11 are indicating to the slopes in coarse grained nepheline syenite area which is adjacent to the hornfels.

Pedology

Mont St. Hilaire lies in the broad range of the north temperate climatic belt. The lowlands are not subject to serious summer droughts and precipitation is fairly evenly distributed throughout the growing seasons and heavy snow covers the entire area forming an insulating blanket against frosts. Rains and melting snow supply moisture.

The yearly mean temperature is 43.7°F. The extremes in the mean monthly temperatures range from −12°F in January to 89°F in July. Means of monthly temperatures are nearly equal for the three summer months of June, July and August with 6–7° less for May to September.[5] The morphology of the soils developed on the parent rocks of the area under study can be differentiated on the basis of their colour, texture, structure and to some extent the thickness of the soil horizons.

The soil of syenite area is characterised by black carbonaceous 'A' horizon, which is 4–7 in thick. The 'B' horizon is well defined dark brown, gray and reddish black. The thickness of this horizon ranges between 7 in – 1 ft 7 in. The texture of the soil is medium to fine and the structure is compact in poorly drained localities and loose in well drained conditions. The slope angle ranges from 7° to 23°. The thickness of the soil horizons were found to be more in the localities of low angle slopes. Soil profiles developed at the contact of two or more types of rocks show some irregularities from the descriptions given above and seems related to the rate of disintegration and decomposition of the rocks.

In the igneous breccia area generally the slope angle ranges between 6–13°. The 'A' horizon of the soil profile is ill-developed and ranges between 3–5 in. The colour of the horizon is brown to dark gray. Fragmental material is common in the soil horizons. The 'B' horizon is light gray to brown and ranges in thickness from 8 in to 1 ft 2 in. Rock fragments are common.

The poorly-developed soil horizons in this locality contain rock fragments of gabbro and hornfels. The contamination of the soil horizons by these rock fragments are from the adjacent gabbroic and hornfelsic outcrops which attain much higher topographic features.

In hornfels area the slope angle is 23°. The 'A' horizon of the soil is gray to brown and 6–8 in in thickness. The 'B' horizon is brown to dark brown and 1 - 2 ft 3 in thick. The structure of the soil profile is moderately compact and the texture is medium to fine. Vegetation is dense.

Selection of Sites

Six slopes representing a variety of topographic and drainage conditions were selected. The slopes developed on different types of rocks such as syenite, igneous breccia, hornfels and gabbro are being described here to ascertain the effects of angle of slope, density of vegetation and other factors described earlier. The slope with an angle of 19°, 15° and 28° described in the present text are from a poorly-drained localities of igneous breccia, hornfels and essexite areas. The other three slopes with angles of 37°, 30° and 26° are from well drained syenite, essexite and hornfels areas respectively.

Previous Work

The literature dealing with slope movements, slope form, and land form evolution is large and diverse. It is mostly descriptive and speculative.

The determination of soil creep had been carried out either by surficial observations such as archaeological evidences and bending of trees at the down slope side or by instrumental determination in various parts of the world. The present work is first of its kind with respect to the method adopted for the project.

Lutz and Griswold[6] stated that the bending of trees on a sloping site show down slope gravitative transport of surface and subsurface material, which is imperceptable because of small displacement. In central Norway the strips or probes attached to an electric resistance strain gauge, were used to determine the creep of the soil.[7]

Rubberg[8] measured differential movement in the mantle in the Torne and Abisko mountains of northern Sweden, by lowering plastic cylinders.

Washburn[9] used a mass wasting meter in north eastern Greenland to measure the movement in the soil profiles. Similarly Everett[10] determined relationship between soil creep and the fluctuation in soil moisture of Neotoma valley, southern Ohio, U.S.A., by using linear motion potentiometer method.

Metal pegs used by Young[11] for the determination of rate of movement in soil profiles from slopes in the upper Derwent, southern Pennines, England, cause greater specific gravity difference with respect to the soil horizons. Moreover, when they are not in a vertical column in the soil, the differential movement caused in any part of the slope may affect the regular soil creep. The metal pegs may be appropriate to use in boulder clay which does not possess homogenous soil horizons, as Kirkby[12] used in southern Scotland and Jowett[13] in boulder clay cliff to east Yorkshire, England.

The electric resistance strain gauge and mass wasting meter methods of soil creep determination give more accurate results as compared to pouring of metal pegs and plastic cylinders in the soil horizons, but these instruments require every day observation of soil movement at least for a year or more. Thus it necessitates the establishment of a permanent field station to study the soil creep.

In view of the above considerations and to get satisfactory results in minimum possible time with less expensive devices such as, the putting of marbles in the soil column with the help of a T-shape hollow tube, were taken into account which could meet the above requirements for experimentation. The specific gravity of the material to be poured in the soil profile should be similar or less than the specific gravity of the soil horizons. Effort was also made to use such a type of the material which could have minimum possible contacts among themselves, so that the soil creep could meet the least resistance due to the presence of the external material, poured in the soil column.

As mentioned earlier, Rudberg[8] used plastic cylinders to measure the movements in the soil mantle of the Torn and Abisko mountains of Sweden, but the present writer does not consider the plastic cylinders as suitable material for this type of work. The cylinders have a wider contact between themselves which act, as resistance against the movement of the soil. This resistance would cause a degree of inaccuracy in the soil creep thus determined.

In the present work SiO_2 marbles were used instead of plastic cylinders because the surface of contact between them is comparatively much smaller and the specific gravity of the marbles is similar to the soil horizons, hence the sensitivity to soil creep would be higher.

The thickness of the soil profile on the slope was determined by digging pits for soil sampling. Two trees on the same elevation but at a measured distance from one of the holes were selected to pour the marbles in the soil profiles. A T-shape stainless steel tube fitted with a piston, was used for putting the marbles in the soil column. A plumb bob was used to check that the tube was indeed vertical. The piston was taken out when the tube hit the bed-rock. The penetrated depth was then compared with the soil pits of that area, to make sure that the tube had not hit loose rock instead of bed rock. A known number of marbles having the diameter only slightly less than the internal diameter of the tube were poured into the tube. Then the tube was pulled out slowly while the piston pressure on the marbles was maintained to prevent the marbles from coming out. The hole was then covered with soil. The movement of marbles in a known time period was used to determine the amount of soil creep. The location, the date the marbles were poured in, angle of slope, and depth penetrated were recorded for every hole. Besides, surficial indications such as bending and deformation of trees and also mass wasting were recorded.

Determination of Soil Creep. After about a year the surface material around the original location of each hole was removed slowly with a hand shovel to locate the top of the marble column. A pit was dug about 6 in to one side of the exposed marble

TABLE 1

Slope No.	Angle of slope	Thickness of soil profile	Date of marbles put in	Date of marbles taken out	Movement at 6 ft 8 in	Maximum movement (in)
2	37°	1 ft 2 in	9.6.65	19.7.66	1.0 in	1.2
4	19°	1 ft 3 "	19.6.65	20.7.66	0.7 "	0.9
6	28°	1 ft 8 "	11.7.65	26.7.66	0.7 "	1.2
7	30°	1 ft 4 "	8.7.65	21.7.66	1.0 "	1.3
8	15°	1 ft 9 "	9.7.65	23.7.66	0.7 "	1.0
9	26°	1 ft 6 "	7.7.65	20.7.66	0.9 "	1.1

This pit was then extended towards the marble column until it was exposed. Now a plumb line was suspended from the centre of the top most marble in the column. The distance between the plumb line and the centre of the lower most marble in the column was recorded. This gave the amount of soil creep at that locality (Table 1).

At a depth of 6–8 in, the boundary between A and B soil horizons, a shift in the marble column was noted. This is due to greater movement in the A horizon acting as a unit relative to the B horizon. This difference in soil creep between A and B horizons is due to differences in seasonal variation in moisture content, temperature, and organic matter in the soil horizons and the rate of weathering of the parent rocks. In addition, surficial observations, such as bending of tree trunks and thinning of soil profile at higher elevation of slope and thickening at the down slope side sufficient to give a general idea of the soil creep, were also made.

According to Dawson,[14] the level of the Champlain sea during the Pleistocene was 560 ft above the present sea level. Thus it may be assumed that below that level Mont St. Hilaire was covered by the Champlain sea, therefore, only areas above 560 ft were exposed to weathering. With an average determined soil creep of 0.9 in per year in the upper 6–8 in of the soil profile, the total soil creep since 12,500 year (when the area was uncovered by ice, J.A. Elson, personal communication) is $0.9 \times 12{,}500$ in$=$312.5 yards.

This estimation is for slopes having conditions specified above, but as slope, vegetation, structure of the soil, drainage and microclimatic conditions vary from place to place, the calculated movement is not applicable everywhere at the same rate. However, it does show that if two types of rocks are in contact with one another then the rock which is more susceptible to weathering and is at higher elevation will infiltrate the soil developed on the slope below. For example, such conditions have been found in the areas surrounding limestone inclusions and the syenite-area (Slope no. 2). Mineralogical and geochemical data also favour this hypothesis.[15]

Discussion

Everett[10] while determining the slope movement in Neotoma valley, concluded that there is positive relationship between soil movement and the fluctuation in soil moisture. Microplastic movements in the soil are governed by pore water suction, soil temperature and their influence on cohesion. Plastic movement is highly significant in soils with more finer fractions. The size, angularity, and distribution of grains through the profile results in increasing the internal friction of the soil mantle, which in turn increases the resistance of the mantle to shear. Micromovement become ineffective with larger fraction. Leaf litter hinders evaporation from the soil horizon and so it causes higher moisture content in the soil profile on the slopes.

He could not find any relationship between precipitation and soil movement. He further concludes that freeze and thaw are ineffective parameters of soil movement in Neotoma valley.

The area is completely covered by snow during winter and so freeze and thaw appear as important parameters of soil movement. The ineffectiveness of this parameter in Neotoma valley may be because of its geographical location where there is no snowfall in any part of the year.

Rudberg[8] also found freeze and thaw as effective parameters of soil movement in the soil mantles of Torne and Abisko mountains of northern Sweden.

Other parameters like fluctuation in soil moisture, soil temperature and their effect on cohesion, texture of the soil and leaf litter recorded by Everett[10] as effective agents of soil creep are in accord with the present observations. These agents appear as important parameters of soil creep in the area of the present study, specially during spring and summer seasons.

The effect of precipitation on soil creep cannot be neglected particularly in well drained localities, where soil structure is loose and porosity is higher. The pore water increases the plasticity of the soil and thus enhances the down slope movement of the soil. The roots of maple trees and bushes in the area of the study, most probably hinder the soil movement and make it difficult to understand the relationship between precipitation and movement of the soil. However, it requires more work to conclude any relationship between precipitation and soil creep.

Conclusions

1. The movement of soil in the A horizon is faster than in the B horizon of the same soil profile. The mean down slope movement in the soil profile is 0.9 in per year.

2. The results of soil creep determination from Mont St. Hilaire region are comparable to those of Everette,[10] in Neotoma valley, Young[11] in the Southern Pennines on a slope of 20–30°.
3. Soil creep appears to be related to the type of bed rock and the amount of slope angle.
4. Soil creep is very sensitive to local parameters such as temperature, precipitation, vegetation, parent rock, intermixing of soils developed from different rock types and the angle of slope.
5. Rill wash and sheet wash also act as active agents of surface transport and hence produce differential pressure on soil horizons during the down slope movement.

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References

1. J.A. Dresser and T.C. Denis, Quebec Dep. Mines, Geol. Rep., **20,** 544 (1944).
2. H.W. Fairbairn *et al.*, U.S. At. Energy Comm., Eleventh Annual Progress Rep., 105 (1963).
3. S.K. Rajasakaran, Ph.D. Thesis, McGill University (1966).
4. T.H. Clark, Quebec Dep. Mines, Geol. Rep., **46,** 159, (1955).
5. Canada Year Book, Dept. of Transport, Toronto, Ontario, 157 (1959–60).
6. L.R. Lutz and K.P. Griswold, Polar Studies Rep. 6, The Ohio State University, Columbus, Ohio, 30(1963).
7. P.J. Williams, Am. J. Sci., **255,** 705 (1957).
8. S. Rudberg, Meddel Uppsala, Ser. A, No. 126, 114(1958).
9. L.A. Washburn, Biul. Peryglacjalny, No. 3, 59 (1960).
10. K.R. Everett, Polar Studies Rep. 6, The Ohio State University, Columbus, Ohio, 45 (1963).
11. A. Young, Nature, **188,** 120(1960).
12. M.J. Kirkby, J. Geol., **75,** 359 (1962).
13. C.W. Jowett, Polar Studies Rep., 6, The Ohio State University, Columbus, Ohio 32 (1963).
14. J.W. Dawson, *The Last Million Years* (The University Press, Toronto, Canada, 1941), p. 57.
15. K.A. Mallick, J. Sci., **1** (1), 16 (1970a).
16. D.P. Gold, Ph.D. Thesis. McGill University (1963).