Annals of Glaciology 2 1981

ROCK JOINTING AND ABRASION FORMS ON *ROCHES MOUTONNÉES*, SW FINLAND

by

Jukka Rastas

(Department of Geography, University of Turku, SF-20500 Turku 50, Finland)

and Matti Seppälä

(Department of Geography, University of Helsinki, Hallituskatu 11-13, SF-00100 Helsinki 10, Finland)

ABSTRACT

The influence of bedrock structures, especially joints, on the formation of *roches moutonnées* and different glacial abrasion forms on *roches moutonnées* were studied in the south-west archipelago of Finland. The size and form of *roches moutonnées* are closely connected with the frequency and state of joints in the bedrock. The fewer and smaller the joints are, the larger are the *roches moutonnées* that can be formed. Vertical joints in the direction of the ice movement form the weakest zones and determine the width of the *roches moutonnées*. Joints dipping against glacial movement determine the dip of the eroded rock surface. Horizontal joints provide a suitable base for large and gently-dipping *roches moutonnées*, which are normally lower than others with less frequent horizontal joints. Striae, friction cracks, facets, fracture lines, and plucked surfaces, and their positions on the surfaces of *roches moutonnées*, were observed. On the basis of these observations, a stereographic model of the distribution of different abrasion features on the surfaces of *roches moutonnées* was produced.

INTRODUCTION

The south-west archipelago of Finland consists of some 60 000 small, rocky islands sculptured by the continental ice sheet during the Pleistocene. The most common rocks are granites, gneisses, migmatites, granodiorites, and leptites. This Pre-Cambrian crystalline bedrock is cut into a mosaic-like relief by crossing fault lines. Because of the relatively rapid rate of land uplift, at present 4 to 5 mm a^{-1} (Kääriäinen 1964, Lisitzin 1964), fresh, unweathered rock surfaces cleaned by wave action are available for morphological studies. A small area (about 22 km^2) was chosen in the vicinity of Lom island (60°06'N 21°40'E) in Korppoo commune (Fig. 1). In this region the islands rise less than 30 m above the present sea-level and the maximum depth of water is about 50 m, normally 15-20 m. There are many *roches moutonnées* in the archipelago, but few detailed studies of them have hitherto been made (for example, Edelman 1949, 1951). Two studies (Sahlström 1913, Strömberg 1971) from the Stockholm archipelago should be mentioned in this connection.

The aim of this investigation was to map different glacier erosional forms on *roches moutonnées* and to chart the influence of bedrock structures, especially joints, on their formation. Detailed studies were made of 141 *roches moutonnées*. Different features of glacial erosion (striae, lunate fractures, crescentic gouges, crescentic fractures, polished facets, fracture lines, plucked surfaces, etc.) were observed and mapped. The dip and strike of the rock surfaces were measured with a geological compass, and the morphology of *roches moutonnées* was levelled and mapped. Rock types were determined, and the dip and strike of rock joints and fractures, and their frequency distribution, were measured. Three-dimensional material was plotted in the form of stereographic diagrams and then collected together into a stereographic model of different erosional features on different types of *roche moutonnée* surfaces.

GENERAL DIRECTION OF GLACIER FLOW

Measurements of the orientations of glacial striae were made in the study area and it was found that the local direction of glacial flow changes quite considerably (up to 45°). A mean direction was calculated for each observed point. These directions, ranging from 307 to 330°, are presented in Figure 1. For the whole area the general direction of the last glacial flow is 318° (north is 360°).

By measuring the orientations of the longitudinal axes of *roches moutonnées*, the general direction of the last ice movement was estimated to be some 323°. Sometimes it was difficult to determine the exact orientation of the axis. This indicates that the striae observations are more accurate but the local topography has more effect on their orientation.

In some localities transverse striae were found. The older direction of flow was not taken into consideration when the last direction of flow was determined.

JOINTING AND MORPHOLOGY OF *ROCHES MOUTONNÉES*

The form of *roches moutonnées* is controlled by two main factors: the physical conditions under the glacier, and the structure and other characteristic features of the rock in contact with the glacier. By studying the former, it is

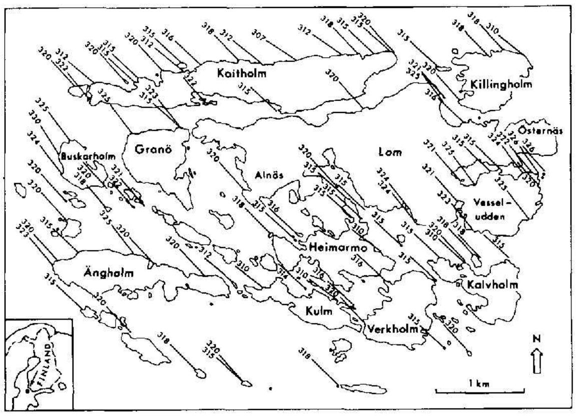

Fig. 1. General direction of the last ice movements in the Lom region, south-west archipelago of Finland, based on mean orientation of striae. The numbers are degrees, indicating the direction from which the glacier flowed.

possible to obtain only indirect knowledge of the course of glacier erosion, but, by studying the latter, real observations can be made of the eroded surfaces. Sahlström (1913) and Mathes (1930) have suggested that bedrock structure and texture influence the formation of *roches moutonnées*, and that these factors mainly determine their form.

In the present study, the directions of joints and their frequency distributions were determined. It was found that transverse joints and fractures are usual in *roches moutonnées* (Fig. 2) but that joints parallel to the movement of the ice are rare. This does not mean that there is any difference between the frequencies of transverse and parallel joints in the bedrock. Erosion works selectively so that areas with joints parallel to the ice movement are depressions and areas with transverse joints form elevations in *roches moutonnées* (Fig. 3).

The frequency of transverse jointing in *roches moutonnées* in the Lom region varies from three to five joints per metre in the direction of the ice movement. On and near the tops, the frequency is higher than in the middle sections. Where the frequency of transverse joints is much higher, the rock surface is plucked, as is normal on the lee sides of *roches moutonnées*, or

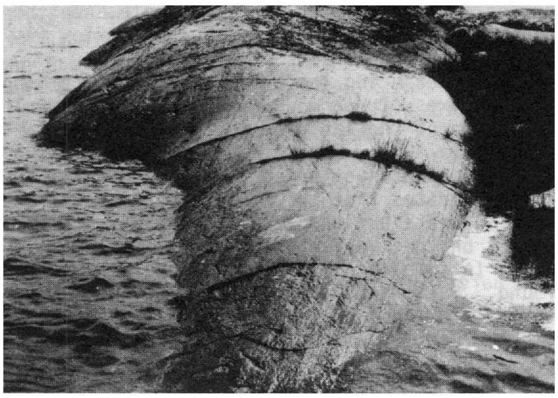

Fig. 2. Striae and transverse joints on a *roche moutonnée* in south-east Kulm. (Photographed by Jukka Rastas.)

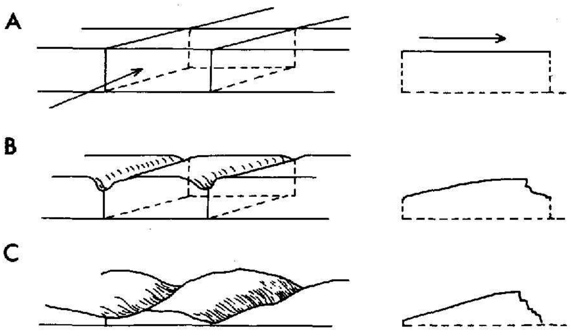

Fig. 3. A model of joint patterns and their influence on the formation of *roches moutonnées*.

unpolished. If wide joints, joints with intrusions, or joints with contacts with different rocks are transverse to the ice movement, the resulting abrasion may produce depressions in the profiles.

Longitudinal joints determine the breadth of a *roche moutonnée* (Fig. 3) and the length depends on the frequency of transverse joints (Fig. 4). Johnsson (1956) had already reached a similar conclusion from his study in southern Sweden. The frequency of more or less horizontal joints determines the height. If the horizontal joints are close to each other the relative height of the *roche moutonnée* is less than if the horizontal joints are further apart. The ice can move large blocks bounded by horizontal joints (Fig. 4). This might be the reason why *roches moutonnées* in one particular region are of much the same elevation. Large and flat foresides of *roches moutonnées* often follow the "Bankung" of bedrock (Hausen 1945).

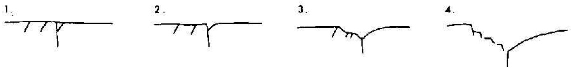

Fig. 4a. The influence of transverse joints on the formation of *roches moutonnées*. One *roche moutonnée* is shown forming directly down-glacier of another.

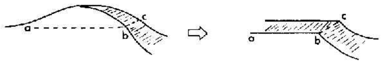

Fig. 4b. The influence of a horizontal joint (abc) on the formation of a *roche moutonnée*.

The long and narrow forms of *roches moutonnées* are often connected with the foliation of rock parallel to the ice movement, and their dip is vertical. Granites with low jointing frequency do not form long *roches moutonnées*; they form short, broad types. If the foliation is diagonal to the ice movement, the *roches moutonnées* are orientated along the foliation rather than along the ice movement (Fig. 5).

ABRASION FORMS ON *ROCHES MOUTONNÉES*

Striae

The plastic ice mass follows the small-scale roughness of the base and therefore the directions of striae differ from place to place, even on the same *roche moutonnée*. Rock surfaces which dip less than 30° have only a small effect on the general direction of ice movement. If the dip is more than 50° it changes direction markedly (Fig. 6). The greatest differences in

https://doi.org/10.3189/172756481794352504 Published online by Cambridge University Press

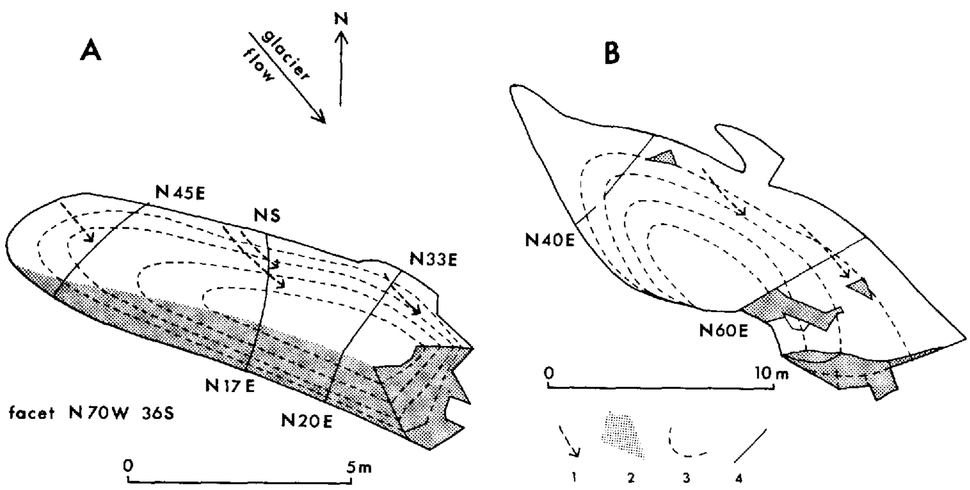

Fig. 5. Influence of jointing and foliation on the orientation of two *roches moutonnées*. A. Direction of foliation N 70° W. B. Direction of foliation N 40° W. Key to symbols: 1. Striae. 2. Plucked surface. 3. Contour line with interval 0.20 m. 4. Main joint.

the general direction are found on surfaces dipping steeply against the direction of flow of the ice sheet. On such surfaces the striae are indistinct and only weakly etched. Carol (1947) has explained that the absence of striae on the surfaces more or less vertical to the ice movement is the result of hydrostatic pressure, which makes the ice more plastic. As a result the stones and blocks moving with it are pushed into the ice mass. Andersen and Sollid (1971) reported a nearly vertical surface facing up-glacier, which was devoid of striae. On gently dipping surfaces the striae are longer and better formed than on steep surfaces. On the foreside striae are found up to the edge of the plucked area. On the topmost parts of *roches moutonnées* striae are rough and are found at wide intervals. On the sides the striae are finer and denser. The longest observed striae are as much as 8.5 m in length.

The rock type has an effect on the formation of striae. On coarse-grained and fragile rocks striae are unusual and they are destroyed by weathering. On granites, gneisses, and amphibolites striae are clearly visible. On schists they are well-formed but on pegmatites they are not found at all.

Microstriae can be discerned on rock surfaces on the sides and lee sides of *roches moutonnées* using a lithographic method. The rock surface is covered with printing ink and porous paper is then pressed on to it so that the microstriae can be observed on the paper.

Friction cracks

Friction cracks are found at the top of the foreside of the *roches moutonnées* (Fig.6). The surfaces dip slightly against the ice movement. The size of friction cracks ranges from a few centimetres to some decimetres. The largest friction cracks in the Lom region are almost one metre long. They are not a very reliable indicator when determining the direction of movement. The best-formed friction cracks exist on granites and gneisses but they can also be found on coarse-grained rocks.

Facets

Facets are well-polished surfaces on the lee side of *roches moutonnées*. They are formed by the rock flour produced by friction under the ice. Ljungner (1930) and Edelman (1949) consider facets to be erosional forms similar to crescentic gouges. Facet surfaces dip downwards into the direction of the ice flow. Normally

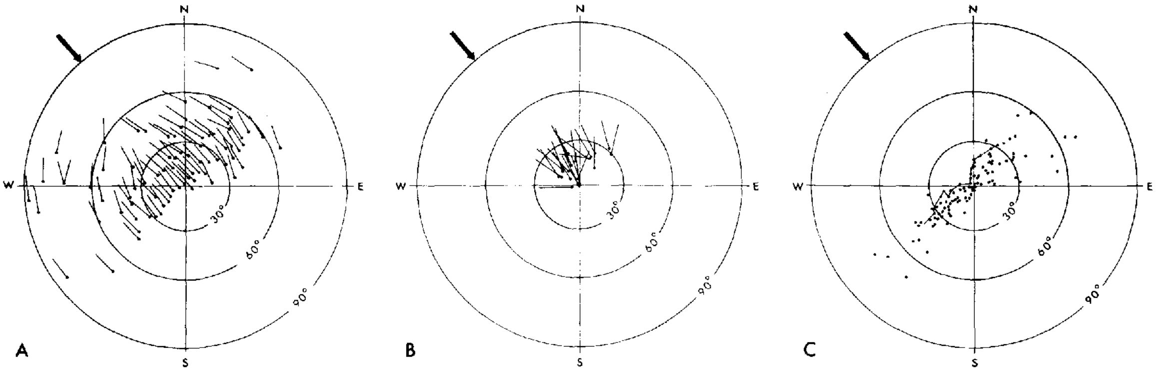

Fig. 6. Stereographic diagrams (upper projection) showing poles to the planes on several *roches moutonnées*. Arrows indicate the general direction of glacier flow. A. Striated surfaces with striae directions indicated by lines. B. Surfaces with friction cracks. Lines indicate the direction perpendicular to the cracks. C. Surfaces truncated by plucking. The irregular line joins all the poles from a single *roche moutonnée*.

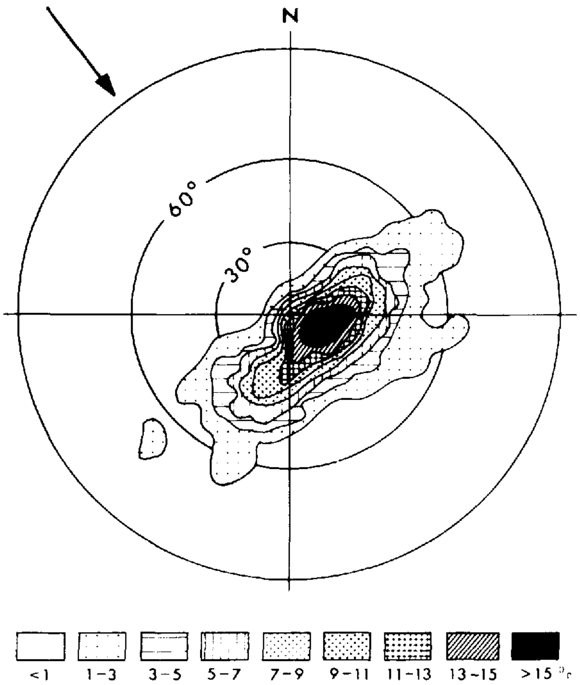

Fig. 7. Contoured stereographic diagram (upper projection) of the orientations of 232 polished facets on *roches moutonnées*. Arrow indicates the general direction of glacier flow.

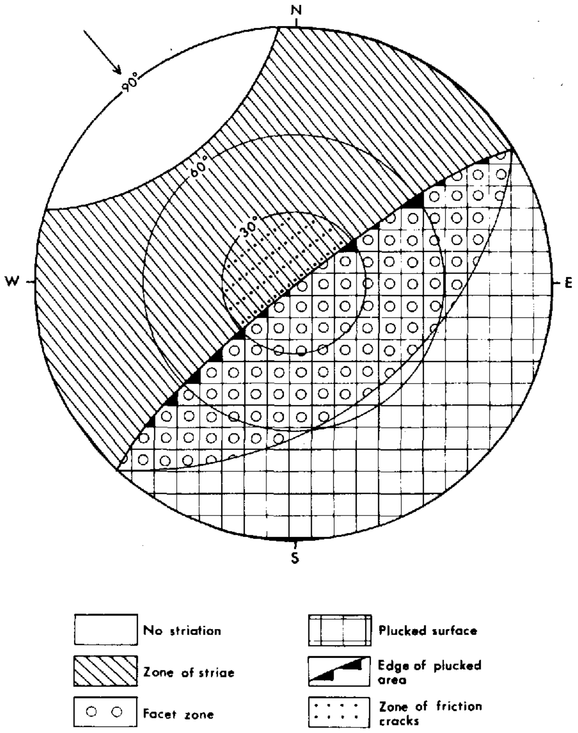

Fig. 8. Stereographic model (upper hemisphere projection) of the distribution of different abrasion features on different surfaces of *roches moutonnées*. Arrow indicates the general direction of glacier flow.

they are located just behind the edges of plucked surfaces (Fig. 7). It seems clear that fracture and fissure surfaces in certain positions at the upper edges of *roches moutonnées* are more subject to polishing and the formation of facets. Joint surfaces have been found with similar exposure but without polishing. This might depend on the duration of glacier erosion and, if plucking took place just at the end of glaciation, there may not have been time for polishing to take place.

Fracture lines

The edge between the polished stoss side and plucked lee side of a *roche moutonnée* is called the fracture line. It is very seldom steep, straight, and exactly perpendicular to the ice movement. Normally the fracture line follows joints. Often it exists on the top of a *roche moutonnée* with a horizontal surface or on a surface which dips a little (0.5°) to the lee side. On the sides of *roches moutonnées* fracture lines are often located farther forward than on the topmost parts (Fig. 6).

CONCLUSIONS

It has been proved that bedrock structures and especially joint patterns are important factors influencing the form of *roches moutonnées*.

The form of *roches moutonnées* determines the form and type of abrasion features created on the surface. On the basis of our observations from the south-west archipelago of Finland we have suggested a general model for the surfaces of *roches moutonnées* and an explanation of how the abrasion forms are located on these surfaces (Fig. 8). The steep slopes are at the edges of this stereographic model and the horizontal surfaces are in the centre. This gives a general idea of the abrasion processes under the continental ice sheet during the last glaciation in south-west Finland. It might be applied to other regions also but we have to bear in mind that physical conditions under the ice differ greatly from time to time and place to place (Sugden and John 1975), and these differences may produce other types of abrasion patterns on *roches moutonnées*.

ACKNOWLEDGEMENTS

The Archipelago Research Institute, University of Turku, placed the boat and housing at our disposal. Final drawings of the figures were made by K. Lehto. C. Grapes checked the manuscript.

REFERENCES

Andersen J L, Sollid J L 1971 Glacial chronology and glacial geomorphology in the marginal zones of the glaciers, Midtdalsbreen and Nigardsbreen, south Norway. *Norsk Geografisk Tidsskrift* 25(1): 1-38

Carol H 1947 Formation of *roches moutonnées*. *Journal of Glaciology* 1(2): 57-59

Edelman N 1949 Some morphological details of the *roches moutonnées* in the archipelago of SW Finland. *Bulletin de la Commission Géologique de Finlande* 144: 129-137

Edelman N 1951 Glacial abrasion and ice movement in the area of Rosala-Nötö, S.W. Finland. *Bulletin de la Commission Géologique de Finlande*. 154: 157-169

Hausen H 1945 Die Bankung als regionale Oberflächenerscheinung im präkambrischen Felsgrund des Schärenhofes im südwestlichen Finnland. *Fennia* 68(3)

Johnsson G 1956 Glacialmorfologiska studier i Södra Sverige. *Meddelanden från Lunds Universitets Geografiska Institution. Avhandlingar* 31

Kääriäinen E 1964 Land uplift in Finland computed by the aid of precise levellings. *Fennia* 89(1): 15-19

Lisitzin E 1964 Contribution to the knowledge of land uplift along the Finnish coast. *Fennia* 89(4)

Ljungner E 1930 Spaltentektonik und Morphologie der schwedischen Skaggerrak-Küste III(1). *Bulletin of the Geological Institute of Upsala* 21: 255-478

Mathes F E 1930 Geologic history of the Yosemite Valley. *U.S. Geological Survey. Bulletin* 160

Sahlström K E 1913 Glacial skulptur i Stockholms yttre skärgård. *Sveriges Geologiska Undersökning* C258

Strömberg B 1971 Isrecessionen i området kring Ålands hav. *Stockholms Universitet. Naturgeografiska Institutionen. Forskningsrapport* 10

Sugden D, John B 1976 *Glaciers and landscape.* London, Edward Arnold