Interpretation of flat-lying Precambrian structure by geological photogrammetry along a 65 km coastal profile in Nuussuaq, West Greenland

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Photogrammetry employing several unequal models was used in the study of a *c.* 65 km long coastline of Precambrian basement rocks along Qarajaq Isfjord in north-eastern Nuussuaq, central West Greenland. A geological profile was drawn parallel to a steep and inaccessible coastline at a scale of 1:50 000, on the basis of photographs at scale *c.* 1:175 000 taken with a hand-held camera from a helicopter. Two short profiles along the same coast were drawn at a scale of 1:25 000 from photographs at scale *c.* 1:40 000. The multi-model photogrammetry provided an accurate, flexible and powerful geological mapping tool in inaccessible terrain, whereby the general flat-lying structure could be analysed. Broken-up remnants of an extensive anorthosite-gabbro complex could be correlated, and several geological features not recognised in the field were discerned. However the application of multi-model photogrammetry along irregular cliff faces is less suitable in folded rocks with complex three-dimensional structures, than in flat-lying sequences of undeformed rocks.

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Nuussuaq has alpine topography with elevated plateaus up to *c.* 2000 m above sea level, dissected by narrow ice-carved valleys with long lakes. The high ground is covered in part by permanent ice, partially by boulder fields or frost-shattered, nearly *in situ* rock. Access by foot is difficult and in many places impossible, and exposure is poor by Greenlandic standards except on cliff faces. The north-eastern coastline of Precambrian basement rocks along Qarajaq Isfjord (Fig. 1) consists of steep (in some places vertical) cliffs, permanently in shadow except for early mornings of the arctic summer when the low sun is in the north-east. Access by boat along the inner parts of this coastline is severely hindered by icebergs and the danger of calving ice from Store Gletscher at the head of Qarajaq Isfjord, and access by helicopter is impossible in many places. It is therefore difficult to obtain a good overview of the geology.

Regional geology

Ongoing investigations by the Geological Survey of Greenland (GGU) in central West Greenland (Kalsbeek, 1989, 1990) includes geological reconnaissance mapping of the eastern half of Nuussuaq. This mapping, undertaken by the author and A. Steenfelt (GGU), was aided by the geological photogrammetry studies reported here and supplements very limited earlier GGU reconnaissance work. The area consists of quartzo-feldspathic gneisses of presumed late Archaean age, with subordinate metavolcanic and metasedimentary rocks as well as intrusive igneous rocks belonging to a layered anorthosite-gabbro complex (Garde & Steenfelt, 1989). Marble of Proterozoic age with zinc mineralisation occurs in the central part of the area (Garde & Thomassen, 1990).

The structural geology of eastern Nuussuaq reflects intense subhorizontal movements which took place during the Proterozoic in the Rinkian mobile belt and were superimposed on older (Archaean) structures. The tectonic processes resulted in large-scale flat-lying tectonic interleaving and locally isoclinal folding of the Archaean gneisses, supracrustal rocks, anorthosite-gabbro complex, and Proterozoic marble units, in a way similar to that described by Grocott (1984), Pulvertaft (1986), Henderson & Pulvertaft (1987) and Grocott & Pulvertaft (1990) from the Uummannaq district north of Nuussuaq.

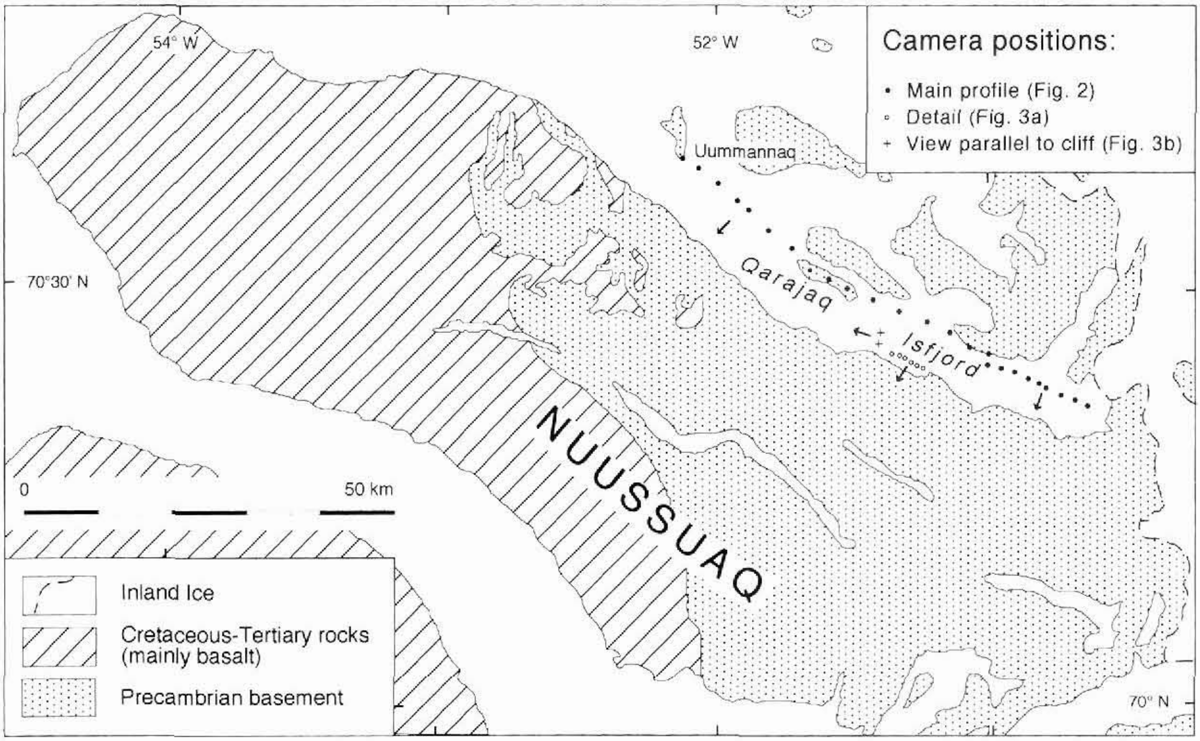


Fig. 1. Index map of Nuussuaq showing the distribution of Precambrian basement rocks and the camera positions for the three geological profiles described in the text.

Geological photogrammetry

Objectives and methods in the field

The objective of the geological photogrammetry was to obtain precise information about the large-scale structure and distribution of rock types along the north-eastern coast of Nuussuaq. The multi-model photogrammetry method (Dueholm, 1992) provided a means of viewing the north-east facing cliffs under optimal light conditions, in continuity, at the desired detail, in colour, and with the ability to measure orientations of geological structures. Existing black-and-white vertical and oblique aerial photographs obtainable from Kort- og Matrikelstyrelsen, Copenhagen, are a long way from fulfilling these conditions.

The photography was undertaken from a helicopter between 6 and 7 a.m. in the morning of July 14th, 1989, before the sun disappeared from the cliffs. Morning haze reduced the sharpness of the pictures, but this slight loss in quality was outweighed by the advantage of direct sun. The pictures were taken on Kodachrome 64 ASA diapositive film with a 70 mm Hasselblad camera, using a 40 mm (wide angle) lens. For the main profile a continuous series of 25 exposures with *c.* 75% overlap was taken, using *f* 4–5.6 and 1/250 sec. The angle of view was kept approximately horizontal and perpendicular to the coastline at a distance of about 7 km, resulting in a scale of *c.* 1:175 000 for the photographs. The chosen distance was a compromise between the geological detail desirable and the number of stereoscopic models necessary to cover the 65 km long coastline. The complete coastal profile drawn from these exposures is shown on Fig. 2. A selected cliff section of *c.* 7 km with many lithological variations was photographed at a closer distance of *c.* 1.5 km (photograph scale *c.* 1:40 000, 7 exposures, see Fig. 3a). In addition, one stereoscopic model was established from two exposures taken along the coastline towards the north-west, in order to obtain a view parallel to the axis of a subhorizontal fold in the cliff.

The actual photography was not difficult to carry out. However, a photography flight should be well prepared and carried out under optimal light conditions. It is an advantage if the appropriate aircraft altitude and distance from the target are estimated before the actual flight (see Dueholm, 1992, for details). Being an indirect technique, geological photogrammetry must be supported by ground observations in order to ascertain the nature of identifiable rock units and obtain information about their mutual small-scale relations and internal structures. Therefore, whenever topographic conditions allowed, helicopter landings and limited field work by foot were carried out. Further field control was provided by earlier observations by boat along part of the profile (T. C. R. Pulvertaft, personal communication, 1988).

Model orientation

A Kern DSR-15 analytical plotter with multi-model software (Dueholm, 1992) at the Institute of Surveying and Photogrammetry, Technical University of Denmark, Copenhagen, was used for model orientation and interpretation. The pictures were mounted on four templates, each with room for nine 70 mm exposures, to provide two groups of models at a scale of *c.* 1:150 000. Orientations of the two groups, which covered about 20 and 45 km of coastline, were undertaken as described by Dueholm (1992). The necessary control points (about 10) were transferred from four models of standard vertical aerial photographs at scale 1:150 000. The tilt was further controlled by incorporating several new height points chosen at sea level (known elevation, 0 m). Aerotriangulation of the vertical models had previously been carried out by GGU using ground control points surveyed by Kort- og Matrikelstyrelsen, Copenhagen. Control points for the more detailed models shown on Fig. 3 were established by transference of 10 points from the two already established hand-held series. In the present case the only difficult and time-consuming part of the photogrammetrical procedure was the acquisition of those ground control points for model orientation which had to be transferred from standard aerial photographs.

The estimated standard deviation on the orientation of the vertical models at scale 1:150 000, in which control points for the absolute orientation of the hand-held models were measured, is about 5 m. To this error must be added a standard deviation of *c.* 3 m during the transference of points from the vertical to the hand-held models. Thus, the resulting standard deviation in the orientation of the hand-held models is about 6 m. The relative error, which is often more interesting for the geologist, is much smaller, about 2 m (10 microns on the photographs).

The most difficult part of the orientation procedure is the identification of identical points in the vertical aerial photographs and oblique hand-held photographs. The problems are caused by lapse of time (variation in snow cover), different film materials, scale variation, and in particular the grossly different angles of view. As many as 15% of the transferred points had to be abandoned because of unacceptably large error margins. In contrast, it is very easy to transfer points between the new hand-held models at various scales.

Geological results

During the interpretation in the analytical plotter it was possible to separate and follow about five different lithologies along the profile and study their large-scale structural relations. On Fig. 2 it is apparent that the rocks form a general flat-lying structure with superimposed weak undulations at a wavelength of many kilometres. It can further be seen that the anorthosite-gabbro complex is not confined to a distinct tectonic level (which was the impression during the field reconnaissance), but occurs intermittently along strike through the eastern and central parts of the profile. It should be noted that in the far eastern end of the profile the basement rocks reach dips of up to *c.* 30° which are oblique to the direction of the profile. In the same area the geological profile contains information (geological boundaries and trend lines) projected from up to 2 km behind the profile line. Therefore, in the chosen projection some of these trend lines cannot be safely correlated with each other.

On the detailed profile (Fig. 3a) the resolution of individual layers is improved, and a new lithology appears as a thin zone of tectonically mixed gneiss and metagabbro (marked by dashed lines). In the central part of the 65 km profile a large overturned synform fold occurs, the true shape of which can be seen on Fig. 3b which is a view along the fold axis parallel to the coastline. Small deformed, intrusive metabasite bodies of presumed Proterozoic age were identified on both of the detailed profiles.

Conclusions

The multi-model geological photogrammetry reported here made it possible to analyse a long inaccessible coastline which is normally cast in shadow, and draw a complete geological profile. The simultaneous mounting of many models, linked together with automatic shifts from model to model (as described by Dueholm, 1992) means that relevant features can be studied and compared in adjacent models, at different scales and from different viewpoints (compare Figs 2 and 3). Furthermore the easy shifts from model to model allows one to study and interpret one particular geological aspect at a time over several stereographic models, and then to attack the next problem in a similar systematic way.

Many geological features were discovered during the

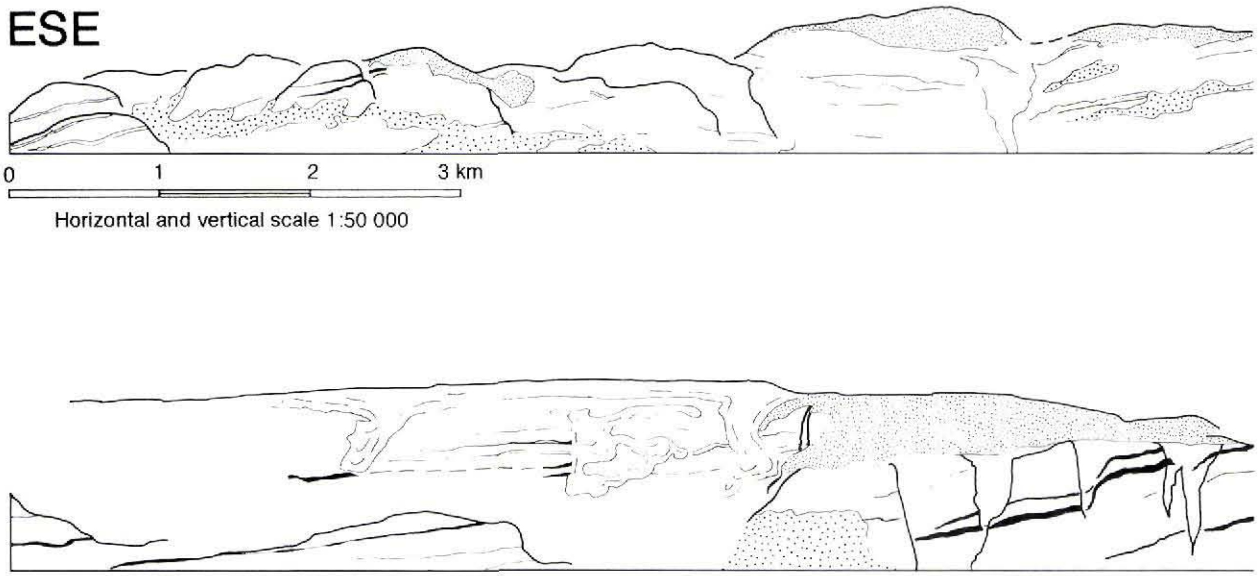

ESE
0
1
2
3 km
Horizontal and vertical scale 1:50 000

Fig. 3a

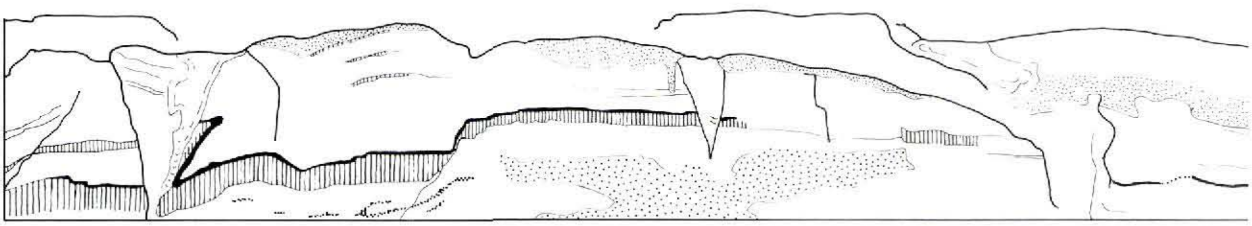
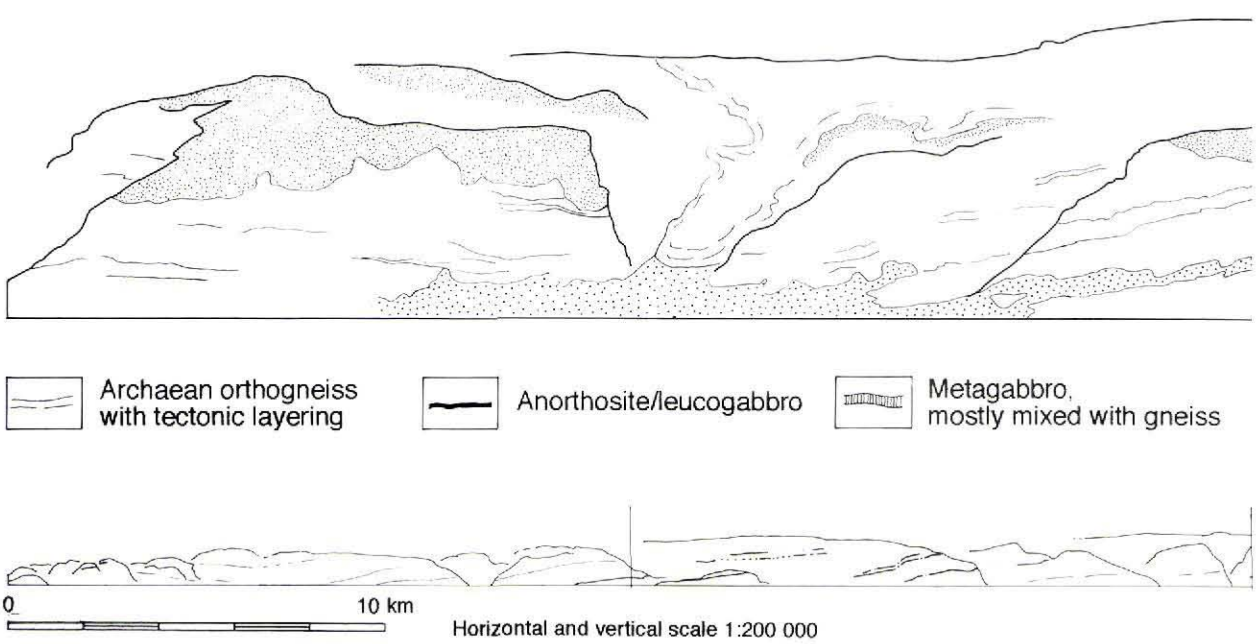


Fig. 3b


Archaean orthogneiss with tectonic layering
Anorthosite/leucogabbro
Metagabbro, mostly mixed with gneiss
0
10 km
Horizontal and vertical scale 1:200 000

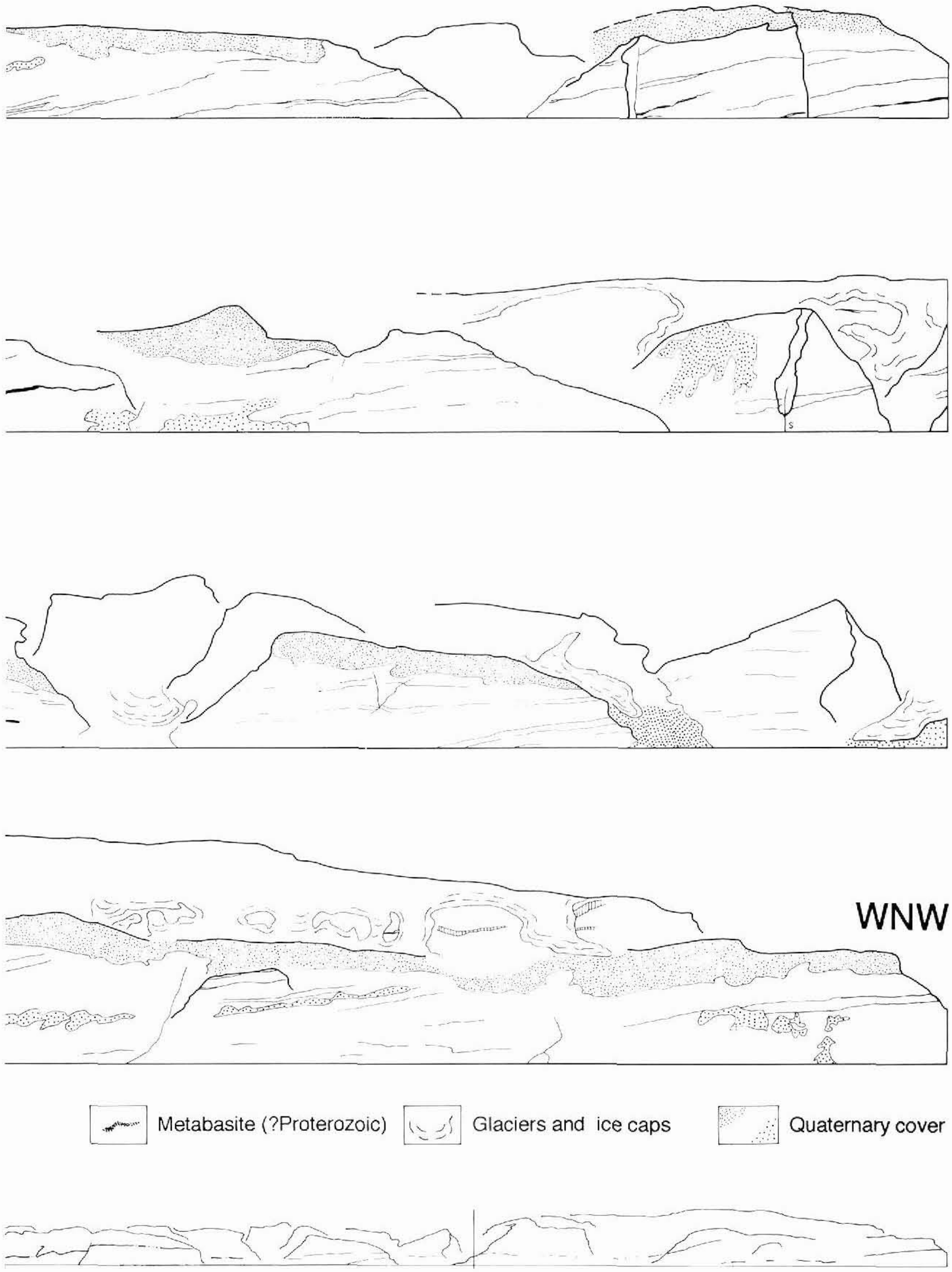


Fig. 2. Profile in four parts of Archaean basement rocks along the northern coast of Nuussuaq at scale 1:50 000, without vertical exaggeration (the outline of the profile is also shown in continuity at scale 1:200 000).

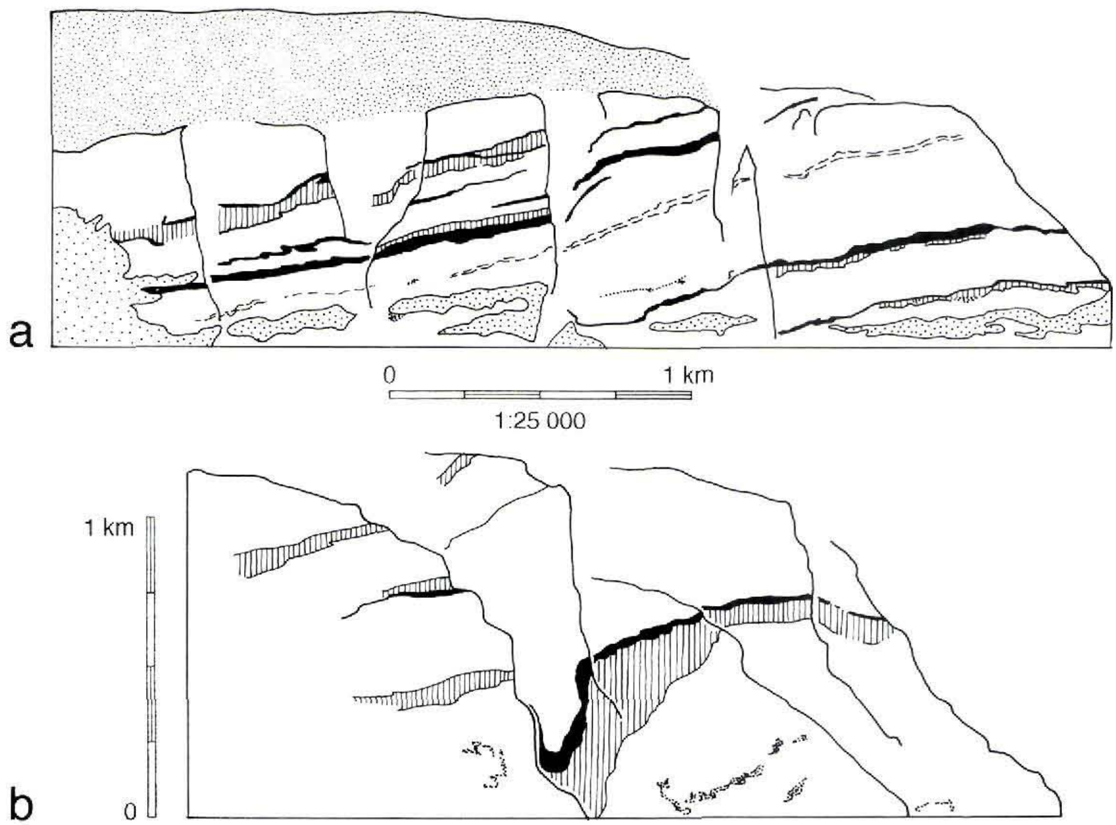


Fig. 3. Profiles along the northern coast of Nuussuaq at scale 1:25 000 (no vertical exaggeration). Locations are shown on Figs 1 and 2; legend as on Fig. 2. Fig. 3a shows a quartzo-feldspathic host gneiss and anorthosite-leucogabbro-metagabbro layers with small-scale east-vergent folds and a narrow zone of tectonically mixed anorthosite-gabbro and gneiss (short dashes). Fig. 3b shows a tight synformal fold outlined by anorthosite-metagabbro, viewed towards west-north-west along the fold axis. The metabasite intrusives left and right of this fold may also have been folded.

interpretation with the analytical plotter which had not been noted in the field, both details and important elements of the large-scale geological structure. This aspect of hand-held geological photogrammetry is considered just as important as the ability to produce accurate maps and profiles of already recognised geology.

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