Stoping versus ductile deformation in the emplacement of the rapakivi intrusion of Qernertoq, South Greenland

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Subsidence of Ketilidian metamorphic rocks adjacent to mushroomshaped intrusions of rapakivi granite in South Greenland has been described by Bridgwater *et al.* (1974) and compared to the theoretical predictions of Ramberg (1967). Observations on the island of Qernertoq show that where the rapakivi magma rose through massive granite rather than schistose country rocks stoping was a major factor. This difference in intrusive mechanisms can be attributed to ductility contrasts in the different types of country rock.

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Structural relationships of post-orogenic rapakivi intrusions and their Ketilidian metamorphic country rocks in South Greenland have been described by Bridgwater *et al.* (1974). The rapakivi suite occurs as elongate mushroom-shaped intrusions, adjacent to which the country rocks have subsided by at least one kilometre with extreme ductile deformation of schists adjacent to vertical contacts. The purpose of this note is to describe the contrasted mechanisms of emplacement of rapakivi magma when intruded into massive granite as compared to migmatitic schists. These observations were made on a brief visit to the island of Qernertoq about 25 km north-west of Kap Farvel (fig. 1).

Over the southernmost part of Greenland the migmatitic country rocks form a gentle dome on a regional scale (Bridgwater *et al.*, 1974). An early regionally concordant, sub-horizontal granite sheet, which pre-dates the rapakivi suite, provides a convenient datum for the division of the migmatitic rocks into an upper psammitic schist unit and a lower unit of semipelitic to pelitic schists (Bridgwater *et al.*, 1966; Sutton & Watterson, 1968). At its maximum this granite sheet is at least one kilometre thick and is bounded by spectacular zones of veins. The idealised vertical section of a rapakivi intrusion is reproduced in fig. 2 (after Bridgwater *et al.*, 1974). As individual schist layers approach the vertical feeder of the rapakivi intrusion they become steeper and greatly attenuated. The fold profiles resulting from this ductile deformation are of similar rather than parallel type. Bridgwater *et al.* (1974) suggested a maximum depth of crystallisation of the upper parts of the rapakivi intrusions of around 6 km, on the basis of clearly defined aureoles in which occur cordierite-andalusite and wollastonite-bearing rocks. Around deeper parts of the intrusions hypersthene-bearing migmatitic gneisses may extend outwards from the contacts for 2–3 kilometres and show gradual loss of structural coherence as the contacts are approached. These areas of high-grade assemblages are interpreted by Bridgwater *et al.* as having crystallised 3–4 kilometres deeper than the well defined hornfelses at the upper contacts.

The downfolded country rocks show structural changes throughout a much greater width than that seen to be affected by contact metamorphism, suggesting that when the rapakivi magmas were intruded the regional temperatures were within the metamorphic range at which ductile deformation could take place. Similar downturns were observed by Ramberg (1967) in centrifuge model experiments illustrating the rise of a layer of less dense material through an overlying denser cover. Bridgwater *et al.* (1974) adapted

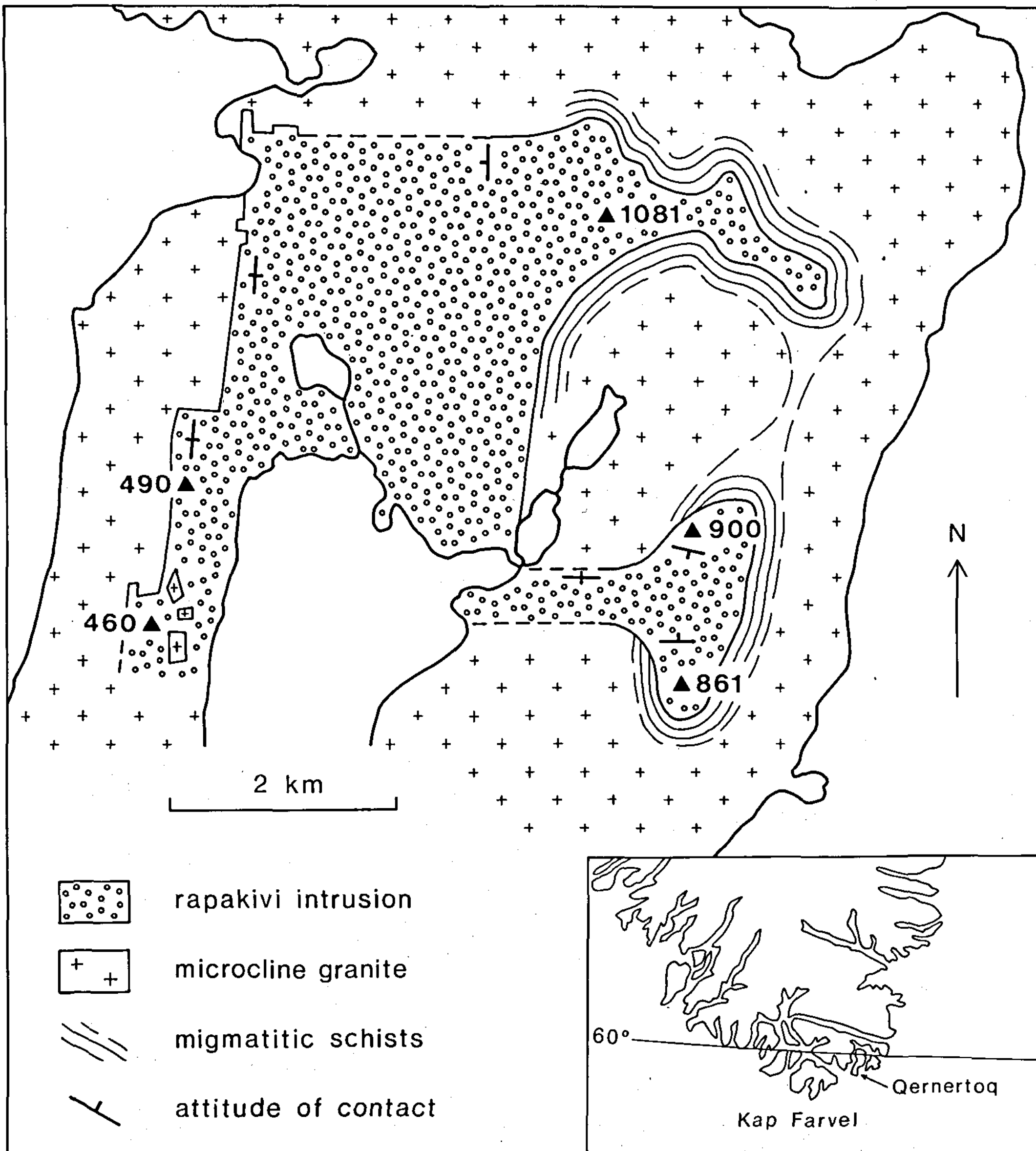

Fig. 1. Sketch map of Qernertoq.

Ramberg's findings to their own observations by viewing the phenomena as the result of injection of less viscous material through a more viscous overlying plate.

On the southern part of the island of Qernertoq (fig. 1) the upper part of the early granite sheet is very well exposed along with the flat-lying zone of veins transitional to the overlying psammitic schist unit. The rapakivi body has vertical contacts where it crosscuts the early granite sheet but becomes flat-lying within the schist unit.

The steep contacts of the rapakivi body are displayed to advantage on the west side of the island where a broad ridge of bare rocky hills rises 490 metres from sea level (fig. 3). The country rock is an homogeneous coarse granite with phenocrysts of microline up to several centimetres long. The

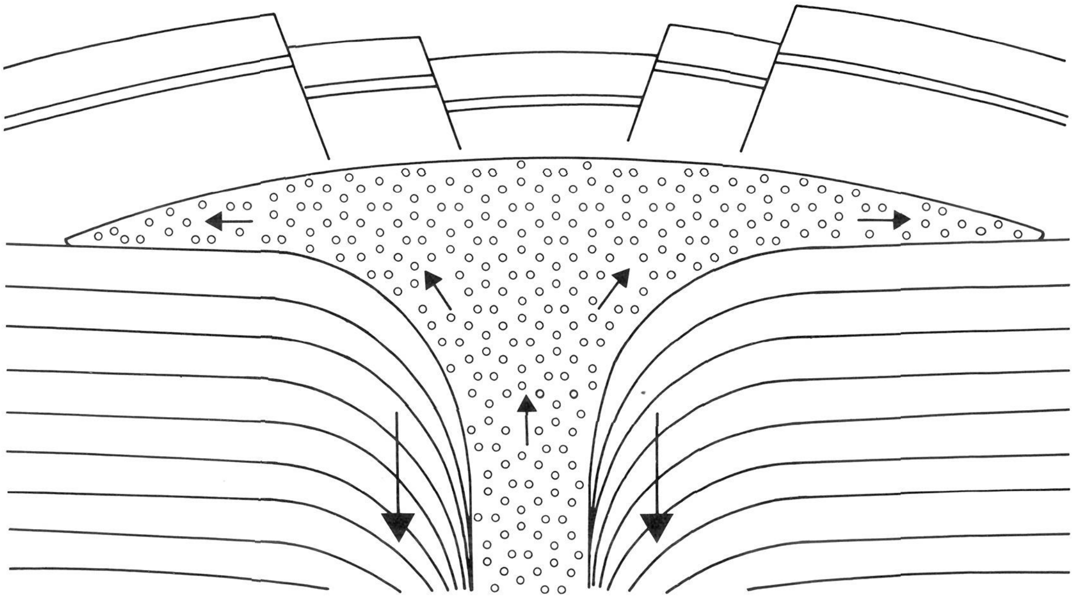

Fig. 2. Idealised vertical section of a rapakivi intrusion (open circles) (after Bridgwater *et al.*, 1974), the arrows indicating directions of relative movement.

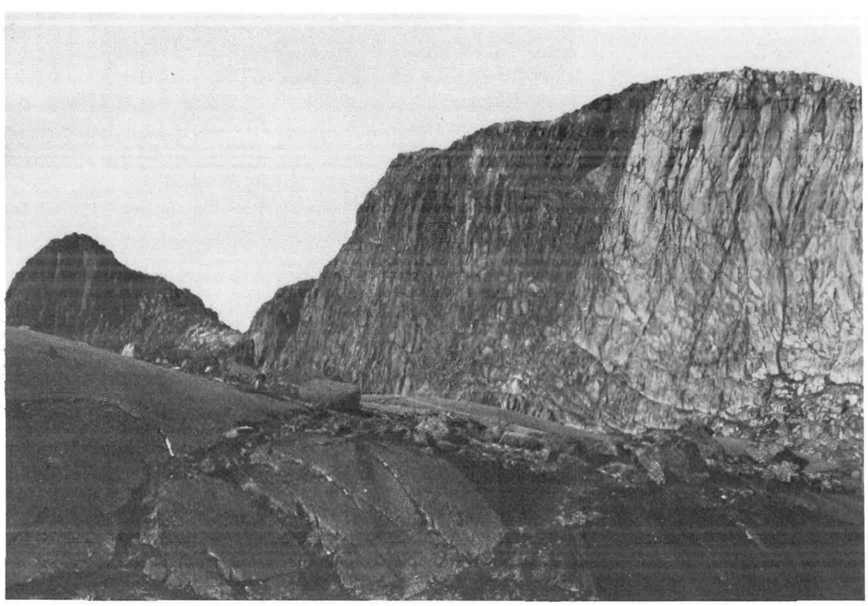

Fig. 3. Steep contact of the rapakivi (dark) against the microcline granite (pale) on the east face of peak 490 m.

vertical contact of the rapakivi intrusion follows pre-existing north-south and east-west weaknesses in the microcline granite which itself is not deformed. The east-west offsets of the predominantly north-south trend of the contact are on all scales up to several hundred metres (fig. 4). The rectangular nature of these steps in the contact and the lack of deformation in the microcline granite is in contrast to the ductile deformation adjacent to the steep schist contacts described elsewhere in South Greenland by Bridgwater *et al.*, a contrast which is emphasised by the preservation

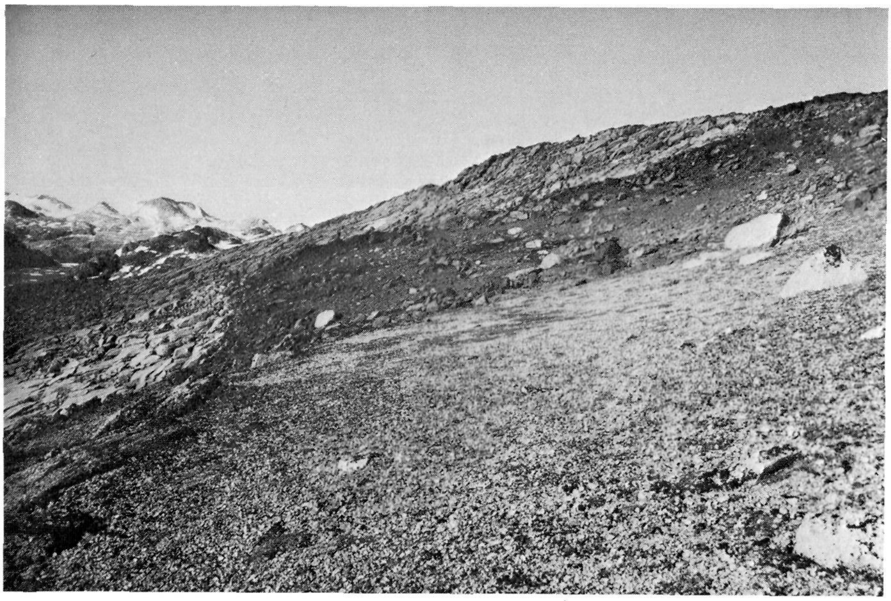

Fig. 4. Rectangular offsets (near summit 490 m, looking north) of the contact between the rapakivi (foreground) which is weathered to brownish gravel, and the microcline granite which takes the form of massive slabs. The east-west offset shown is several hundred metres long.

Fig. 5. Stoped blocks of microcline granite (white) in rapakivi (dark) on the eastern side of summit 460 m. The larger stoped blocks are up to several hundred metres across.

on Qernertoq of stoped blocks of microcline granite up to several hundred metres across (fig. 5).

On the east side of Qernertoq the contact of the rapakivi intrusion is flat-lying and occurs within the zone of veins in the psammitic schist unit (fig. 6). The upper contact of the rapakivi body is not present. The transition from vertical contacts in the lower parts of the rapakivi body where it cuts the microcline granite, to flat-lying contacts in the migmatitic schists, can be seen in

Fig. 6. Contact of flat-lying rapakivi sheet on the psammitic schist unit east of the summit 1091 m. The schist is heavily migmatized by early granite (pale colour) which decreases in amount upwards.

Fig. 7. North-west face of summit 900 m showing the change of attitude of the contact between the psammitic schist unit (pale) and the rapakivi (dark, forming the summit).

steep cliffs both to the north-west and south-west of summit 1081 m. This change of attitude is also clearly visible on the north-west face of summits 900 m and 861 m (figs 1 and 7) where a vertical east-west trending feeder to the rapakivi body progressively assumes a sub-horizontal aspect with increasing height. As in the idealised model, the veined schists beneath the rapakivi body are downturned towards the contact but not to the extent of becoming parallel to it, so that, as can

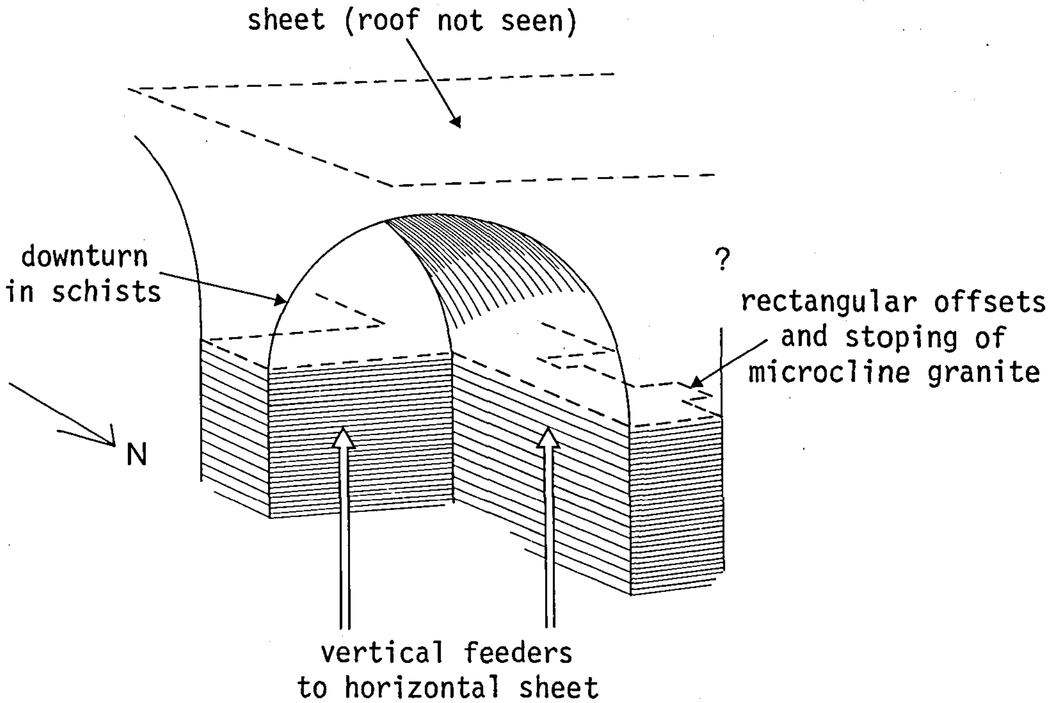

Fig. 8. Idealised interpretation of the rapakivi intrusion on Qernertoq viewed from the north-east, illustrating the rectangular nature of its contact with the microcline granite and the merging of vertical feeders to form a horizontal sheet in the overlying psammitic schists.

be seen in fig. 7, the schists in the arch of the turnover, although deformed, are progressivly truncated.

Figure 8 is an idealised interpretation of the shape of the Qernertoq rapakivi intrusion and illustrates the control which east-west and north-south structures in the microcline granite sheet exerted on the development of the rapakivi body in general and in detail.

The vertical contacts in the feeders to the main rapakivi sheet are governed by the pre-existing joint weaknesses in the microcline granite. Stoping of large blocks of microcline granite utilising these weaknesses was a major factor in the rise of the rapakivi magma. This emphasises the contrasting rheological properties of the microcline granite and the migmatitic schists under similar physical conditions at a depth of around 6 km. In the Bridgwater *et al.* (1974) analysis of the downturned schists the fold profile of the downturn is modelled by strain varying logarithmically with increase in differential stress towards the feeder wall. Also it is inherent in the model that the lateral width of the underlying source layer of rapakivi magma must have been very much greater than the width of the downfold zone.

On Qernertoq, although the feeders to the rapakivi body have non-ductile stoped contacts, the overlying schists do show some downturn. It was not possible to examine the microcline granite immediately beneath the downturned schists nor the contact between them, but the implication of the downturn is that there must be some accommodation at this level between deformation in the schist and the granite. Figure 9 is a possible section through the transition from vertical feeder to horizontal rapakivi sheet which would meet this difficulty by allowing the feeder to flare outwards with depth, but such a geometry was not confirmed in the field.

The different structural behaviour of the masive microcline granite, and the overlying schists in response to the uprise of the rapakivi magma, is quite in accord with the typical competence contrast which Ramsay (1982) recorded for rocks deformed under greenschist or lower amphibolite facies conditions. It is unfortunate that the available collection of Qernertoq rocks, i.e. mi-

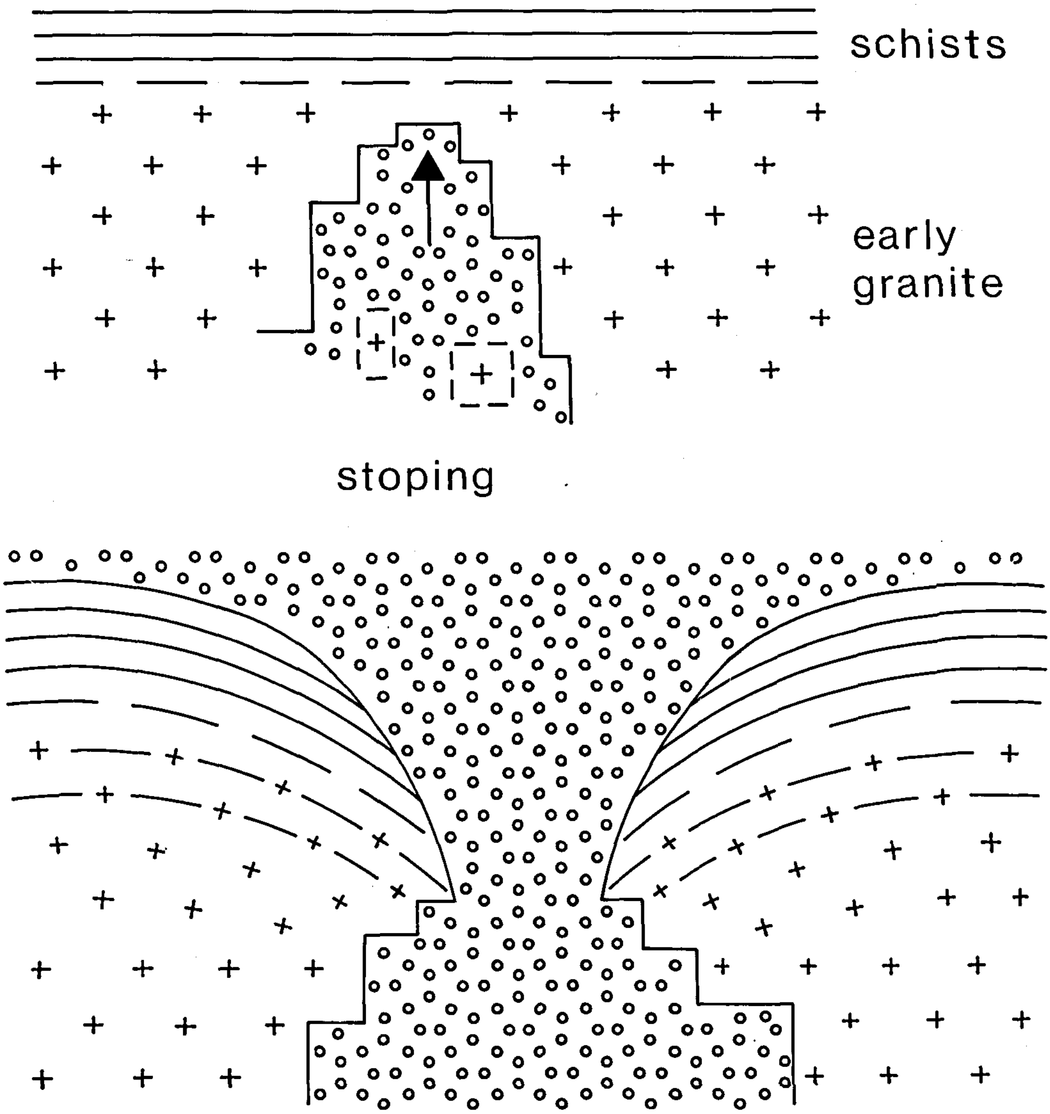

Fig. 9. Different structural behaviour is shown in response to the intrusion of the rapakivi magma (open circles) by the relatively rigid granite, where pre-existing joint weaknesses favour stoping as a mechanism, and by the more ductile schists, which turn downwards towards the contact.

crocline granite and psammitic schist, does not include lithologies suitable for diagnosing precise metamorphic conditions in proximity to the rapakivi intrusion.

Ramsay's 'competence contrast lists' were the result of a systematic study of relative rock ductility in a number of orogenic zones, using cleavage refraction, fold shapes, boudinage, and finite strain state comparison for assessment of differing degress of ductility. Quantification of the ductility contrast of the rocks in Qernertoq was not undertaken and may not be feasible due to lack of suitable deformation monitors in the contrasted rock types.

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Dansk sammendrag

Indsynkning af ketilidiske bjergarter, der støder op til paddehat-formede intrusive rapakivigranitter i Sydgrønland blev beskrevet af Bridgwater et al. (1974) og sammenlignet med Rambergs teoretiske forudsigelser.

Iagttagelser på øen Qernertoq viser, at hvor rapakivismelten steg op gennem massiv granit i stedet for gennem skifrige bjergarter var stoping en hovedfaktor. Forskellen i intrustionsmekanik kan tilskrives den uens måde de relevante bjergarter undergår plastisk deformation.

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