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Curved joints in gneiss

BY

IVAR OFTEDAL

In aerial photographs of the island of Justöy, on the Norwegian Skagerrack coast south of Lillesand, a pattern of long, almost rectilinear joints is a highly predominant feature (Fig. 1). The majority of them are very nearly vertical and at right angles to the main schistosity plane of the gneiss (OFTEDAL 1956), i.e. directed with minor deviations

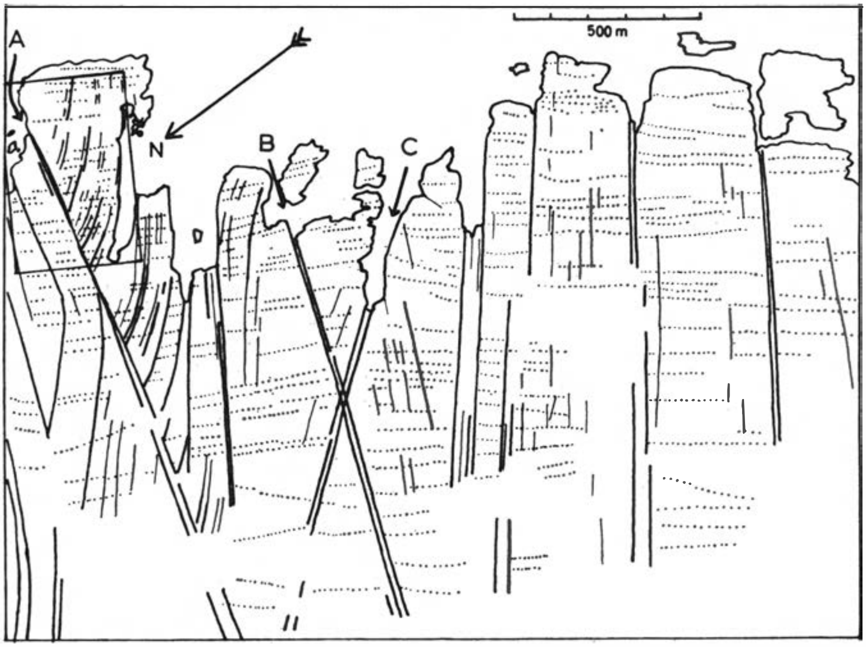

Fig. 1. Part of Justöy. Vertical joints (full lines) and ridges, etc. along the strike (dotted lines). Heavy lines indicate joints which are morphologically predominant. (See also Fig. 4.)

towards E 35°S. In the field, it can be seen that the joints belonging to this quasi-parallel set are much more numerous than appears from the aerial photographs; in fact, neighbouring joints are often about 1 m, or even less, apart. (Fig. 2) Vertical rock walls due to some of these joints show the presence of other sets of joints — one apparently horizontal and one dipping steeply landwards (about W 35°N) (Fig. 3). As the outcrops of the latter must be approximately parallel to the strike, they are not morphologically conspicuous. The gneiss, which accounts for nearly all of the country rock, is mechanically massive; it does not easily split along schistosity planes. It seems natural to interpret all of these joints as pure tension cracks.

There are some joints of a different kind. A few of them are highly conspicuous, having given rise to narrow clefts and valleys. They are nearly straight and form angles of about 20° with the vertical joints of the above set (Fig. 1, A, B, C). They are very long, and one of them (A) actually persists for more than 1 km beyond the area shown in

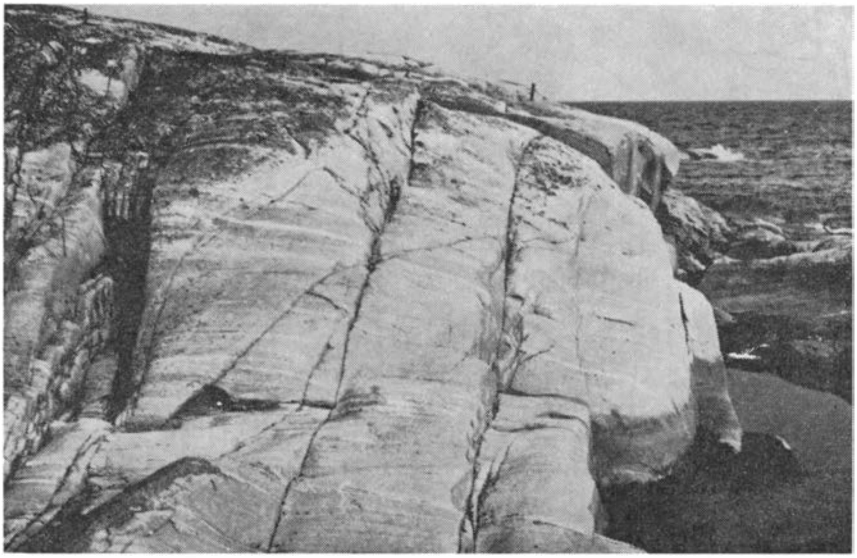

Fig. 2. Vertical joints of the E 35°S set. The joints at the centre are about 1 m apart.

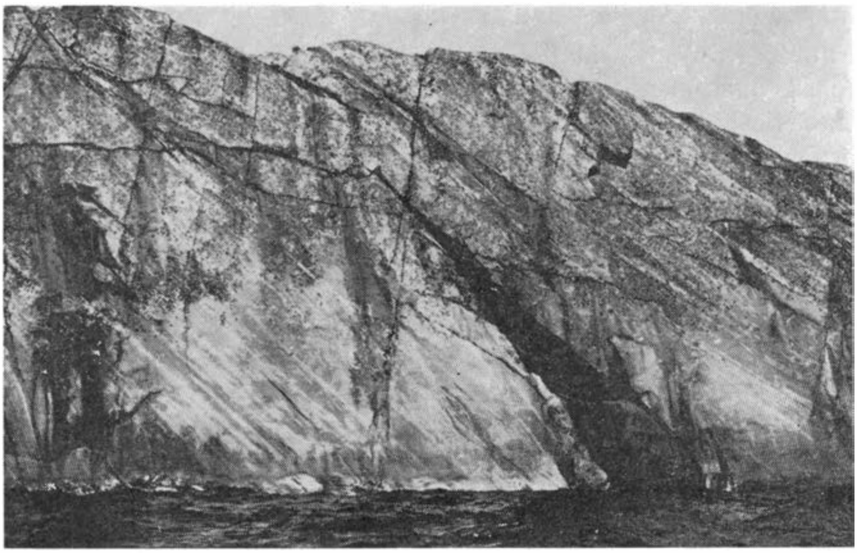

Fig. 3. Vertical rock wall about 10 m high, due to one of the E 35°S joints.

Fig. 1. These joints may possibly represent shear fractures due to a compression perpendicular to the strike, a final stage in the stress action which produced (or enhanced) the schistosity of the gneiss, though it must be admitted that the angle between them and the supposed stress direction is very small for such an interpretation. (Even if it is assumed that the stress was perpendicular to the main schistosity plane, i.e. inclined by about 45° from the horizontal, the real shear angle will not be very much greater, about 27°.) Presumably these joints are the older ones.

Approaching joint A (Fig. 1) from the south, the joints of the E 35°S trend are seen to bend gradually so that at the contact they form an angle of about 70° with joint A. It should be noted that the strike of the gneiss is not influenced by this curving (Fig. 4). A curve which is everywhere parallel to these joints can be simulated by combining the directions of two joint systems, the one parallel to the general E 35°S trend, the other perpendicular to joint A. The effect of the latter clearly decreases with increasing distance from joint A; at distances exceeding 200 m, it is practically negligible. As the joints are nearly vertical, it is sufficient in a simple treatment to consider only the two dimensions in the horizontal plane.

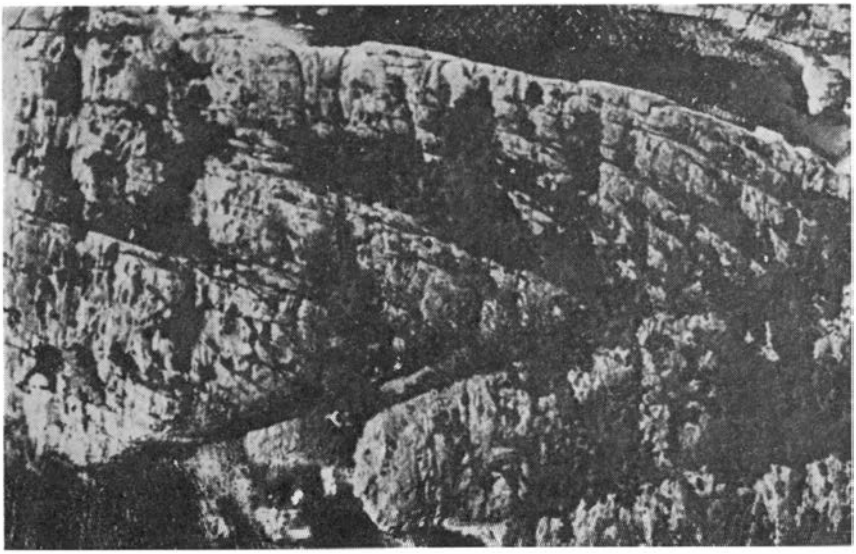

Fig. 4. Aerial photograph of curved joints. The area pictured is outlined in the upper left corner of Fig. 1. Photo: Nor Flyselskap.

Take the x-axis along the joint A and the y-axis perpendicular to it, the unit vectors $\mathbf{i}$ and $\mathbf{j}$ representing their directions. The constant (E 35°S) component is represented by the unit vector $\mathbf{j}_1$, which forms the angle α (about 70°) with $\mathbf{j}$. (Fig. 5). The other component is parallel to $\mathbf{j}$ and its magnitude depends on the distance, ξ, from the x-axis. Assuming this dependence to be exponential, the direction of the curve tangent at any distance from A is, in the simplest case, given by

$$\mathbf{r}^1 = \mathbf{j}_1 + e^{-\xi}\mathbf{j} = -\mathbf{i}\sin\alpha + \mathbf{j}(\cos\alpha + e^{-\xi}).$$

The curves themselves are then given by

$$\mathbf{r} = -\mathbf{i}(\xi + c_1)\sin\alpha + \mathbf{j}[(\xi + c_2)\cos\alpha - (e^{-\xi} + c_3)].$$

For the particular curve passing through the origin, c_1 and c_2 must be zero, and $c_3 = -1$:

$$\mathbf{r} = -\mathbf{i}\xi\sin\alpha + \mathbf{j}(\xi\cos\alpha - e^{-\xi} + 1).$$

This is equivalent to $x = -\xi\sin\alpha$ and $y = \xi\cos\alpha - e^{-\xi} + 1$, or

$$y = -x\cot\alpha - e^{x\operatorname{cosec}\alpha} + 1.$$

Inserting numerical values, α being chosen equal to 68°54′,

$$y = 1 - 0.386x - e^{1.07x}$$

For the relevant part of the curve, x is always negative. The Table shows some corresponding values. If the unit length is taken as 100 m, the curve conforms well to those formed by the joints, as shown in Fig. 5.

The tensions which produced these joints must be assumed everywhere normal to the tangent of the curve passing through the point in question. Their directions are then given by

$$\tan\varphi = \frac{\sin\alpha}{\cos\alpha + e^{-\xi}} = \frac{0.933}{0.360 + e^{-\xi}}$$

The angles φ corresponding to the listed values of ξ are shown in the last column of the Table; one instance is shown in Fig. 5.

The tension component parallel to x clearly has some relation to the gneiss body immediately beyond (north of) joint A. This body may have subsided rapidly along joint A, thus forming an approximately

Table

	Coordinates of curve through the origin		Direction of normal
ξ	x	y	φ
0	0	0	$34°27' = \frac{1}{2}a$
0.1	−0.093	0.131	36°30′
0.2	−0.187	0.253	38°20′
0.3	−0.280	0.367	41°55′
0.4	−0.373	0.474	42°10′
0.5	−0.466	0.573	44°00′
0.7	−0.653	0.755	47°40′
1.0	−0.933	0.992	52°05′
1.5	−1.400	1.317	58°00′
2.0	−1.87	1.585	62°03′
2.5	−2.33	1.818	64°40′
3.0	−2.80	2.03	66°15′
∞	$-\infty$	∞	$68°54' = a$

vertical, relatively rigid and cool boundary wall towards the hotter and more plastic gneiss at somewhat deeper levels. Plastic flow along A and along the strike at deeper levels, as well as contraction by cooling near the surface and near A, may have contributed to the formation of the joints and their curving as A is approached. It seems probable that the curved joints formed during a relatively short time interval, since the very special conditions required are not likely to persist for a long time in a gneiss area. Also, the temperature (and rigidity) at the boundary of the northern subsided gneiss body could not be maintained notably different from that of the southern gneiss in contact with it for any appreciable length of time. The existence of plastic flow at a suitable depth at the relevant stage is highly hypothetical, although it has been shown that some plastic deformation of the gneiss did occur at a very late stage (Oftedal 1956). Contraction by cooling is more easily visualized as a cause for the formation of the joints. The general E 35°S trend of the vertical joints is only locally and moderately modified by the extra cooling effect of the supposedly subsided gneiss body to the north.

To obtain a satisfactory agreement between the observed and calculated curving of the joints, it has been sufficient to take $e^{-\xi}$ instead

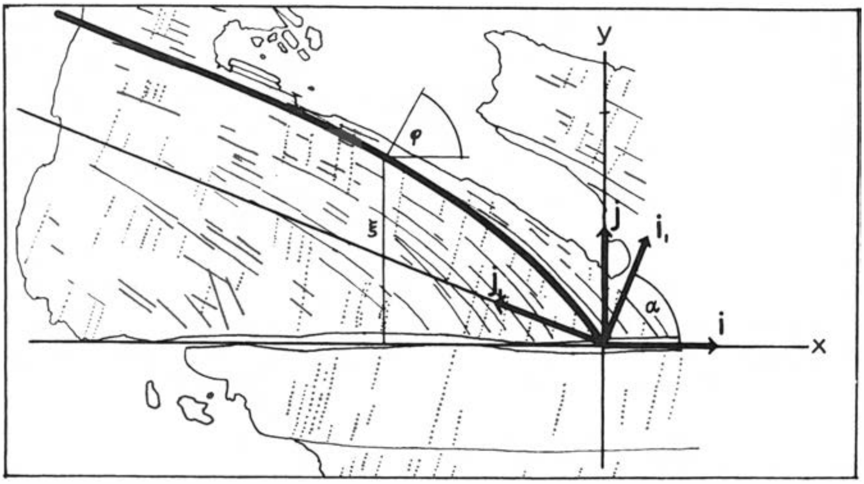

Fig. 5. The coordinate system with the principal unit vectors and a representative of the calculated curves, super-imposed on the joint pattern partly shown in Fig. 4. The length of the unit vectors is 100 m.

of $ke^{-\xi}$ in the above analysis. This seems to imply that the tensile force component parallel to $\mathbf{i}$ close to fault A and that parallel to $\mathbf{i}_1$, were of the same order of magnitude. If each of them is taken equal to 1, the resultant tensile force close to A will be $|\mathbf{i} + \mathbf{i}_1|$, or 1.65. Receding southwards from A, it will, naturally, decrease towards 1 as $|\mathbf{i}e^{-\xi} + \mathbf{i}_1|$. The effect of this may have been to start the formation of the joints close to A at the moment a force corresponding to the tensile strength of the gneiss which had been built up there, and make the fracturing proceed gradually therefrom. Within the direction field in question (between $\mathbf{i} + \mathbf{i}_1$ and $\mathbf{i}_1$), the gneiss appears to have behaved as a mechanically isotropic body.

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A pillow lava locality in the Grong District, Norway

By

Ebbe Zachrisson

(Sveriges Geologiska Undersökning, Stockholm 50)

In the course of field work during the summer of 1963, well-preserved pillow lavas were found in the Caledonian of the Grong district (Fig. 1). Due to road-work, ice-scoured outcrops north of Solberg farm had been cleared of their moraine cover. Although no detailed mapping was carried out, exposures with pillow lava structures could be followed for at least 1 km along the road to the northeast where they are associated with more coarse-grained gabbroic rocks. At the road junction west of Solberg, fragmental rocks, apparently of pyroclastic origin, can be seen.

The pillows, the size of which varies from a few decimetres up to more than a metre, are closely packed. The contact between different pillows is clearly marked by a dark border zone ranging from one to a

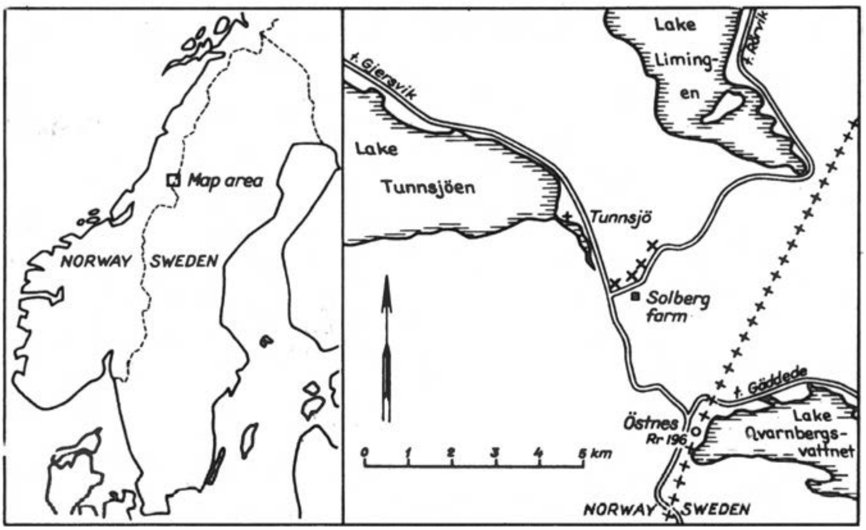

Fig. 1. Sketch map showing the localities of pillow lavas and pyroclastic rocks at the roadside near Solberg farm, Nord-Tröndelag, Norway.

Fig. 2. Pillows with thin border zones. Length of the compass about 12 cm. At the roadside NW of Solberg farm.

Fig. 3. Pillows with broad border zones. At the lower right corner, the vesicular texture is visible. Locality as Fig. 2.

few centimetres (see Figs. 2 and 3) in thickness. Generally, the interior of the pillow is lighter in colour, a little more coarse-grained and often shows an amygdaloidal structure. In thin sections, the rock is very fine-grained and mineralogical identifications are nearly impossible. X-ray diffractometer studies, however, point to a rather high content of amphibole (probably tremolite-actinolite), chlorite and plagioclase, some epidote, muscovite and calcite, and the presence of sphene. The quartz content is negligible, though some is present in calcite aggregates, which probably represent vesicular fillings. Apparently, the rock has a basaltic to andesitic composition.

Ever since Reusch (1888) gave the first description of Caledonian pillow lavas (using the word 'ellipsoider') from the island of Bömmelöen (Bömlo) on the western coast of Norway, rocks of similar type have been reported from a great many places in the southern and middle part of the country (see Vogt 1946). As late as 1960, Carstens stated that 'pillow lavas ... have so far not been observed north and west of Steinkjer'. Generally, these volcanics are looked upon as belonging to the Stören Greenstones and thus assigned an Upper Cambrian to Lower Ordovician age.

From the Swedish part of the Caledonides, pillow lavas have been described from S. Storfjället in Västerbotten (Beskow 1929) and from Låtats and Stuorab Titir in Norrbotten (Kulling 1948, Kautsky 1953). They have also been reported by Marklund from the Patta amphibolite southwest of Kebnekaise (see Kulling 1964).

Pillow lavas might have been observed in the Grong district by field geologists, but no mention of such structures is found in the literature dealing with the area. The well-preserved pillow lavas at Solberg, situated some 130 km northeast of Steinkjer, thus may be valuable when making stratigraphical correlations between this area and the Trondheim district, even if the stratigraphic position of such rocks in the Caledonides is a question that deserves further investigation.

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