SMALL SCALE TECTONICS

in a South Norwegian Gneiss Complex

BY

IVAR OFTEDAL

With 2 plates.

The plagioclase gneiss complex on the coast off Lillesand is remarkably uniform both in composition and in large scale structure. Along the shore towards the open sea the rocks are excellently exposed, so that every structural detail can be studied.

Plagioclase gneiss accounts for about 95 % of the rock surface, on the average. The main constituents of the gneiss are acid andesine (about An_{33}) and quartz. Subordinate but varying contents of biotite make the colour shift somewhat in shades of grey. Small quantities of epidote are usually present. Accessories are mostly scarce. Apart from a subparallel arrangement of the mica flakes the texture is perfectly granoblastic. The grain size is somewhat variable, but usually it is confined within the limits 1 and 2 mm. As will be shown below, the gneiss may be divided into roughly 2 types, mainly on tectonical grounds. On the average the one type — the more «competent» one — is more coarse grained and somewhat darker than the other. Both types are of great importance.

The remaining 5 %, roughly, of the area are made up of amphibolite, «micaschist» (really very biotite-rich gneiss), granite pegmatite, and vein quartz, in bodies of varying size and shape.

The amphibolite consists of an ordinary green hornblende, andesine (about An_{43}), and common accessories. At the contact towards granite pegmatite amphibolite may contain abundant biotite, epidote (about 30 % Fe-component), and sphene. The «micaschist», which is also extremely rich in epidote and sphene, may represent a further development of this process: the alteration of amphibolite through potassium metasomatism. The amphibolite is mostly fine grained, grain size 1 mm or less. The central parts of thicker bodies are massive with nearly equidimensional hornblende grains. Border zones and small bands etc. are schistose.

Granite pegmatite bodies are of highly variable shape, size, and tectonic setting. The grain size is approximately proportional to the thickness of the body and varies between a fraction of a mm and about 10 cm. The pegmatites are obviously of a metasomatic origin. Both amphibolite and pegmatite have appeared at various stages of development of the complex. The quartz veins are the youngest rocks in the area.

It is evident from the above statements that the complex is in high epidote-amphibolite or low amphibolite facies, according to the facies definition adopted (epidote in equilibrium with plagioclase up to about An_{40}). The rocks are all very fresh and exhibit very few traces of subsequent alterations. The present facies may be assumed to represent the conditions during the main phase of crystallization.

The large scale structure of the area can be closely represented by a schistosity plane striking N 38° E and dipping E 38° S $45 \pm 10°$. In the field the gneiss bands may appear from several meters down to a few millimeters thick. They are mostly straight for long distances. In hand specimen also the thicker bands usually exhibit a fine lamellar schistosity. In certain bands of the coarse grained type the schistosity may be absent or highly irregular. On the whole the schistosity is much more prominent in the fine grained gneiss bands than in the coarser ones. (Fig. 7).

Examples of small scale tectonics. Almost all the rocks show very distinct signs of internal movement in the main schistosity plane, and nearly all rock units have obviously been highly flattened (Figs. 1,2). As the original shapes of the various bodies are unknown, nothing definite can, however, be said about the amount of flattening. Some of the gneiss units, and possibly all of them, may gave formed from a medium which was in a state of continuous flow; in this case their original shapes may not have differed appreciably from the present platy and lenticular ones.

Some rock types, notably fine grained gneisses and still more the locally occurring «micaschist», show much stronger signs of flow than all the others. They behave in a very incompetent manner as compared with the coarser gneiss types, the amphibolites and the pegmatites. In many cases it can be seen that the competent rocks have been broken into larger and smaller pieces partly or wholly surrounded by fine gneiss or «micaschist». The schistosity surfaces of the latter then bend around corners and other irregularities of the fragment boundaries, giving boudinage-like structures or even breccias on larger and smaller scales (Figs. 5, 8, 9). Such observations demonstrate convincingly that the fine gneiss was some time highly mobile, and that it appeared later than the more competent rocks. Most of the fine gneiss, however, occurs in the regular way as straight bands alternating with bands of the other rocks (Fig. 7). Therefore it is assumed that fracture of the competent rocks most frequently occurred along already existing schistosity planes, and that adjacent competent plates afterwards moved relative to each other. The fine gneiss may have been introduced between the fragments from below, by plastic flow. However, I think it is more probable, since the fine and coarse gneiss types are very similar in composition, that mylonitic zones were formed in connection with the fracturing, and that the mylonite recrystallized afterwards during plastic flow movement, giving the fine grained and fine lamellar gneiss types. Recrystallization should take place preferably in such mylonitic zones, both because of the simultaneous movement and because of the small grain size. The competent plates and fragments themselves apparently were not notably deformed or recrystallized during this process. There are reasons to believe that the stress causing the flow was comparatively very slight. It has been able in some cases to fold and otherwise deform small bands and dikes embedded in incompetent rocks (Figs. 3, 4, 6). But it has not been able to break large single microcline crystals in immediate contact with flowing gneiss (Fig. 11).

It appears that the competent rocks once formed an «old complex» which had reached a stage of relative rest and a high degree of rigidity, when renewed activity on the same lines as before caused the fine gneiss to form and flow, and new granite pegmatites to appear.

The metasomatic origin of these pegmatites is highly evident. Remnants of gneiss are frequently seen within the larger bodies, which in addition may exhibit very irregular boundaries depending on the relative «solubility» of the various gneiss bands (Fig. 13). In thin section it can be seen how the pegmatite formation begins:

small microcline individuals accompanied by myrmekite appear thinly scattered in the plagioclase gneiss. As this incipient pegmatite formation is often observed along narrow gneiss bands, it is assumed that potassium metasomatism and plastic flow took place simultaneously. The potassium metasomatism must have continued until the renewed movements had nearly stopped and the complex attained its present structure. Some pegmatite bodies, especially veins and small dikes, show more or less folded, squeezed or flattened shapes (Fig. 6). But some relatively large ones, up to many square meters in size, form irregular patches («petroblasts») in the gneiss, completely massive and undeformed (Figs. 13, 14). These latest pegmatite bodies are not visibly influenced by the stress at all, even if the surrounding gneiss itself still shows weak signs of plastic flow (Fig. 14). The central parts of these pegmatites may contain microcline crystals up to 10 cm in size. But a narrow border zone is still fine grained, evidently because here the formation of new growing microcline crystals was still going on.

About at this stage the whole area was traversed by a set of vertical joints, most of them perpendicular to the main schistosity plane. These joints are now highly conspicuous features in the landscape. They are doubtless due to a continued action of the stress which formed the gneiss structures, now acting on nearly rigid rocks. Complete rigidity had not been reached, though, for it is sometimes observed that the rocks have been slightly deformed after the formation of the joints, e. g. more compressed on one side of the joint than on the other (Fig. 12). The deformation is of the same order of magnitude as that which occurred after the formation of the latest pegmatites; therefore it is assumed that these and the joints were formed about at the same time. The mechanical properties of the gneisses at this stage must have been such that they could yield slowly to a long lasting stress but at the same time develop internal tensions strong enough to produce sudden cracks. The joints have sometimes been opened and filled with vein quartz. Similar quartz fillings are also found between pegmatite boudins (Fig. 10) and between more irregular rock fragments.

Typical boudinage structures seem to belong to late stages of development, i. e. to stages (or localities) where the relative movements were very slow. Rapid flow of incompetent rocks along competent bands would presumably take most boudins far apart. It might even rotate the fragments and produce breccia structures like those referred to above. In any case the incompetent rock would fill completely the spaces between the fragments, not just bend slightly towards the space between boudins, leaving most of it open for the usual quartz filling (Fig. 10).

Boudinage and similar structures may form in various mineral facies. The competent bands usually consist of amphibolite (or equivalent gabbroic rocks) and granite pegmatite. In the present case the (chemically uniform) plagioclase gneiss itself occurs in both competent and incompetent bands, and as both fragments and matrix in breccias. This would hardly be possible in higher facies, where all of the gneiss would presumably be rapidly mobilized and recrystallized.

Oslo, Mineralogisk institutt,
august 1956.

Manuscript received, August 27, 1956.
Printed, November 1956.

PLATE I.

Fig. 1. View in the strike direction, towards NE. Gneiss with amphibolite and pegmatite (light) bands.

Fig. 2. Vertical rock wall some 10 m high, perpendicular to the schistosity. View towards NE. Gneiss with lenticular amphibolite body.

Fig. 3. Amphibolite band, 10 to 20 cm thick, folded in fine grained gneiss.

Fig. 4. Band of fine grained gneiss, a few cm thick, folded and highly distorted in biotite-rich gneiss.

Fig. 5. Amphibolite fragments in a matrix of fine grained gneiss.

Fig. 6. Small pegmatite dike folded in fine grained gneiss. Horizontal rock surface. Area about 40 by 30 cm.

Fig. 1

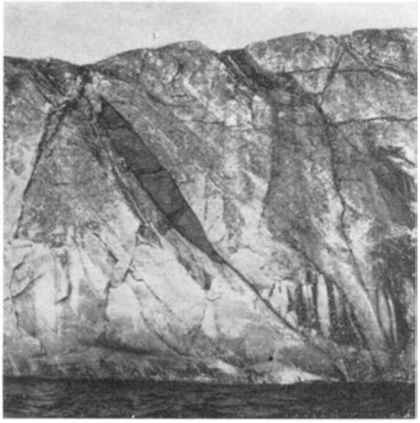

Fig. 2

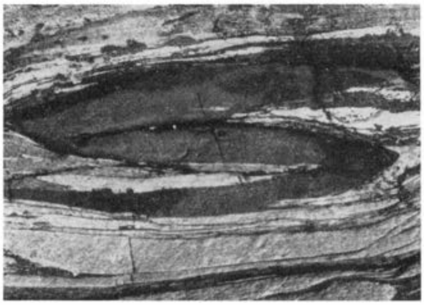

Fig. 3

Fig. 4

Fig. 5

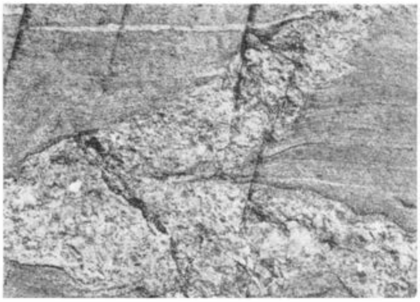

Fig. 6

PLATE II.

Fig. 7. Broad bands of coarser (left) and finer gneiss in contact. A few m^2 of the rock surface.

Fig. 8. Lenticular fragment, some 2 m long, of coarser gneiss in finer gneiss.

Fig. 9. Lenticular fragments of amphibolite separated by veins of fine grained gneiss. The lower very regular lens is about ½ m long.

Fig. 10. Boudinage structure with quartz filling in a granite pegmatite band, about ½ m thick.

Fig. 11. Pegmatite «knot» with angular microcline crystals (left) in «flowing» gneiss. Nearly horizontal rock surface. Area about 40 by 30 cm.

Fig. 12. Unequal deformation of gneiss on the two sides of a joint. Horizontal surface. Area about 40 by 30 cm.

Fig. 13. Remains of partly consumed gneiss bands protruding into massive irregular pegmatite body. Upper right corner: large amphibolite body.

Fig. 14. Pegmatite body, about 1 m long, replacing gneiss. Most of the body is quartz, possibly younger vein quartz. Microcline occurs in a narrow border zone only.

All the photographs have been taken near the East end of the island of Justøy.

PLATE II

Fig. 7 ←

Fig. 8 →

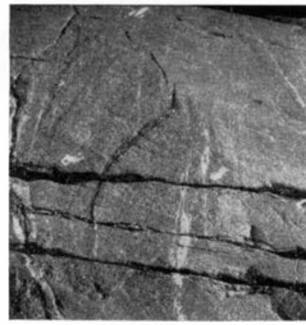

Fig. 9 ←

Fig.10 →

Fig.11 ←

Fig.12 →

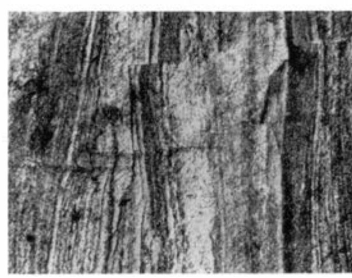

Fig.13 ←

Fig.14 →