A Discussion. The Relation of Joint Patterns to the Formation of Fjords in Western Norway

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Nilsen's (1973) recent description of joint patterns from the Solund area and the regional-scale application of his results provides an interesting contribution to the long-standing debate on the genesis of the Norwegian fjord system. Although a good deal of Nilsen's synthesis and interpretation is fair comment, it is difficult to turn a blind eye to certain statements which one feels may have arisen simply through not having had access to current literature. The present note, rather than being contentious in any way, aims principally at providing supplementary information arising from points made by Nilsen.

Before dealing with regional aspects, it is interesting to compare Nilsen's figs. 3, 4 and 5 and Table 1 with his proposition (p.192) that, for west Norway, the major N-S joint set may represent tension joints with the NE-SW and NW-SE oriented sets being shear joints. Considering the three prominent joint orientations in the Devonian rocks, I have calculated the mean value for each of these taking into account the joint frequencies in the two sectors adjacent to each frequency peak and assuming a circular normal distribution. Means of 295° and 353° can indeed be readily interpreted as conjugate shear joints disposed symmetrically to the dominant NE-SW to ENE-WSW strike of the Devonian strata, the 065° set representing tensional fractures. The inference of this is that the Solund/Buelandet-Værlandet joint system could well have been initiated by the Svalbardian tectonism. While this would seem to clash with Nilsen's thesis of a probable Tertiary age for these fractures, it is important to remember that stress fields change with time such that, e.g. shear joints of one period may be rejuvenated and enlarged in a later tensional regime, thus effectively camouflaging their earlier history.

Turning to the question of the regionally prominent N-S and E-W fjords and their parent structural features, restriction of discussion to the ground delimited in Nilsen's fig. 1 gives a false impression of major structural and geomorphological trends within southern Norway as a whole. Fractures, both faults and master joints, trending NE-SW and NW-SE dominate the tectonic picture; this is clear from a glance at the geological map (Holtedahl & Dons 1960), and is even more apparent from an examination of ERTS-1 satellite photographs now in progress at Norges Geologiske Undersøkelse (F. W.

Haarbrink, pers. comm.). This would suggest that it is inadvisable to continue using Kolderup's (1931) terminology of 'strike' and 'fissure' fjords. The former is a particularly unfortunate choice of term, not only because of the variability of bedding and foliation strike but also as the predominant tectonic trend-lines within Norway approximate to NE-SW, not E-W as in Kolderup's original definition and usage.

Recognition of this basic NE-SW and NW-SE fracture system within southern Norway is also reflected in Hast's (1969) determinations of absolute stresses and the existing horizontal stress field in the Fennoscandian region. In the coastal areas of southern Norway the measured directions of maximum horizontal shear in vertical planes are virtually constant at NE-SW and NW-SE, a characteristic which Hast logically associated with the main fjord and coast trends. It is well known, however, that many of these fractures were initiated in Precambrian times (Wegmann 1960) so that the existing horizontal shearing stresses are in effect utilizing pre-existing faults or joints. In this regard it is worth noting that the existing or *in situ* stress in the earth's crust comprises several components, e.g. current tectonic stress, weight of over-burden, fluid pressure and residual tectonic stresses. Residual stresses are of immediate interest here; the existence in rocks of self-equilibrating components of earlier tectonic stresses has long been known, and it has been demonstrated that remanent elastic strains dating back even to Precambrian events are measurable to the present day (Hooker & Johnson 1969, Eisbacher & Bielenstein 1971). It is thus quite feasible that part of the stress field operating in the upper crust in Norway today contains residues of Precambrian tectonic stresses as well as components from later deformations.

These findings have application in discussion of the origin of the Norwegian Channel, considered by Nilsen to represent a major fracture zone of Tertiary age. Although a tectonic origin for the Norwegian Channel has had many advocates (e.g. De Geer 1924, Holtedahl 1950, 1960, Pratje 1952), recent geophysical studies, some of which were not published when Nilsen wrote his paper, have favoured derivation of this depression *per se* by glacial erosion (Sellevoll & Aalstad 1971, Flodén & Sellevoll 1972, Talwani & Eldholm 1972, Flodén 1973) following the view of Shepard (1931). The results, to date, of seismic profiling across the Channel have indeed shown that intense glacial activity has produced its present-day morphology and bathymetry and that Tertiary faulting is minimal, but in the present writer's view this need not preclude a fundamental tectonic influence. Proponents of the 'fault theory' have based their notions of channel development exclusively on *Tertiary* uplift, but it appears more likely that older, moderately deep-seated, fracture zones, of Precambrian or later age, have provided the initial crustal discontinuities which have subsequently been periodically reactivated even up to the present day. A similar possibility for the Skagerrak part of the Norwegian Channel, in this case involving Permian movements, has recently been voiced by Åm (1973); Vokes (1973) has also discussed the fracturing in this S.E. Norway region.

The considerable seismic activity centred on the Channel (Kvale 1960), as well as the results of Hast's stress-field work, certainly attests to the fact that major crustal weaknesses are present and movements still occurring along these NE-SW, NW-SE and, in west Norway, N-S trends. The steep scarp-like character of the crystalline basement beneath the inner margin of the Channel does appear to suggest that pre-Mesozoic tectonism has played its part in facilitating subsequent erosion along these lines of weakness. The depressions would then have been infilled by Mesozoic and Cenozoic deposits (the buried fractures being to some extent rejuvenated during the Tertiary uplift), and eventually acted as loci for Quaternary glacial overdeepening. In this scheme of events the Norwegian Channel is thus envisaged as a compound linear feature, the Mesozoic and later sedimentation and Pleistocene glacial erosion totally masking the older crustal discontinuities.

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