A Reply. A Late Precambrian Tilloid from Varangerhalvøya – Evidence of both Glaciation and Subaqueous Mass Movement

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In his comments on our interpretation of the origin of the Løkevik tilloid, K. Bjørlykke questions the possible glacial affinities which we suggested could be represented by certain listed criteria. The actual mode of emplacement of the unsorted conglomerate, by the agency of subaqueous mudflow, is not challenged; on the other hand, Bjørlykke considers that two of the petrological characteristics of the lithology definitely reject the possibility of any glacial connection. Before dealing with these points, we would like to put on record that our suggesting a probable composite origin, and an indirect glacial influence, for the tilloid, was initially conveyed in our phrasing the title of the manuscript in the interrogative. Most regrettably the question mark was omitted at a late stage of printing, too late in fact for the error to be rectified.

The two controversial characteristics of the Løkevik tilloid, in Bjørlykke's view, are (a) the predominance of vein quartz pebbles and fragments and (b) the subordinate amount of feldspar in the matrix. Concerning the first point, we do not doubt that selective weathering in tropical regions would result in local concentration of quartz fragments. Nor do we deny that, in the conglomerate in question, most of the other pebbles are of 'rock types resistant to weathering'. We are surprised, however, that this criterion is put forward as an anti-glacial argument. In the first place the Løkevik tilloid occurs within a fairly deep marine turbidite sequence and, since it is allochthonous in the sedimentary sense, it is only to be expected that the most durable lithologies and minerals would represent the greater part of the stone material. As we pointed out, the actual composition of the stones, of intrabasinal and extrabasinal derivation, is not critical.

Following on from this, Bjørlykke maintains that few signs of selective enrichment of pebble material are to be found in glacial conglomerates from geological periods older than Quaternary. This is quite an erroneous statement; for example, one only has to read descriptions of the Dwyka Formation tillites in southern Africa and equivalent glacigenes in many parts of

South America, Antarctica, Australia and the Falkland Islands to find that vein quartz frequently occurs abundantly as clasts, and locally may even constitute the dominant stone material (Frakes & Crowell 1967, 1969, 1970, Lindsay 1970). Nearer at hand, the Varangian Moelv Tillite of southern Norway is also locally enriched in quartz pebbles; and even older, Precambrian, glacial conglomerates from Spitsbergen also contain many durable quartz and quartzite fragments. Clearly, the provenance of the stone material in tillites is the all important factor in their petrography. It is therefore most surprising that Bjørlykke should suggest that the composition of the Løkevik tilloid appears 'untypical' as compared with true glacial conglomerates.

On the grounds of retarded chemical weathering in colder climates, a comparatively high detrital feldspar content of tillites would, in theory, appear to be a more telling criterion in distinguishing glacial from non-glacial deposits. Bjørlykke's second objection relates to our reference to 'subordinate feldspar' in the matrix. For descriptive purposes, the matrix of the tilloid was divided into two grain-size classes, this 'subordinate' feldspar relating to that of sand-sized grains (Siedlecka & Roberts 1972, p. 138). Modal analyses of the matrix of the tilloid have shown the following: sand-sized quartz 44 %, sand-sized feldspar 6 %, rock fragments 5 %, silt- to clay-sized groundmass 45 %. In a *stained* thin-section, comparative figures showed: quartz 35 %, feldspar 15 %, rock fragments 5 %, silt- to clay-sized groundmass 45 %. The higher feldspar content in the stained thin-section is partly related to the fact that many, small, untwinned grains of plagioclase are otherwise very difficult to detect.

In the abundant silt-size groundmass, a part of the sericitic material almost certainly represents altered feldspar, but the low grade metamorphism has masked this breakdown. Thus, the *total* matrix feldspar content of the tilloid prior to metamorphism was probably somewhat more than 15 %.

If we compare this matrix feldspar content with that reported from Pre-Quaternary glacial deposits, it is generally either greater than or falls within the frame of most observed variations (Frakes & Crowell 1967, 1969, 1970, Lindsay 1970, Pinet et al. 1971). In a selection of South American diamictites, matrix feldspar content varies from 1 to 15 %, averaging 5.3 % (Frakes & Crowell 1969). It is therefore clear that undue significance is attached to matrix feldspar content as constituting reliable evidence in any glacial *vs.* non-glacial controversy. Variations are dependent largely on the lithology of the area of supply, as in the case of clast content and composition. Examination of several other parameters in the matrix of Quaternary tills bears this out, lateral trends of composition reflecting the lithology of the overridden bedrock (Jacobs 1972).

In our paper we noted that the conglomerate at Løkevik differs markedly in character from other ruditic rocks in the Kongsfjord Formation (Siedlecka & Roberts 1972), and has the appearance of a tillite. In adopting the term 'tilloid' (definition in Harland et al. (1966)), we recognized an element of

uncertainty as to the precise origin. Even though the lithology, as we see it today, has been emplaced by some form of subaqueous mudflow, we suggest that it is conceivably polygenetic. The reasons were outlined in the paper, but we would like to emphasize that we consider the general stratigraphic and regional evidence to be important in any discussion of the possible existence, or close pre-existence in geological time, of a glacial environment.

Evidence for an intermediate glacial period between the Huronian and Varangian is present in NE Spitsbergen, East Greenland and NW Russia, and these particular tillites occur at a similar niveau to that of the basal Barents Sea Group rocks. The tillite-like character of the Løkevik tilloid made us try to discover whether or not any objective evidence could be found in favour of glaciation. Some appears to exist, but it is not enough; hence our conclusion that the lithology could possibly represent an *allochthonous tillite*. Alternatively, it could be an example of a *derived tillite* (Harland et al. 1966). In this regard, lithostratigraphic correlation within east Finnmark (Siedlecka & Siedlecki 1972) suggests that an older, Late Precambrian, glacial event is already represented in Norway. Laird (1972) has shown that the Ifjord Formation of the Laksefjord Group is a glacial conglomerate; based on Siedlecka & Siedlecki's (1972) correlation, this is older than the Kongsfjord Formation.

Notwithstanding these regional and intercontinental correlations, we would conclude in agreeing with Mr. Bjørlykke that the evidence provided by the Løkevik tilloid *alone* is insufficient to demonstrate the existence of a glacial period. As Harland et al. (1966) have noted, the use of the term 'tilloid' is convenient in that it delays judgement and encourages further investigation. This is surely something that we all would endorse.

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