Precambrian primary volcanic structures in the Alta-Kvænangen tectonic window, northern Norway

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In a small area in the western part of the Alta-Kvænangen window it has been possible to reveal the presence of a minimum of six basaltic lava layers separated by tuff/tuffite beds. The lavas have well-preserved primary structures including pillow lava, columnar jointing, pillow breccia, and pipe vesicles, while massive lava lacking specific structures is common. The tuff/tuffite beds exhibit sedimentary bedding, graded bedding, and cross-bedding. Available evidence indicates a subaquatic 'mise en place' for all the rocks of Middavarre.

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The present publication reports some of the results of a field and laboratory project designed to study the geology of the Middavarre iron and copper showings. In the following text, attention is given to a description of the primary volcanic structures in the Middavarre area in Burfjorddalen which is located on the northern side of the fjord Kvænangen in northern Norway. Middavarre is situated in the western part of the Alta-Kvænangen tectonic window of Precambrian rocks (Reitan 1960, Zwaan et al. 1973). The rocks of this window as well as those of the Altenes window (Roberts & Fareth 1974) and the Komagfjord window (Reitan 1963) belong to the Raipas Group, which is considered to be of relatively young Precambrian age, most likely Karelian (Reitan 1960).

Geology of Middavarre

The Middavarre rock complex belongs to the Lower Raipas Group and has been metamorphosed to greenschist facies. The tectonic deformation is insignificant with the layers lying right way up. A geological map of the Middavarre area is presented in Fig. 1 with a profile in Fig. 2. Along Storelva the volcanic rocks have a faulted contact to the Bossekop Group quartzite (Holtedahl 1918, Føyn 1964) which close to the contact is mostly white, occasionally reddish. The rocks to the north of Storelva have been downfaulted relative to the Middavarre rocks. The actual area appears to be one where the contact between the Raipas rocks and the rocks belonging to the Bossekop Group is tectonically disturbed. The effect of this probably local disturbance (Føyn 1964, Roberts & Fareth 1974) is noticeable as a schistosity of the volcanic rocks a few metres away from the contact. Furthermore, lenses of volcanic rocks occur in the quartzite close to the contact.

The western part of the Alta-Kvænangen window, including Middavarre, was mapped in small scale by Zenzén (1915). Many small iron and copper ore mineralizations on Middavarre have attracted the attention of prospectors through the years. The three largest known occurrences are Malmkula, Storskjæringa, and Søndre Middavarre, which periodically have been worked as mines. On the map of Zenzén (1915) and in available written reports the country rock is called metagabbro or diorite.

Pillow lava

In the present area, pillow lavas were first observed and mapped by Zenzén (1915). This lava type occurs as closepacked piles of pillows with restricted lateral regional extension for each layer of pillows in the Middavarre area. The pillows are well preserved allowing a safe determination of the facing of the piles.

Especially the Gammeelva is an area where it can be demonstrated that the two dimensional

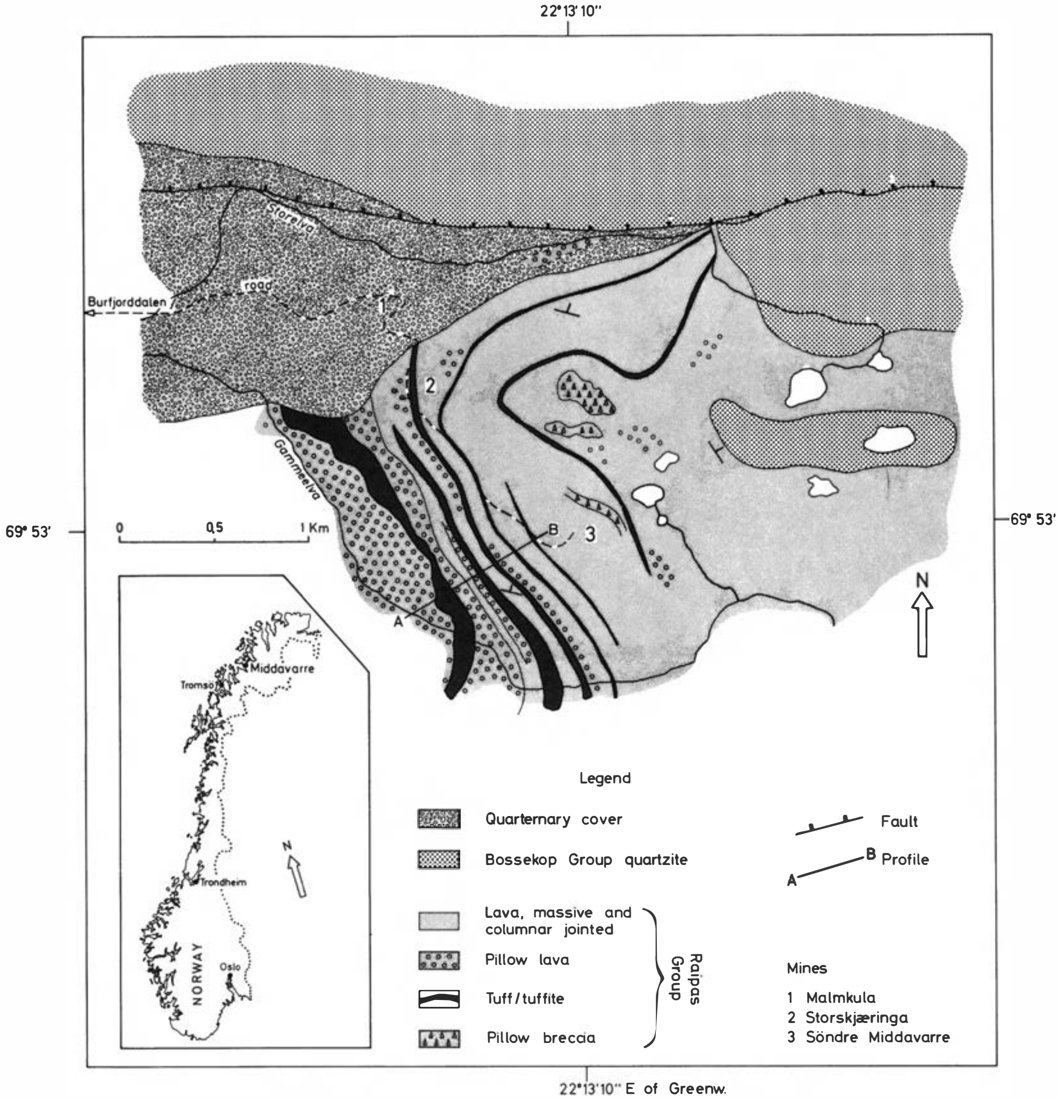

Fig. 1. Geology of Middavarre, north Troms.

shape of the pillows is highly dependent upon the orientation of the outcrop planes in the pillow lava stream. Along Gammeelva the pillow lava flow (lowermost layer, Fig. 1) is lying in an approximately horizontal position with good exposures in the plain of lava flows as well as normal to this plane. The vertical outcrops are found to be orientated at different angles in relation to the general direction of the flow which is approximately east-west. Accordingly a three-dimensional view of the structures is offered, and the overall impression is made even better because of the fact that the individual pillows are standing out in relief with good preservation of original pillow morphology.

Studied from above, most pillows are elongated and 'sausage' shaped, sometimes bent and twisted and with variations in thickness (Fig. 3). The longest pillow found in outcrop is 160 cm and strongly bent. This length is about five times the longest cross-section diameter of this particular pillow. In cross-section exposures, the

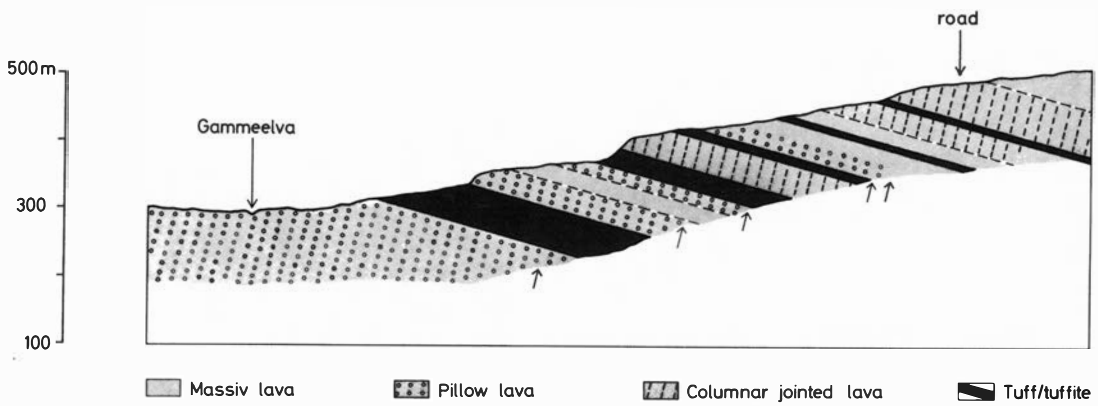

Fig. 2. **Profile across the southwestern slope of Middavarre. For exact location see Fig. 1. Arrows indicate layers along the profile where the facing has been determined. Note that bedding is about horizontal along Gammeelva.**

pillows exhibit several forms including bun, balloon, bean, and pedunculate shapes (pillow terminology from Vuagnat 1975). In outcrops diverging more or less from a normal orientation with regard to the longest dimension of the pillows there is a tendency for the sections to have more or less lensoid or elliptic shapes. Occasionally the pillows fork into two parts, thus showing the flow direction of the lava stream. It is even possible to find pillows whose crust has been pierced and thereby has formed a protuberance or a new pillow. Connected pillows are commonly observed. Our observations on the pillow lavas appear to conform well with reported evidence from Montegenevre in the French-Italian Alps and other places, as described by Vuagnat (1975).

The individual pillows in the pillow lava streams are generally well-jointed and separated from each other by what is the former glassy crust about 1 to 2 cm thick. The crust consists now mostly of chlorite along with a little epidote and crumbles rather easily by chemical action causing the pillows to weather out almost unbroken in some instances.

On a cut and polished surface the internal structure of a pillow is clearly visible, starting with an outer dark chlorite crust which has been a glass matrix. This is followed inwards by a thin, light coloured variolitic zone which is in contact with an amygdule zone about one centimetre from the pillow border. The amygdules consist of dark chlorite, and are often coated with epidote; the size is up to 3–4 mm. From the amygdule zone to the centre of the pillow there is a fine-grained matrix. Under the microscope it is evident that metamorphic transformations have to some degree altered the original texture which is now defined by an intimate mineral intergrowth involving actinolite, epidote, albite, and sphene/leucoxene. The pillows are cracked in a somewhat irregular manner with central empty spaces found now and then.

Pillow breccia

Fragmental volcanic rocks have been found on the top plateau of Middavarre and exposed on flatlying surface close to the Søndre Middavarre mine. Boulders of similar rock were also found in the northern screes of Middavarre.

The breccias of Middavarre have unsorted fragments of several types. A tracing of part of the best exposure found is shown in Fig. 4. One seemingly whole, unbroken pillow can be seen here (fragment A, Fig. 4). However, it could not be excluded that this is a fractured pillow of similar type as fragment B. Pillow fragments are easily recognized by their crust and amygdule zone, like fragment C. Fragments lacking any specific characteristics are abundant (illustrated by fragment D of Fig. 4), and many fragments without crust and amygdule zone are very likely interior parts of disaggregated pillows.

The fragments are enclosed in a fine-grained metahyaloclastic matrix without bedding or sorting. The matrix appears to be very rich in epidote, and in places there are radial aggregates of redbrown tourmaline (tourmaline suns).

Fig. 3. Elongated sausage-shaped pillow. At Gammeelva.

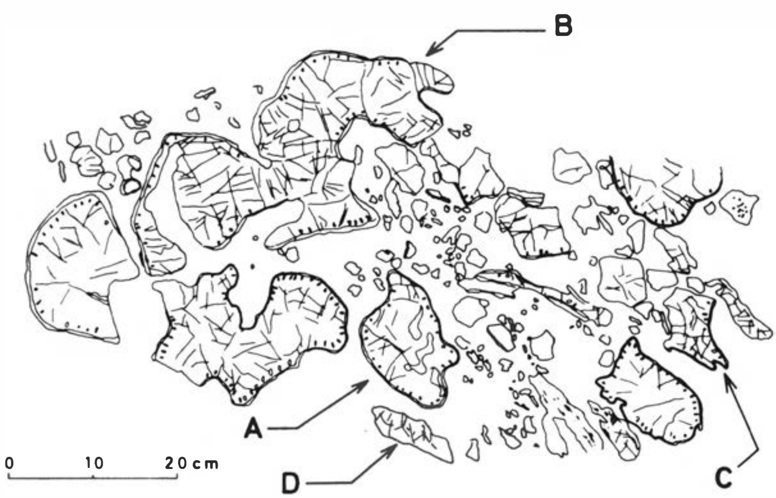

Fig. 4. Pillow breccia with different types of fragments. A: Possibly unbroken pillow. B: Partly broken pillow. C: Pillow fragment with amygdule zone. D: Fragment without amygdule zone. Traced directly from outcrop. Søndre Middavarre area.

Columnar jointing

A characteristic feature of Middavarre is a steep, irregular jointing which can be readily observed in many places. On flatlying or moderately inclined surfaces the jointing is seen to form irregular networks. In some outcrops a distinct polygonal pattern is clearly visible. Well-developed jointing on nearly horizontal surfaces causing multisided polygons are exposed inside and close to the Søndre Middavarre mine.

Along the northwest escarpment of the Middavarre plateau a three-dimensional view of the jointing is afforded (Fig. 5), and it is seen here that the steep jointing actually is a columnar jointing. The columns, which at this locality are seen to terminate abruptly downwards against a tuff/tuffite layer, are 15–20 cm across, and the columns are somwhat bent in all directions.

The best and most regular columns were found in a big boulder lying close to upper Gammeelva. The five or six-sided columns are here 30–40 cm

Fig. 5. Basalt columns starting abruptly above a tuff/tuffite layer. NW escarpment of the Middavarre top plateau.

across extending without curvature for two metres. A five-sided fragment is shown in Fig. 6 broken by a saucer-shaped cross-joint with a flat lip between the edge of the column and the edge of the saucer. This is probably a 'ball-and-socket' joint (Preston 1930), which is quite common in columnar basalts of younger age.

The columnar jointing is approximately at right angles to the tuff/tuffite layering. The rocks affected by this type of jointing are otherwise massive, fine- to medium-grained. The relatively coarse grain of the rock, often visible to the naked eye, has misled prospectors and others to identify the rocks as metagabbro or diorite. The steep jointing described above is not seen in pillow lavas or in tuff/tuffites.

Fig. 6. Fragment of a regular five-sided column with 'ball-and-socket cross-joint.

Massive greenstone

Within the Lower Raipas Group massive greenstones are frequently found lacking pillow structures and columnar jointing. The massive greenstones are in concordant positions and have widespread lateral extensions. In places there seems to be a transition to pillow lava. The texture is often blasto-ophitic, fine- to medium-grained, individual grains being often visible to the naked eye.

In the Middavarre area there occurs within the massive greenstone bodies a massive coarse-grained rock with an easily recognized ophitic texture. The plagioclase laths are up to one centimetre long set in a matrix of uralitic hornblende. The border against massive greenstone seems to be transitional and the lateral extent of the coarse-grained rock is clearly restricted in every case. In an ore prospect located between Malmkula and Storskjæringa this coarse-grained rock has a somewhat crude, but distinct columnar jointing.

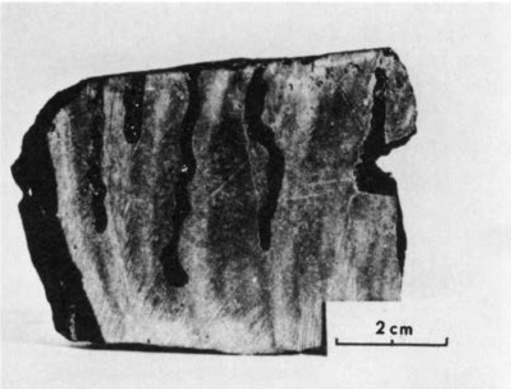

Fig. 7. Curved pipe vesicles. The vesicles have been coloured. Søndre Middavarre area.

We presume that the massive greenstones, including the coarse-grained varieties, are submarine flows that did not develop pillow structures or columnar jointing. This assumption is supported by the close interbedding of massive greenstone with pillow lava. The coarse-grained rocks may represent inner, central portions of lava streams with a slower cooling rate than the outer parts. The probability of the massive greenstones being sills is excluded as no indications of intrusive contacts have been observed.

Pipe vesicles

Not far from Søndre Middavarre mine the surface of the massive lava outcrop is perforated by elongated vesicles. The average diameter is 2–5 mm; in some places holes attain a diameter of 1 cm. In sections at right angles to this lava surface the pipe vesicles are seen lengthways, the longest vesicle measured being 4 cm.

The pipe vesicles are chiefly filled with calcite and dark chlorite together with a little epidote. Postglacial weathering has removed some of the secondary vesicle fillings, leaving partly empty holes on exposed surfaces.

The overall feature of this structure seems to be in accordance with the definition of pipe vesicles in the sense of Shrock (1948). When a lava stream flows over a wet substratum the steam formed rises into the lava flow with a considerable force forming 'pipes'. Two adjacent channels might meet each other, forming an inverted Y. This is assumed to be a facing figure (Shrock 1948). On Middavarre and also in the surrounding areas this facing criterion indicates that the sequence is right way up.

Rocks with sedimentary structures

Closely associated with lavas of different structural types there occur layers exhibiting sedimentary features, such as cross bedding, graded bedding, and sedimentary layering. The sedimentary layers appear to be fine-grained and massive in some localities, whereas in other places microbreccias lacking any form for sorting and with rock fragments up to 1 cm long, are seen. Spherical fragments resembling mudballs (Shrock 1948) were also discovered. The observed sedimentary facing as seen from cross bedding corresponds perfectly well with all observations on pillow lavas. The sedimentary rocks might be considered mostly as tuffs and tuffites, using the classification of Blokhina et al. (1959) for ancient clastic rocks.

Discussion

The layered sequence of volcanic rocks and their derivatives constitutes a stratigraphic pile of layers which can be seen to be some 400 m thick along the profile shown in Fig. 2. By means of the tuff/tuffite layers it is possible to separate a minimum of six individual lava-flows. The number of flows may, however, exceed this figure since some flows are probably not separated by any marker horizon and are therefore difficult to delineate.

The close association of the pillow lavas of Middavarre with water-formed sediments exhibiting structures like sedimentary bedding, graded bedding, and small scale cross-bedding confirms the assumption that the pillow lavas are subaquatic. The exceptional feature concerning Middavarre is a close proximity of columnar jointing to these subaquatic structures. The intimate interlayering of columnar jointed layers with pillow lavas, pillow breccias, and subaquatic sediments strongly indicates a subaquatic formation also for the columnar jointed layers. It should be stressed that columnar jointing with various grades of perfection is the most common structure seen in the Middavarre area. There is little evidence to suggest that columnar jointed layers on Middavarre represent sills. The regular trend of all layers seems to be in contradiction to the idea of several rather thick and closely spaced sills. It would also appear that the columnar jointed layers are too thick to develop a regular jointed pattern when regarded as sills (Macdonald 1967).

In the Middavarre area proper the individual pillow lavas have restricted lateral extension. It is evident from field examination of the second lava layer to the northeast of Gammeelva (Fig. 2) that more than one structure is present in the same layer, viz. lava pillows, columnar jointing, and massive lava. It appears highly possible that the different lava flows have in general given rise to several types of structures in a single stream. A multistructural lava stream may have formed by the development of pillows in the advancing lobes of the lava stream with simultaneous formation of columnar jointing and massive lava behind and within. Our observations from Middavarre appear to some extent to be in accordance with experience from Iceland, reported by Sigvaldason (1968), where Cenozoic volcanic formations display a multitude of structures in subaquatic lava flows. The physical and environmental factors giving rise to closely associated lava structures of several kinds could, according to Sigvaldason, be special combinations of lava viscosity, rate of lava production, and bottom slope gradient.

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References

Blokhina, L. I., Koptev-Dvornikov, V. S., Lomize, M. G., Petrova, M. A., Tikhomirova, E. I., Frolova, T. I. & Yakovleva, E. B. 1959: Principles of classification and nomenclature of the ancient volcanic clastic rocks. *Inter. Geol. Review, 1,* 56–61.

Føyn, S. 1964: Den tillittførende formasjonsgruppe i Alta – en jevnføring med Øst-Finnmark og med Indre Finnmark. *Nor. Geol. Unders. 228,* 139–150.

Holtedahl, O. 1918: Bidrag til Finnmarkens geologi. *Nor. Geol. Unders. 84,* 1–314.

Macdonald, G. A. 1967: Forms and structures of extrusive basaltic rocks. 1–61. *In* Hess, H. H. & Poldervaart, A. (Eds.) *Basalts.* Interscience Publishers.

Preston, F. W. 1930: Ball and socket jointing in basalt prisms. *R. Soc. London Proc. ser. B, 106,* 87–93.

Reitan, P. H. 1960: Precambrian of northern Norway. *In* Holtedahl, O. (Ed.). Geology of Norway. *Nor. Geol. Unders. 208,* 67–98.

Reitan, P. H. 1963: The geology of the Komagfjord tectonic window of the Raipas suite, Finnmark, Norway. *Nor. Geol. Unders. 221,* 1–69.

Roberts, D. & Fareth, E. 1974: Correlation of autochthonous stratigraphical sequences in the Alta-Repparfjord region, West-Finnmark. *Nor. Geol. Tidsskr. 54,* 123–129.

Shrock, R. R. 1948: *Sequence in Layered Rocks.* McGraw-Hill, 507 pp.

Sigvaldason, G. E. 1968: Structure and products of subaquatic volcanoes in Iceland. *Contr. Mineral. Petrol. 18,* 1–16.

Vuagnat, M. 1975: Pillow lava flows: Isolated sacks or connected Tubes? *Bull. Volcanol. 39–4,* 1–9.

Zenzén, N. 1915: Rapport öfver en geologisk undersøkning af Altens Koppargrufvors område i Kvänangen, Tromsø amt, Norge. *Nor. Geol. Unders. archives,* Trondheim.

Zwaan, K. B., Ryghaug, P., Gautier, A. M. & Föyn, S. 1973: Geological map sheet Alta. *Nor. Geol. Unders.*