Cross-bedding and Palaeocurrents in the Ahlmannryggen, western Dronning Maud Land

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Cross-bedding in the Pyramiden, Schumacher and Högfonna Formations has a clear preferred orientation with a relatively small variability in azimuth, indicating continual uplift of the provenance area. In the case of the Tindeklypa Formation volcanic activity caused frequent shifts in current direction as a result of which cross-bedding in this formation shows no clear preferred orientation.

The results, especially in the upper part of the Schumacher Formation and the three members of the Högfonna Formation, indicate a clockwise movement of the provenance area relative to the Ahlmannryggen during deposition.

Kruisgelaagdheid in die Formasies Pyramiden, Schumacher en Högfonna het 'n duidelike voorkeur-oriëntasie met relatief klein afwykings in die hellingsrigting. Dit dui op voortdurende opheffing van die brongebied. In die geval van die Formasie Tindeklypa het vulkaniese aktiwiteit herhaaldelike veranderings in die stroomrigting veroorsaak as gevolg waarvan kruisgelaagdheid in die formasie geen duidelike voorkeur-oriëntasie toon nie.

Die resultate, veral in die boonste deel van die Formasie Schumacher en die drie lede van die Formasie Högfonna, dui op 'n regsom-beweging van die brongebied relatief tot die Ahlmannryggen tydens afsetting.

Introduction

Mapping of cross-bedding and other primary structures has proved useful in reconstruction of regional palaeoslopes (*Potter & Olson*, 1954), fixing the trend of ancient shore lines (*Tanner*, 1955), locating probable source areas of the sands forming the cross-bedded strata, clarifying certain correlation problems and reconstructing the depositional environment. With this in mind primary vector properties in clastic assemblages belonging to the Pyramiden, Schumacher, Högfonna and Tindeklypa Formations were investigated during the field season of 1973. These formations are all probably of Precambrian age (*Neethling*, 1970), but apart from the Högfonna and Schumacher Formations their relative stratigraphic positions are not clear. At Grunehogna the Högfonna Formation can be seen to overlie the Schumacher Formation conformably (*Aucamp*, 1972).

The Pyramiden Formation, of which Pyramiden nunatak is the type locality, consists predominantly of coarse clastic rocks, i.e. graywacke and gritty quartzite. Monomictic flat-pebble conglomerates are abundant and characteristic. Cross-bedding is well developed throughout the sequence.

The Schumacher Formation ranges from medium-grained arkosic quartzite in the lower horizons to fine-grained argillaceous layers near the top. In the upper 50 m of the sequence at Grunehogna purple mudstones make up the finer fractions of the graded bedding units. Structures like slumped bedding, graded bedding and mud-cracks, the latter mainly in the upper part, are common. Cross-bedding is fairly common in the coarser units, but usually poorly developed and of small scale.

The Högfonna Formation was defined by *De Ridder & Bastin (1968)* as comprising all the sediments between two polymict jasper-rich conglomerates at Högfonna, the type locality. *Aucamp* (1972) divides the formation at Grunehogna into three members, using two jasper-bearing conglomerates as demarcation. The thickness of the predominantly quartzite sequence at Grunehogna is given as 210 m. The co-existence of mud-cracks with structures like large-scale cross-bedding and erosion channels suggests an environment approaching deltaic conditions (*Aucamp*, 1972).

The Tindeklypa Formation (including the Istind Formation) is mainly volcanogenic in the lower part. In the upper part there are some clastic horizons, and primary sedimentary structures like ripple marks, current lineations, mud-cracks and cross-bedding occur (*Van Zyl*, 1974).

Methods of Investigation

As the cross-laminated sets are generally bounded by lower and upper plane surfaces, one could measure strike and dip of the cross-bedded unit, strike and dip of the cross-laminations, and thickness of the cross-bedded layer. Most of the cross-laminations are plane surfaces; only a few are tangential to the base of the bed so that there was no difficulty in ascertaining the strike and dip. It was necessary to find an exposed surface of laminations or to see the traces of the lamination on two intersecting surfaces in order to measure and plot the exact attitude of the lamination planes.

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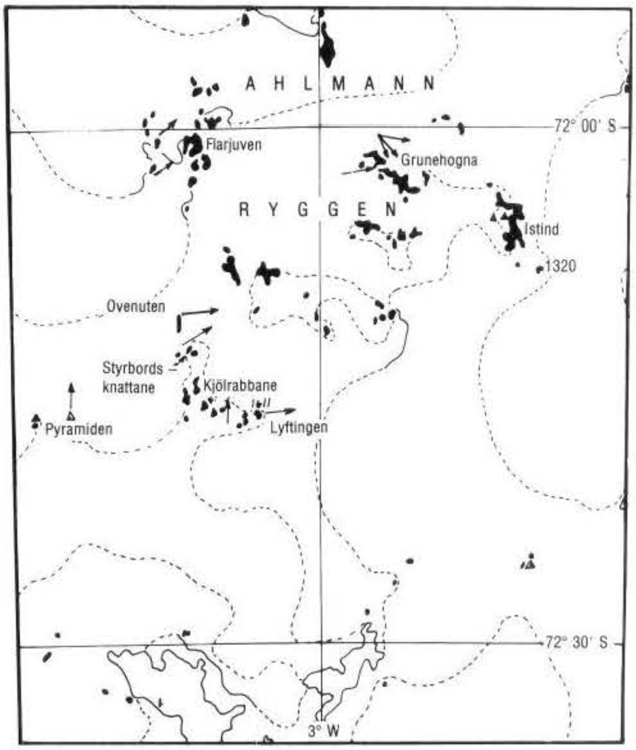

Fig. 1. Palaeocurrent directions in the Ahlmannryggen.

As far as possible, measurements were taken in every bed, the number per bed depending on the actual thickness of the sedimentary sequence. One hundred measurements were regarded as the minimum on which a reliable interpretation could be made. Where no major change in attitude of the cross-lamination was apparent in different stratigraphic horizons of any sequence, all measurements for that nunatak were plotted on the same diagram.

As the strata were in all cases sub-horizontal, it was necessary to correct the readings on the cross-beddings for this tilt by rotating the pole of the cross-bed, plotted on a stereonet, through the angle of dip of the bed itself about the strike of the bed. The relative azimuth for the different localities and inclination of the cross-bedding are then considered to be the same as at the time of deposition.

The stereographic projections of the poles of the cross-laminations were contoured and in most cases a distinct unambiguous preferred orientation was revealed.

Cross-bedding

Thickness

The thickness or scale of the cross-bedded units varies widely and is, on average, greatest in the Högfonna Formation where it attains a thickness of up to 1,5 m. On the basis of about forty determinations of thickness that were made, the average thickness of the cross-bedded units in the Pyramiden, Schumacher and Högfonna Formations is 44 cm, whereas that for the Tindeklypa Formation is only 16 cm. Several authors, notably *Schwarzacher* (1953) have discussed the scale of cross-bedding units, but the significance of this property is still uncertain. It may be correlated in part with coarseness of grain – the finer fraction normally exhibiting a "small-scale" cross-bedding, and the coarser quartzites and grits much larger cross-bedding.

Inclination

For measurement and analysis the cross-laminations are considered planes. In theory cross-beds are tangential to the base of the bed and truncated by the top surface. In fact such concavely curved surfaces were rare and the inclination of cross-beds can therefore be defined as the dihedral angle between the plane of the cross-bedding and the plane of the true bedding.

In the rocks studied the inclination varies widely between about 10° and 40°. It must be a function of the angle of repose of the material at the time of deposition. According to *Bagnold* (1942) this angle has an upper limit of 36° for dry sands. The high inclination (>36°) observed in a number of places should probably be ascribed to depositional deformation. In some cases evidence of slumping was observed, but slight tilting due to folding was definitely the more important mechanism. In a few instances the inclination of the cross-laminations was still greater than 36° after rotation (on a stereonet) of the true dips of the cross-bedded strata to their original (horizontal) position. Factors like particle size, shape, roundness, composition and moisture content of the material probably have some influence on the angle of repose as determined by *Bagnold* (1942).

Azimuth

Far more important than inclination for palaeogeographic interpretation is the direction of dip of the cross-laminations *(Pettijohn*, 1956). The measuring and recording of this vector were the prime objects of this work.

Numerous studies have made it apparent that fluviatile, aeolian and marine cross-bedding patterns are generally regionally consistent and imposed by the prevailing current system at the time of their deposition. In stream-laid sandstones and gravels the cross-bedding will dip down the regional slope. The significance of consistent azimuthal orientation of cross-bedding in marine sandstones is less clear, but the pattern must in general indicate down-slope movement of the sand-laden currents *(Pettijohn*, 1956). Cross-bedding of an ancient sandstone therefore indicates the regional palaeoslope, i.e. movement from the provenance to the depositional area and from older rocks to younger ones. The palaeogeographic importance of this is obvious. The variability of the cross-bedding, i.e. variance around a mean, is dependent on the tectonic stability of the region. If the provenance area is continually uplifted, regional slope will be maintained. If the slope is not so maintained, through lack of diastrophic movement, the area of deposition will slowly approach an equilibrium with the result that streams and currents will become more feeble and less directionally stable.

The most striking feature of the cross-bedding in the Ahlmannryggen is its marked preferential orientation (except in the Tindeklypa Formation) in different localities. Another significant feature is the change in current direction as indicated by cross-bedding in strata belonging to stratigraphically different formations.

Discussion and Conclusions

Pyramiden Formation

Cross-bedding in the quartzite rocks at Pyramiden, the type locality, may at first glance seem almost randomly orientated. Measuring and plotting a large number of

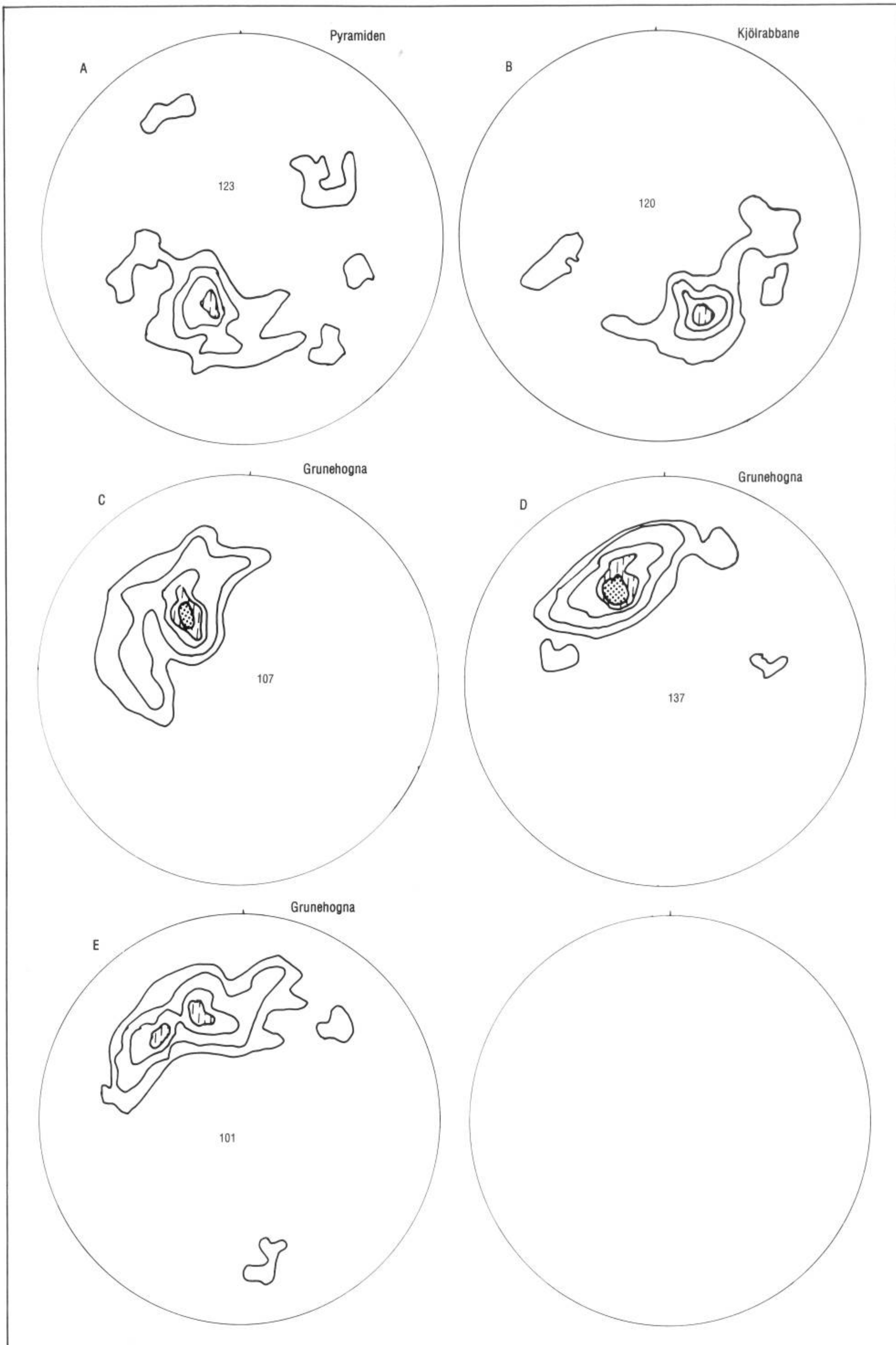

Fig. 2. (A – E) Lower hemisphere plots of poles to cross-bedding planes.

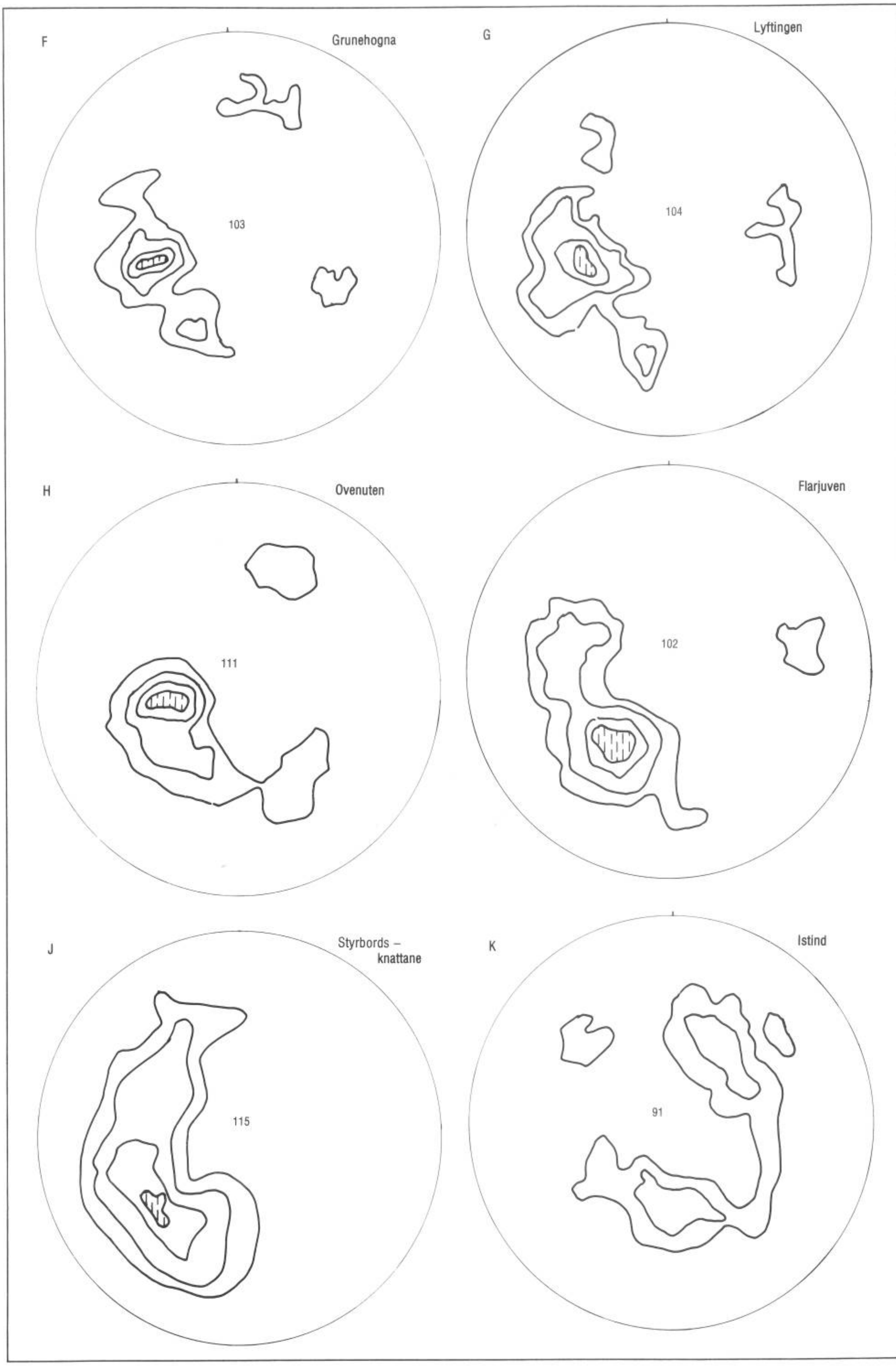

Fig. 2 (continued). (F – K) Lower hemisphere plots of poles to cross-bedding planes.

cross-bedding poles, however, revealed a clear preferred orientation indicating a main current direction of almost due north (6°) (Fig. 2A). At the time of deposition the area was fairly stable and, because regional slope was not always steep, a degree of shift in current directions as indicated by different attitudes of cross-beds at some stratigraphic horizons resulted. No systematic change in current direction is evident from the bottom to the top of the succession.

A succession, 30 m thick, of sediments at Kjölrabbane 1611 (Fig. 1) was correlated by *Bredell & Paterson* (1972) with the Pyramiden Formation on lithological grounds. Cross-bedding, although not as well developed as at Pyramiden, seems to substantiate this correlation. The mean current direction for this locality is 355° which corresponds well with the direction obtained at Pyramiden (Fig. 2B). These sediments are underlain by a thick mafic sill and are sub-horizontal. Correction for tilt could easily be made, but it should be kept in mind that intrusion of the sill could also have caused slight rotation in a horizontal plane, for which no correction is possible.

Schumacher Formation

Sediments belonging to this formation occur over a wide area and cross-bedding was measured at Ovenuten, Styrbordsknattane, Lyftingen, Flarjuven and Grunehogna.

Clear preferred orientations at all nunataks were found and current directions range between approximately 50° and 80°. An interesting feature is that where the sequences undoubtedly belong to the upper part of the Schumacher Formation, the palaeocurrent directions are more north-westerly than elsewhere. Thus the cross-bedding at Grunehogna, Ovenuten and Lyftingen indicates currents flowing in a direction between 70° and 80° while that at Flarjuven and Styrbordsknattane gives current directions ranging between 50° and 70°. The significance of this will be discussed later.

Högfonna Formation

The most striking feature of the cross-bedding in the Högfonna Formation is the shift in a clockwise direction of the palaeocurrent from the Lower Member to the Upper Member. The mean azimuth for the Lower Member is 130° and that for the Middle Member 150°. The diagram for the Upper Member shows two maxima of cross-bedding poles indicating palaeocurrent directions of 140° and 155° (Fig. 2). At the initial stages of deposition the provenance was in a direction 310° from Grunehogna, shifting as a result of diastrophism to 330° during accumulation of the Middle Member and ultimately to 335° in the last stages of deposition of the Upper Member.

The postulated shift in provenance is substantiated by the palaeocurrent directions obtained from cross-bedding for the Schumacher Formation. The upper part of this formation had a source area lying to the west-south-west (palaeocurrent direction 70 – 80°) whereas the source area for the older part was situated to the south-west (palaeocurrent direction 50-70°). There can be little doubt that during deposition of the Ahlmannrygg Group *(Neethling,* 1970) the source area was moved in a northerly direction relative to the Ahlmannryggen by diastrophic movements.

The relative stratigraphic position of the Pyramiden Formation is as yet unclear. *Neethling* (1970) regarded it as the oldest formation of the Ahlmannrygg Group. In the light of the previous discussion, the palaeocurrent direction obtained for this formation (0°-6°) i.e. a source area more southerly than for the Schumacher and Högfonna Formations, seems to substantiate Neethling's view.

Tindeklypa Formation

Cross-bedding in this formation, as measured at Istind and Peak 1320, shows no real preferred orientation (Fig. 3K) and it may thus be concluded that there was no main current direction during deposition of these sediments. It must be borne in mind that the Tindeklypa Formation is primarily of volcanogenic origin and that the resultant instability would no doubt have caused frequent shifts in the current system.

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