The sub-Caledonian Unconformity on Hjelmsøy – New Evidence of Primary Basement/Cover Relations in the Finnmarkian Nappe Sequence

M. RAMSAY, B. A. STURT & T. B. ANDERSEN

Ramsay, D. M., Sturt, B. A. & Andersen, T. B. 1979: The sub-Caledonian unconformity on Hjelmsøy – new evidence of primary basement/cover relations in the Finnmarkian nappe sequence. *Norges geol. Unders. 351*, 1–12.

A new and important occurrence of a primary stratigraphic unconformity beneath the Caledonian cover in the allochthon of the Finnmarkian segment of the North Norwegian Caledonides is described. This unconformity, on the island of Hjelmsøy, is excellently although only locally preserved as a geological accident. The basal lithology above the unconformity is an orthoquartzite. This is overlapped by meta-arkoses containing clasts of the crystalline basement rocks. The effects of Caledonian tectonothermal processes produce a structural and tectural convergence of both members along the cover/basement interface, which may blur the precise contact. The Caledonian structural and metamorphic development of Hjelmsøy is also briefly discussed, as is the regional significance of the unconformity.

D. M. Ramsay, Department of Geology, The University, Dundee, Scotland.
B. A. Sturt, Geologisk Institutt, Universitetet i Bergen, N-5014 Bergen, Norway.
T. B. Andersen, Geologisk Institutt, Universitetet i Bergen, N-5014 Bergen, Norway

ıtroduction

Recently, Ramsay & Sturt (1977) have described a major unconformity beneath the Klubben Psammite Group on the island of Kvaløy in West Finnmark. The substrate to the Klubben Psammite is a multicomponent gneiss complex of Precambrian age. This complex had undergone a protracted sequence of Precambrian deformational and metamorphic events, followed by uplift and erosion prior to the deposition of the Caledonian cover sequence. The cover sequence, according to Ramsay and Sturt, had been subjected to polyphasal deformation and metamorphism in the upper greenschist facies during the Finnmarkian Phase of Caledonian development. The basement gneisses also experienced both structural and metamorphic reworking during this Caledonian deformation. In analogous situations where Caledonian strains were high and the unconformity is no longer preserved, the gneisses were flattened and a variety of mylonitic gneisses and banded blastomylonitic lithologies were produced. Ramsay & Sturt (1977) drew attention to how, in the wider Finnmark region, the contact between the basal part of the Klubben Psammite Group and the subjacent gneisses has generally been the focus of very high shear strains and mylonite production during Caledonian deformation. In consequence, displacement frequently occurred at such contacts, resulting in

the effective uncoupling of the cover sequence from its pre-Caledonian substrate. At this stage the uncoupled portions of the cover sequence became independent units and continued their translation histories as separate thrust nappes.

Ramsay et al. (1979) have discussed this particular problem in some detail and have demonstrated that the entire Finnmarkian nappe sequence, from Lyngenfjord in the south to North Cape in the north, is characterised by repetitions of a tectonostratigraphic pairing of basement and cover units (see also Zwaan & Roberts 1978). In the allochthon the pattern is a simple stacking of nappes each of which contains representatives of the same Caledonian cover sequence on a variable pre-Karelian basement. The cover sequences contain a well-differentiated metasedimentary sequence which although not uniformly developed throughout the region, can be correlated with the type Finnmarkian stratigraphy of the island of Sørøy (Ramsay 1971).

The thin and less extensive parautochthonous nappes at the base of the nappe pile exhibit a more diverse lithostratigraphic content, reflecting the geology of the nappe substrate. In West Finnmark the Vendian-Cambrian autochthon is less than 300 m thick and many thrusts have penetrated this cover. These nappes, therefore, comprise either single assemblages of Caledonian or Karelian rocks or basement-cover pairings in which the basement is pre-Karelian gneiss while the cover is either low-grade Karelian rocks or Caledonian metasediments. The Pre-Karelian gneiss complexes contain variable contents of paragneiss and orthogneiss, the latter showing a considerable composition range, and some of the gneiss units reveal indications of different patterns of tectono-metamorphic evolution.

Until recently the only well-preserved example known of a primary stratigraphic unconformity between basement and cover was the Stangnes locality on Kvaløy (Ramsay & Sturt 1977). During reconnaissance work in the most northern part of the Finnmarkian Zone, in the summer of 1978, the authors discovered another excellently preserved example of the unconformity at the base of the Klubben Psammite Group on the northern part of the island of Hjelmsøy (Fig. 1).

Description of the Hjelmsøy unconformity

The northwestern part of Hjelmsøy comprises a series of high-grade gneisses (Fig. 1). Reconnaissance studies reveal these rocks to be essentially a series of granitic and granodioritic orthogneisses, which are variably garnetiferous. These gneisses form part of a multicomponental complex and contain xenoliths of earlier, often basic phases. They are themselves cut by granitic pegmatites, aplites and dykes and sheets of basic igneous rocks, now in the condition of amphibolites bearing both biotite and garnet. The gneisses preserve evidence of polyphasal Precambrian deformation and a recrystallisation history which pre-dates the deposition of the overlying cover sequence. In places, however, as the contact with the cover sequence is approached, considerable Caledonian reworking of the gneissose basement can be identified with attendant

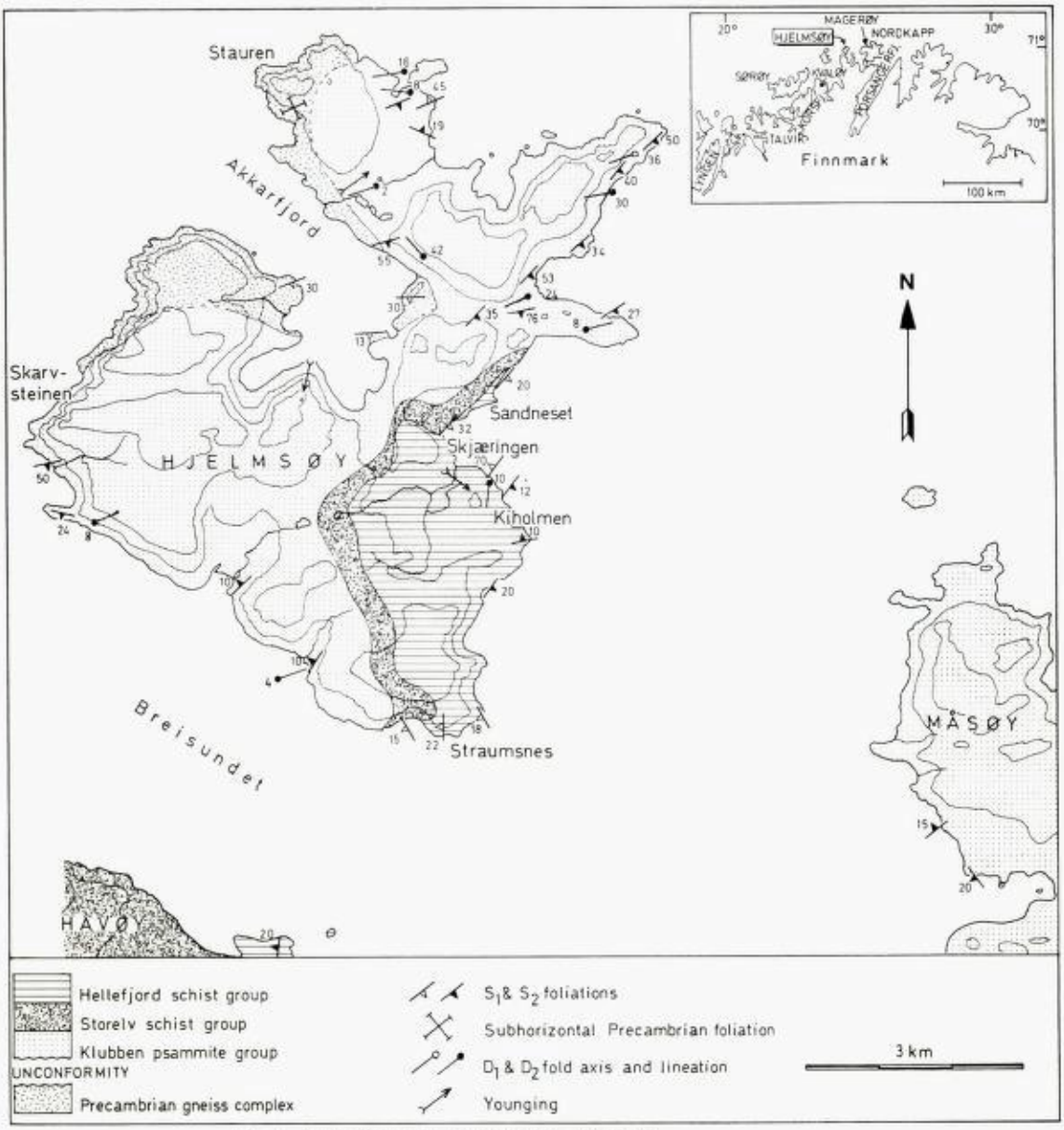

Fig. 1. Geological map of Hjelmsøy, Finnmark.

recrystallisation in amphibolite facies. In this situation both the cover assemblage and the basement gneisses have developed strong Caledonian fabrics, with the result that it is extremely difficult to pin-point the precise boundary surface, e.g. the contact zone east of Akkerfjord.

When the contact is traced west of Akkerfjord, it descends the cliffs at Skarvsteinen (Fig. 1), where it is dramatically exposed as a well-preserved primary stratigraphic unconformity (Fig. 2). The surface of the unconformity

Fig. 2. Primary stratigraphic unconformity at Skarvsteinen, between Klubben Psammite Group (above) and Precambrian orthogneiss complex (beneath). Note that the contact is very sharp, but represents an undulating erosion surface. The orthogneiss has undergone Precambrian reworking and flattened streaks and lenses of pegmatite are cut by the unconformity. Above the unconformity the lower part of the cover sequence is a well-bedded orthoquartzite with progressive overstep onto upstanding irregularities in the erosion surface. In the photograph the upper part of the cover sequence is of meta-arkose and irregular developments of migmatitic neosome can be discerned. The cliff section shown in the figure is approximately 25 m in height.

is gently undulating, cuts into the basement gneisses and abruptly truncates the structures in this substrate. The gneisses at this locality are a series of variable granitic gneisses with more mafic horizons. These rocks have a strong foliation defined by parallel orientation of biotite and muscovite and appear to have been deformed prior to the injection of a suite of granitic pegmatite sheets. The pegmatites display the effects of strong flattening strains in the form of marked pinch-and-swell structures, and in some instances are now seen as isolated lenses lying in the foliation. This deformation sequence clearly predates the unconformity, as flattened pegmatite lenses are truncated at angles of up to 30 degrees by the overlying basal quartzite beds of the Klubben Psammite Group. The lowest member of the Klubben Psammite at this locality is a fairly pure orthoquartzite. This has a well-bedded aspect with the lowermost 10 m comprising beds up to 1 m in thickness which progressively overstep on to higher levels of the irregular erosional surface (Fig. 2). In other localities, where the quartzites have been examined in detail, bedding is well-preserved and current-bedding has been observed in two places, the sequence younging upwards away from the unconformity (Fig. 1).

On the eastern side of Akkerfjord a gritty facies of the lower part of the Klubben Psammite Group is preserved in a small recumbent infold within the

Fig. 3. Gritty lithology in the Klubben Psammite on the east side of Akkerfjord. This contains small pebbles of gneiss, granite and vein quartz. Coin measures 2.5 cm across.

gneisses, 10 m below the main contact. This lithology includes many small pebbles of material derived from the underlying gneisses in addition to vein quartz (Fig. 3). Numerous quartz veins do, in fact, cut the basement gneisses and many of them appear to have been emplaced prior to the deposition of the cover sequence. Occasional cobbles, up to 20 cm in diameter, are present and these vary from gneisses bearing the imprint of a pre-Caledonian foliation to virtually undeformed granite (Fig. 4).

From the above, there would appear to be little doubt that the original unconformable contact between Late Precambrian sediments of the Caledonian depositional cycle and the older crystalline basement is preserved in the island of Hjelmsøy. This forms a somewhat irregular surface such that different lithologies of the cover sequence are in contact with the basement. Pebbles derived from the basement complex contribute to a conglomeratic facies in the lower part of the cover sequence.

General characteristics of the metasedimentary cover sequence

The metasedimentary succession occurring above the Hjelmsøy unconformity is comparable in part with the stratigraphic sequence of the island of Sørøy. On Hjelmsøy, however, the standard Sørøy succession is incomplete. The Klubben Psammite, Storelv Schist and Hellefjord Schist Groups are present in typical developments, but both the Falkenes Marble Group and the Åfjord Pelite Group are absent. The omission of these two units is also a feature of the stratigraphic pattern in the Kobbfjord – western Magerøysund area some 30 km

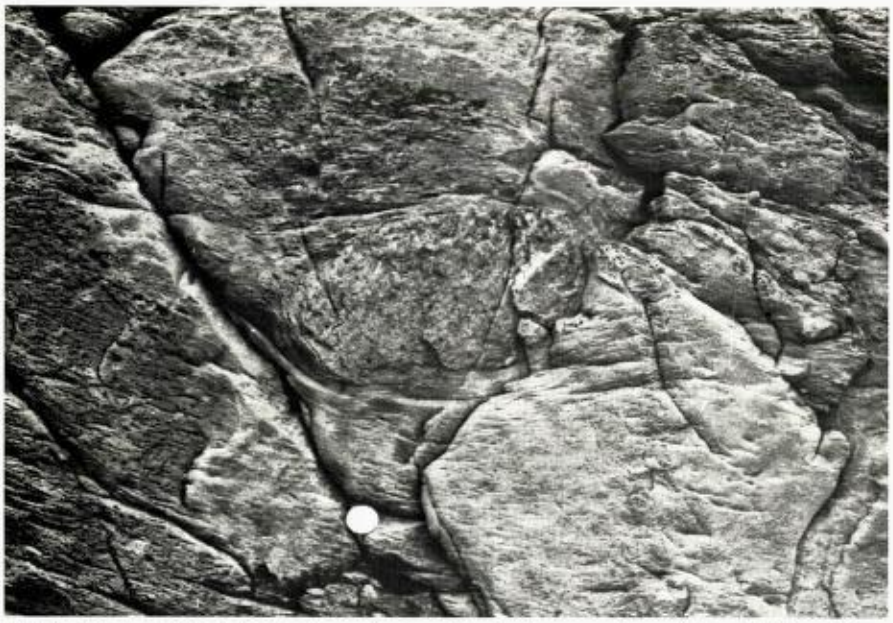

Fig. 4. Large cobble of basement granite in gritty horizon near base of the Klubben Psammite, east side of Akkerfjord. Coin measures 2.5 cm across.

further east, and would appear to represent a primary sedimentary facies variation in this northeastern part of the depositional basin. Although geographically only some 60 km along strike from Sørøy, the Hjelmsøy – Kobbfjord rocks probably occur in a major nappe which underlies the Seiland/Sørøy Nappe (Ramsay et al. 1979). Originally, therefore, they had a much greater separation.

The *Klubben Psammite Group* on Hjelmsøy consists of an alternating sequence of quartzites and meta-arkoses with subordinate variably garnetiferous pelitic schists. The quartzites are in many cases relatively pure orthoquartzites, with occasional heavy-mineral concentrations along bedding planes and with two observed examples of current bedding (Fig. 1). Transitions are observed between the orthoquartzites and meta-arkoses, although the latter tend to dominate the sequence. Within the meta-arkoses, especially where they are coarse-grained, clastic grains of feldspar, quartz and occasional small pebbles of granite and gneiss have been observed. Generally, however, as the result of elevated metamorphic grade (high amphibolite facies) during the Finnmarkian orogenic phase, the meta-arkoses show significant effects of migmatitization and considerable quantities of quartzo–feldspathic neosome have been produced. The neosomal material ranges from vague rootless and topless veins and segregations through discrete, medium-grained cross-cutting granite veins to pegmatite sweats, segregations and intrusive bodies. The migmatites developed in the Klubben Psammite of Hjelmsøy are very similar to those described from the Gjesvær area of Magerøy (Ramsay & Sturt 1976). On the neighbouring island of Måsøy (Fig. 1), strongly migmatized Klubben Psammite is again found and the neosomal material is seen to post-date foliated amphibolite sheets.

Fig. 5. The unconformity in a highly flattened state. The basement gneisses (bottom) have acquired the Caledonian foliation (S_1), which is well-developed in the orthoquartzite at the base of the Klubben Psammite (top); east side of Akkerfjord.

Tracing the contact with the gneissic substrate eastwards from Skarvsteinen meta-arkoses overlap the basal quartzite and rest directly upon the underlying crystalline basement. As the meta-arkoses are now almost invariably in a migmatitic condition it is difficult to locate the precise position of this contact over much of its length. Another factor which plays a significant role in the obliteration of the contact is the magnitude of the Finnmarkian strains in the Klubben Psammite and the subjacent gneisses (Fig. 5). During the late stages of the main, syn-foliation deformation phase on Hjelmsøy, here termed D_1, the rocks experienced strong flattening strains which had the effect of producing a marked reworking in the gneisses near the contact. This in turn produced a prominent foliation and a new gneissic banding which was subsequently overprinted by the Caledonian migmatization; and there was a similar neosomal development to that observed in the cover meta-arkoses. In the contact zone east of Akkarfjord there has therefore been a structural and metamorphic convergence between the migmatized reworked basement gneisses and the meta-arkoses of the cover sequence. The basement gneisses away from the reworked zones might also be expected to bear the imprint of superimposed Caledonian migmatization, but such effects are difficult to distinguish from neosomal material produced during Precambrian metamorphism.

On Hjelmsøy, the preservation of the unconformity in unequivocal terms is due to the fortunate combination of a refractory orthoquartzitic lithology and a somewhat reduced level of straining. Elsewhere, although mylonite is not developed as is generally the case over the region, the products of the high grade of regional metamorphism obscure the original nature of the contact. In the one other published example of the basement-cover unconformity, on Kvaløy, the psammites of the cover sequence display only upper greenschist facies metamorphism.

The *Storelv Schist Group* directly overlies the Klubben Psammite Group and the contact is of a transitional nature. The rocks progressively take on a darker colour and a more schistose appearance with increasing biotite content. Typically, the Storelv Schist is a rusty-weathering, coarse-grained mica schist composed essentially of varying proportions of quartz, biotite, muscovite and garnet. Flakes of mica several centimetres across are not uncommon. Garnet is frequently idioblastic and ranges up to 5 cm in size, as can be seen at Skjæringen. The Storelv Schist is variably affected by the migmatization and pegmatitic neosomal sweats are quite common. The lower part of the Storelv Schist is more quartz-rich, whilst the facies with large garnets is better developed in the upper parts of the unit. A clear division into a Lower and Upper Storelv Schist, which can be made on Sørøy, the more southern parts of the Finnmarkian zone and in the Kobbfjord area, cannot be made on Hjelmsøy.

On Hjelmsøy, the Storelv Schist Group is directly overlain by the metaturbidite sequence of the *Hellefjord Schist Group* (Roberts 1968). The precise contact with the Storelv Schist Group is not exposed, but as one traces the approximate boundary inland no evidence for the presence of the intervening Falkenes and Åfjord Groups (Ramsay 1971) can be found. As no evidence has been found for a tectonic break at this level, the lack of these two groups can probably be explained in terms of regional variations in the environment of sedimentation. The Hellefjord Schist on Hjelmsøy is typically a flaggy, green-coloured sequence of metagreywackes and pelites (Fig. 6), very similar to that of Sørøy. The flaggy aspect relates to the pronounced interbanding of greywacke layers with pelitic and semi-pelitic mica schists, and the sub-parallelism of the S_1 schistosity and the bedding. Both the metagreywackes and the mica schists display considerable thickness variations. None of the metagreywacke beds observed was thicker than 1.5 m although generally they range from 30–60 cm in thickness, while the interbanded mica schist horizons are usually somewhat thinner (10–20 cm). Graded bedding occurs in the metagreywackes, and shows a consistent sense of younging upwards from the Storelv Schist Group.

The rocks of the Hellefjord Schist Group show few effects of the migmatization so characteristic of the underlying lithologies. They are, however, very rich in garnet. No evidence of minerals such as staurolite or aluminium silicates has been recorded either from the Hellefjord Schist or from the underlying lithologies; it must be noted, however, that all observations were made during a relatively rapid field reconnaissance and thin-section studies have not been carried out.

Fig. 6. Interbedded greywacke and semi-pelite at the base of the meta-turbidite sequence of the Hellefjord Schist Group at Sandneset (scale, matchbox 5 cm).

Structural observations

Evidence for a polyphasal pattern of Precambrian structural evolution in the basement gneisses has already been given, and the Caledonian reworking of these gneisses has been discussed. Two principal phases of Caledonian deformation have been recognised on Hjelmsøy, both of which were of a penetrative nature. Minor folds of the first phase (D_1) are only rarely observed and these are tight to isoclinal folds of bedding with a pronounced axial planar mica foliation (S_1). One reason for the lack of preserved D_1 structures is the strong transposition produced by D_2 structures. The anatexis in the Klubben Psammite and Storelv Schist lithologies can be shown to be both syn-tectonic and post-tectonic with respect to D_1. Where migmatization is highly developed, this too has had the effect of obliterating or partially obliterating the D_1 structures.

Excluding the large D_2 Hjelmsøy Synform discussed below, the map (Fig. 1) presents a simple homoclinal pattern of southeasterly dipping S_1 foliation. No evidence of macroscopic D_1 folds has been discerned. The existence of a mesoscopic, D_1, coupled fold of the surface of unconformity can be identified on the eastern shore of Akkerfjord (Fig. 1). All that now remains is an elliptical enclave of Klubben Psammite Group rocks, some 400 m in length, within the gneisses, a remnant of the synclinal part of the fold. Strong attenuation of the long limb of the complementary anticline created markedly fissile fabrics in both basement and cover which, as previously described, became the focus of later injection by leucocratic neosome.

The second major deformation (D_2) produced a pronounced crenulation cleavage (S_2) which in many areas strongly transposes earlier planar structures,

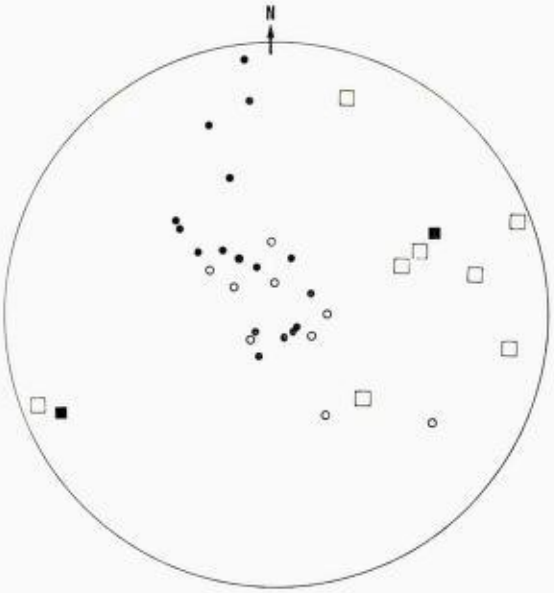

Fig. 7. Stereographic plot of structural elements, Hjelmsøy.
○ Poles to S_1
● Poles to S_2
□ Minor fold axes
■ Intersection lineations S_1/S_2

and effectively becomes the dominant planar structure in the rocks. A plot of the minor structures recorded from Hjelmsøy is given in Fig. 7. Study of D_2 minor folds suggest that fairly elevated metamorphic temperatures continued well into the D_2 deformation phase as minor developments of syn-tectonic neosomal materials are frequently encountered in association with the structures of this phase. This is also a feature which has been noted from the Gjesvær area of Magerøy (Ramsay & Sturt 1976).

The megascopic structural pattern of Hjelmsøy is dominated by a large recumbent synform of D_2 age. This fold has an axis which plunges gently towards SSW and an axial plane inclined at about 15° towards the east. The fold, which we propose to call the *Hjelmsøy Synform*, closes westwards and gives rise to an extensive tract of inverted strata in the southern part of Hjelmsøy and on the nearby island of Havøy. The D_2 minor folds bear a non-coaxial relationship to the Hjelmsøy Synform (Fig. 7), although they show a normal consistent vergence towards the hinge of the main fold on both the right-way-up and the inverted limb. The hinge-zone of the main structure is characterised by a steeply dipping to vertical enveloping surface of S_0/S_1, particularly well illustrated in the area of Kiholmen.

Conclusions

On Hjelmsøy a primary stratigraphic unconformity between the Finnmarkian cover sequence and the underlying pre-Caledonian basement gneisses is preserved. The relationships, in places, are rendered complex through the combined effects of Caledonian D_1 strains and migmatization, affecting both cover sequence and reworked basement. The Caledonian lithostratigraphic sequence of Hjelmsøy is not as complete as elsewhere in Finnmark, and this is explained in terms of primary regional variations in the sedimentary environment.

The migmatization can also be observed in the cover sequences of the islands of Havøy and Måsøy, and would appear to correlate with the migmatization of the Klubben Psammite in the Gjesvær area of Magerøy. The Caledonian structure of Hjelmsøy is dominated by an eastward-facing recumbent synform of D_2 age which produces an extensive zone of inverted strata.

The Hjelmsøy unconformity represents only the second published record of such primary contact in the allochthonous nappes of the Kalak Nappe Complex, although P. Bowden and D. M. Ramsay (pers. comm. 1977) have discovered a further example near Talvik in Altafjord. At the latter locality, although quite strong strains have affected the contact zone, rocks of the Klubben Psammite Group truncate the foliation in dioritic gneisses of the substrate. Such examples of primary stratigraphic relationships between cover and basement, especially where the superimposed effects of Caledonian deformation and metamorphism are clearly displayed, are highly significant.

In recent years it has become apparent that the Kalak Nappe, once regarded as a single major unit, comprises several nappes and tectonic slices derived from Caledonian, Karelian and pre-Karelian assemblages (Roberts 1974, Jansen 1976, Ramsay & Sturt 1977, Zwaan & Roberts 1978). Ramsay & Sturt (Sturt et al. 1978, Ramsay et al. 1979) have demonstrated that this complex pattern of Caledonian nappes falls into a rational pattern, characterized in the allochthon by repetitions of older and younger sequences. These couplets are interpreted as being originally slices of older basement with a cover of Caledonian sediments, despite the common occurrence of tectonic junctions between them. This was confirmed by the finding of a section of the original unconformable contact preserved on the island of Kvaløy (Ramsay & Sturt 1977). This primary contact has, of course, suffered some modification in the ensuing Caledonian deformation, but not to the extent where mylonite was generated, as in the more common situation. Further support for this interpretation came from pre-Caledonian ages obtained from one of the basement gneiss units at Korsfjord (Ramsay & Sturt 1977). The unconformity described in this paper, together with the one reported from Talvik, add further support to this thesis.

Six allochthonous Finnmarkian nappes comprising such pre-Karelian basement with Caledonian cover have been identified between Lyngenfjord and Porsangerfjord, together with six smaller and less extensive parautochthonous nappes (Ramsay et al. 1979). The latter have a more varied composition reflecting the geology of the local autochthon and include non-metamorphosed Caledonian sediments, Karelian rocks and couplets of pre-Karelian basement with Karelian or Caledonian covers.

Acknowledgements. – The authors wish to thank the following organizations for financial support: Natural Environmental Research Council (D.M.R.); Norges Almenvitenskapelige Forskningsråd, grant no. D.48.22.18. (B.A.S.); Norges Geologiske Undersøkelse, Project 1438 (T.B.A.).

This paper represents a Norwegian contribution to the I.G.C.P. Project 27 — "The Caledonian Orogen".

International Geological Correlation Programme.
Norwegian contribution No. 17 to Project Caledonian Orogen.

REFERENCES

Jansen, J. Ø. 1976: *Strukturell og metamorf utvikling i den vestlige del av Komagfjord-vinduet og overliggende dekker.* Unpubl. Cand. real. thesis, Univ. of Bergen, 198 pp.

Ramsay, D. M. 1971: Stratigraphy on Sørøy. *Norges geol. Unders. 269*, 314–317.

Ramsay, D. M. & Sturt, B. A. 1976: The syn-metamorphic emplacement of the Magerøy Nappe. *Norsk geol. Tidsskr. 56, 291–307.*

Ramsay, D. M. & Sturt, B. A. 1977: A sub-Caledonian unconformity within the Finnmarkian nappe sequence and its regional significance. *Norges geol. Unders. 334*, 107–116.

Ramsay, D. M., Sturt, B. A., Roberts, D. & Zwaan, K. B. 1979: The tectonostratigraphic correlation of the Finnmarkian Nappe Complex. (In preparation).

Roberts, D. 1968: Hellefjord Schist Group — A probable turbidite formation from the Cambrian of Sørøy, West Finnmark. *Norsk geol. Tidsskr. 48*, 231–244.

Roberts, D. 1974: Hammerfest. Description of the 1:250 000 geological map. *Norges geol. Unders. 301*, 66 pp.

Sturt, B. A., Pringle, I. R. & Ramsay, D. M. 1978: The Finnmarkian phase of the Caledonian orogeny. *Jl. geol. Soc. Lond. 135*, 597–610.

Zwaan, K. B. & Roberts, D. 1978: Tectonostratigraphic succession and development of the Finnmarkian nappe sequence, North Norway. *Norges geol. Unders. 343*, 53—71.