The Otta Conglomerate, the Vågåmo Ophiolite – further indications of early Ordovician Orogenesis in the Scandinavian Caledonides

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On both geological and geochemical grounds the 'greenstone' sequence of the Otta–Vågåmo area is characterised as a fragmented ophiolite, structurally emplaced over the Baltoscandian miogeoclinal sequence during pre-Middle Ordovician thrusting. Mapping of the Otta–Vågåmo region has clearly established a major stratigraphic unconformity between the ophiolite and the overlying Sel series. The tectonostratigraphic setting of the ophiolite complex is established by this major unconformity beneath the Upper Arenig/Llanvirn conglomerate of the Sel cover series, with its population of clasts derived, in large part, from the ophiolite. The unconformity locally oversteps the ophiolite on to its Heidal substrate while both upsequence levels and lateral equivalents of the 'serpentine' conglomerates reveal abundant clasts of previously deformed and metamorphosed rocks of Heidal affinity, in addition to ophiolitic debris. This clearly demonstrates the 'terrane-linking' nature of the unconformity, while the fauna of the lowermost Sel places a clear upper time-limit to obduction of the Vågåmo Ophiolite across the western margin of the then Baltic Craton.

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Determination of the geologic setting of the Otta Conglomerate in the Otta–Vågåmo area (Fig. 1) is critical in the interpretation of the palaeogeographic significance of its Ordovician fossils. The Otta Conglomerate, an unusual rock that consists largely of rounded clasts of serpentinite, has been explained by many with varied interpretations (Oftedahl 1969). Its fossils are a unique assemblage of abundant, diversified, but poorly preserved gastropods, and a smaller number of better preserved brachiopods and trilobites (Øyen 1930; Yochelson 1963; Bruton & Harper 1981, 1985). The fossils consist of a mixture of forms characteristic of late Arenig–early Llanvirn Baltic, North American and Iapetan peri-insular faunal provinces (Bruton & Harper 1981, 1985).

As a result of investigations, beginning with reconnaissance in the summer of 1985, we find that the Otta Conglomerate is the basal unit of a cover sequence which unconformably overlies previously obducted and deformed ophiolitic rocks. Evidence for an emergent tectonic edifice, the Finnmarkian land mass (Ramsay & Sturt 1986), would thus supplant the postulated wide Iapetus Ocean (Bruton & Bockelie 1980; Neuman 1984; Stephens & Gee 1985) to account for the contrasts between the Otta Conglomerate fossils and those of about the same age at Hølonda in western Trøndelag, that have pronounced North American affinities (Neuman & Bruton 1974; Bergstrøm 1979; Bruton & Bockelie 1982; Schmidt 1984).

The Vågåmo Ophiolite

In the general scheme of Strand's (1951) tectonostratigraphy a major unit of greenstones is placed between the underlying Heidal series and the overlying Sel series[1] (p. 115). Our investigations show that Strand's term 'greenstones' is misleading, and that different parts of the 'greenstone complex' contain distinctive suites of rock types, including serpentinised and steatised ultramafic rocks, layered and isotropic gabbros, gabbros with dykes, a sheeted dyke complex and poorly preserved pillow lavas. These rocks form part of an ophiolitic assemblage and we propose to use the term the *Vågåmo Ophiolite* for this complex (Fig. 1).

It is obvious that the elements of an almost complete ophiolite pseudo-stratigraphy can be recognised in the Otta–Vågå area (Anon. 1972). The ophiolite is, however, considerably fragmented as the result of pre-Sel folding, faulting, thrusting and erosion, and further complicated by post-Sel tectonics. Little serpentinized and/or steatitised ultramafics are rare except at one locality to the NE of Lake Tesse (UTM 005536), where variably serpentinised harzburgites and dunites are found in large blocks and chromite-bearing dunites are in situ. In general, the ultramafic rocks are now serpentinites and soapstones, the latter extensively quarried. Small lenses and streaks of altered chromite have, however, been observed in these rocks, e.g. in the disused quarry at UTM 203545. In most cases, however, the alterations

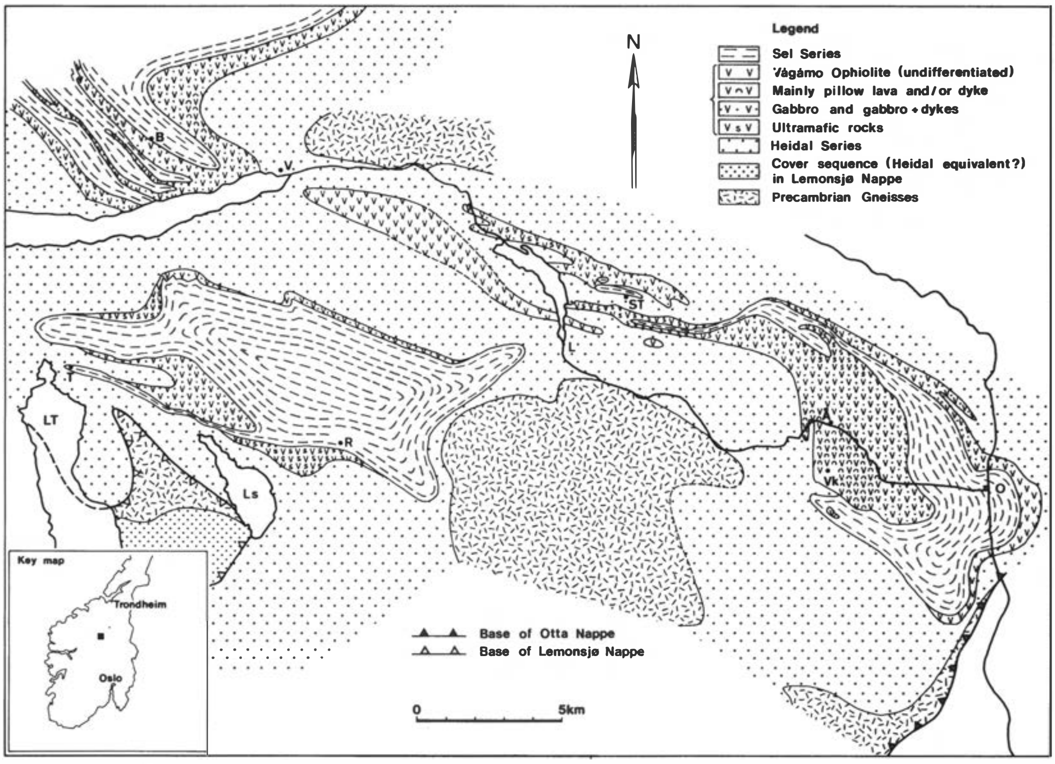

Fig. 1. Generalized geological map of the Vågå–Otta area. B = Bakkehaugen, V = Vågåmo, Å = Åsåren, Vk = Veggemskampen, O = Otta, R = Ragerhaugen, T = Tristeinen, LT = Lake Tesse, Ls = Lemonsjøen, St = Svarttjern.

accompanying serpentinisation, steatisation and subsequent deformation combine to eradicate primary magmatic features. Gabbroic rocks are widely distributed and in the lower part of the pseudostratigraphy are interlayered with serpentinised ultramafic rocks. The lower gabbros are markedly cumulate in character passing upwards into heterogeneous or isotropic gabbros. In spite of locally high strains, well-preserved cumulative layering may be observed in gabbro (e.g. UTM 255500), and both layered and isotropic gabbros may be intruded in varying amounts by metabasic dykes. At several places (e.g. UTM 230513) dyke swarms comprise up to 100% dykes. Pillow lavas and/or pillow breccias are extensively developed in the Åsåren–Veggemskampen area (Fig. 1) and also at a number of other localities (e.g. UTM 009622 and UTM 210539).

In order to test the geochemical affinities of the ophiolite 10 analyses of major and trace elements (Table 1) were made from samples collected in different parts of the sheeted dyke complex. The results are plotted on a number of discrimination diagrams (Fig. 2) and demonstrate an almost ideal N-MORB composition. Although the database is limited, there is no indication of an island arc influence, and our preliminary conclusion is that the rocks of the Vågåmo Ophiolite represent either part of the ancient oceanic crust of the Iapetus Ocean, or little contaminated oceanic crust from a marginal basin. It should be noted that Iversen (1977) concluded, on the basis of major elements, that the greenstones of the Vågåmo area are probably ocean-floor tholeiites.

The contact between the ophiolitic rocks and the

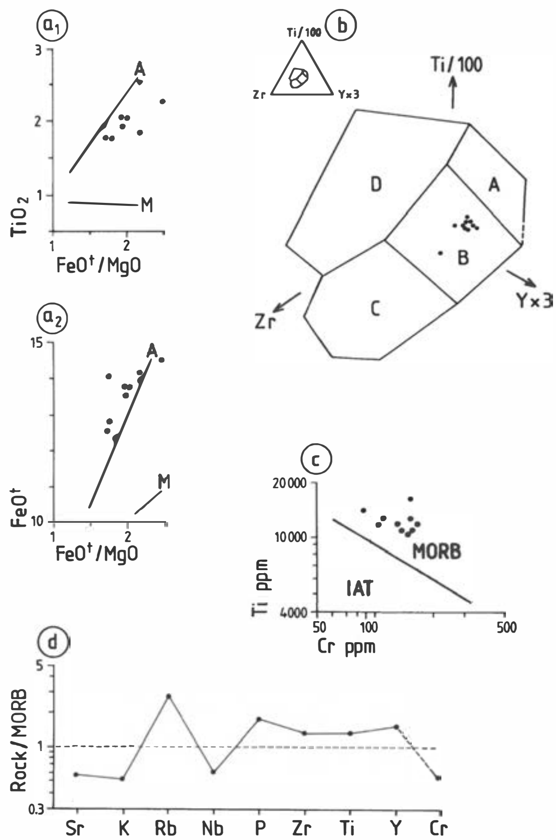

Fig. 2. Geochemistry of dyke rocks, Vågåmo Ophiolite. (a_1) TiO_2–FeO^t/MgO and (a_2) FeO^t–FeO^t/MgO variations in dykes. (b) Ti–Zr–Y plot from dykes (Ocean floor basalts – B; low-K tholeites of island arcs – A & B; calc-alkaline basalts – C, 'within-plate' basalts – D). (c) Ti–Cr plot from dykes. (d) Trace element pattern from dykes (average), normalized against standard – MORB. Normalizing values in ppm.

underlying Heidal series is marked by a major zone of blastomylonites, developed from both hanging-wall and footwall lithologies (e.g. UTM 045603, UTM 987585). This contact must be envisaged as a major thrust, therefore, separating ophiolite from the underlying deformed and metamorphosed sedimentary rocks of the continental miogeocline. The blastomylonites display uppermost greenschist to amphibolite facies parageneses and there does not appear to be a metamorphic hiatus across the contact. This was also a feature observed by Gee & Sjöström (1984) in the Tannfors district, at the contact between the Handøl Ophiolite and its Seve substrate. The basal contact of the Vågåmo Ophiolite probably does not represent the original obduction surface as it is overlain by different parts of the ophiolite complex, i.e. in some places by ultramafic rocks, by gabbro, or most commonly by gabbro with dykes. The possibility that the ophiolite is thrust-on subsequent to initial obduction onto the then continental margin must be envisaged.

The Status of the Otta Conglomerate

The status of the Otta Conglomerate has been much discussed in the literature because of the well-preserved fauna found within the conglomerate. The fossils assign an age close to the Arenig–Llanvirn boundary, with mixed Baltic-North American affinities (Bruton & Harper 1981; Neuman 1984). The conglomerate is also well known because of the distinctive lithology in much of the area where it is described as a serpentine conglomerate.

Remapping of the geology within the 1:50,000 Otta and Vågå map-sheets reveals that this conglomerate locally forms the base of the Sel series, as was indeed indicated by Strand (1951). The systematic mapping of the Sel series rocks and their heterolithic substrate, formed by the Vågåmo Ophiolite and the rocks of the Heidal series, reveals that the Sel series lies with profound unconformity upon this substrate which had undergone extensive deformation, metamorphism, uplift and erosion prior to their blanketing by the cover sequence. The mapping programme, which is still in progress, shows that there are many variations in the sedimentary facies within the basal sedimentary rocks of the Sel series which reflect in large degree the nature of the local substrate. The Sel sequence usually commences with conglomerates, which in some localities may occur somewhat up-sequence, separated from the substrate by thin developments of metasandstones, grits and/or garbenschiefer phyllites. The conglomerates and associated sandy facies may also vary considerably in their petrology, grain-size, bedform and thickness. In many localities the distinctive 'serpentine conglomerates' (the Otta Conglomerate) or the 'greenstone conglomerate' of Strand (1951) directly overlie the rocks of the Vågåmo Ophiolite and in some cases can be observed to be unconformable upon the latter.

The unconformity was formerly well exposed just to the northeast of the large soapstone-serpentinite quarry at Barstad (UTM 158562) where it was observed by two of the authors (B.A.S. and R.B.N.) in May 1985. Here the virtually undeformed (faintly cleaved) conglomerate rested abruptly upon the foliated soapstone/serpentinite (Fig. 4a) and a number of pebbles containing obvious pre-pebble foliation could be observed. During the summer of 1985 and the spring of 1986 considerable land-sliding has destroyed this exposure. Drill-cores passing through this contact can, however, still be studied from a number of old core-boxes scattered on the hillside above the former face. In sub-vertical drill-cores (UTM 160561) (Fig. 4b) the serpentine conglomerate exhibits a weak cleavage sub-parallel to the core axis. This contrasts with the more complex pattern in the serpentinite substrate which has both a strong foliation inclined at a high angle to the core axis and a later crenulation cleavage sub-parallel to the core axis (Fig. 4b). The clasts are essentially of serpentinite and variably steatitised serpentinite and usually have a thin rim of magnesite, some of the clasts are variably replaced by magnesite. The matrix contains talc, chlorite and magnesite. Small clastic grains of chromite partly replaced by ferrite-chromite and magnetite are common. The conglomerate is relatively fine grained and the average clast long-axis, in the lower part, is around 2 cm.

At the soapstone quarry at Åsåren (UTM 230538) the unconformity is intermittently exposed according to the position of the quarry face. In the summer of 1989 the contact could be observed in a shallow synclinal closure with virtually undeformed 'serpentine conglomerate' resting directly on the foliated soapstone. The conglomerate is clast supported in its lower part, and contains rounded clasts up to 20 cm diameter of variably steatitised serpentinite set in a matrix of essentially talc, chlorite and magnesite. Clastic grains of partly altered chromite are scattered through the matrix. Above the quarry the serpentinous sedimentary rocks pass transitionally up into the more normal garbenschiefer and sandy phyllites of the Sel. At a number of localities, such as Ragerhaugen to the east of Lemonsjøen (UTM 053508) and Bukkehaugen above Nord Herad (UTM 998619), where the serpentine conglomerates are at or close to the contact with the rocks of the ophiolite complex, the strains are extremely low and primary features such as current-bedding, erosional surfaces, channels, plane-parallel lamination and primary pebble imbrication are well preserved in marked contrast to the foliated rocks of the substrate. At the Bukkehaugen locality, in the course of sedimentary logging, one well-preserved coarsely ribbed brachiopod was recovered, by Reidulf Bøe (pers. comm. 1988), from a plane-laminated serpentine-rich siltstone. The fossil is now lodged at the Palaeontological Museum in Oslo with Dr D. Bruton for description. To our knowledge this is the first documented occurrence of the Otta fauna in situ[2] (p. 115).

Within a tight syncline on the hill Tristeinen, 10 km

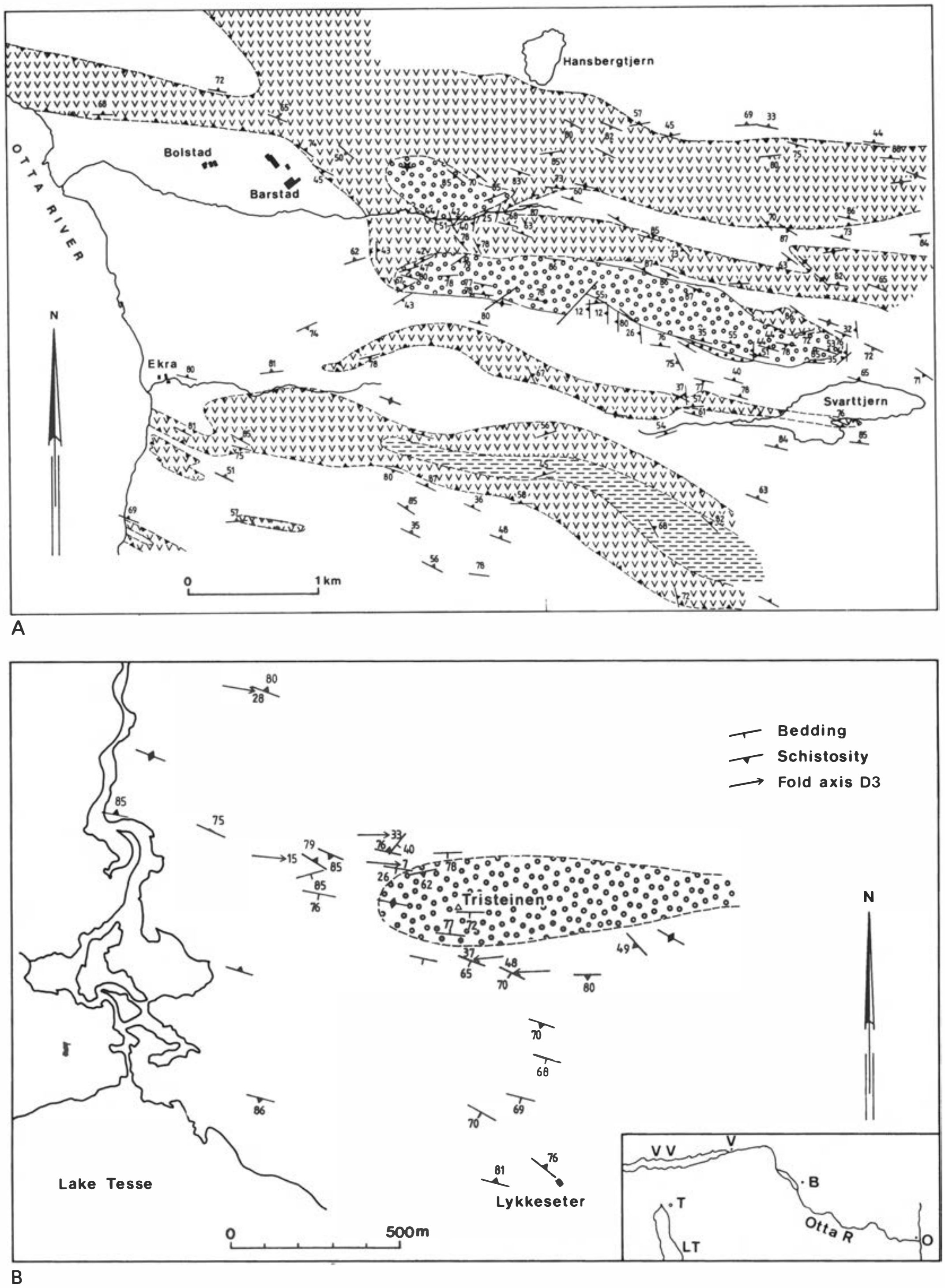

Fig. 3. Localities of conglomerate overstep. (a) Bolstad, (b) Tristeinen. Inset map shows locations. Ornamentation: blank – Heidal Gp., Random ornament V – Vågåmo Ophiolite; open circles – Otta conglomerate; closed circles – polymict conglomerate, horizontal dashes – remainder of Sel Gp.: Localities: B – Bolstad, LT – Lake Tesse; O – Otta; T – Tristeinen; V – Vågåmo; VV – Vågåvatn. Stratigraphic contacts shown by full or dashed lines, tectonic contacts shown by barbed line. On Fig. 3a drill-core site shown with star.

southwest of Vågåmo (Fig. 3b), massive serpentine conglomerate rests on rocks of the Heidal Series. The conglomerate is poorly sorted though erosional channels and pebble imbrication are well preserved. The conglomerate displays weakly deformed clasts in a fine-grained and only weakly cleaved serpentinous matrix and the general level of strain contrasts markedly with the mylonitic character of quartzite and psammite in the subjacent Heidal series. The strain hiatus across the unconformity partitions the bulk strain into pre- and post-unconformity components correlated with pre-Middle Ordovician (?Finnmarkian) and Scandian orogenic phases respectively.

The unconformity was, at least in some places, originally angular, as could be observed at the now landslipped locality and within the drill-cores near Barstad or as seen in the quarry at Åsåren. There are also a number of localities where mapping clearly demonstrates the overstep of the conglomerates across the rocks of the ophiolite complex onto the subjacent Heidal series (Fig. 1). An excellent example of this is seen just to the NW of Svarttjern (Fig. 3a), where progressive overstep can be observed. Approximately 0.5 km to the NW of Svarttjern the basal part of the conglomerate, over a distance of some 150 m, is markedly polymict containing pebbles of psammites and calc-silicates (which have pre-pebble deformation fabrics), foliated and non-foliated greenstone and metagabbro together with rare serpentinite. The contact clearly transgresses the tectonically transposed bedding of the Heidal metasedimentary rocks and the psammite and calc-silicate pebbles in the polymict conglomerate are identical with the subjacent lithologies. The polymict conglomerate probably represents an infill of the pre-existing topography and is overstepped laterally both east and west by the 'typical' serpentine conglomerate. The overstepping relationship (Terrane-Linking unconformity) of the basel Sel conglomerates over this heterolithic substrate is of considerable significance for models of belt evolution which will be referred to later.

When we started the remapping of the 1:50,000 map-sheets of Otta and Vågå and discovered the unconformable relationships of the basal Sel clastic rocks we were of the opinion that the 'serpentine conglomerate' together with the 'greenstone conglomerate' of Strand (1951) were unique lithologies at the base of the Sel, and derived almost entirely from a source in the Vågåmo Ophiolite. Investigation of particularly the latter conglomerate showed this to be more polymict than stated by Strand (1951) and occasional clasts of psammite and quartzite resembling those in the Heidal series were observed. The detailed mapping of the ridge to the north of Svarttjern, however, revealed the presence of a polymict basal conglomerate resting directly on a Heidal substrate. The pebbles in this conglomerate appear to be largely derived from this Heidal substrate.

The re-mapping of the northwestern part of the Vågå sheet (summer 1989) clearly demonstrates that the Skarshøi Conglomerate of Strand (1951) also represents the basal facies of the Sel and rests essentially on a Heidal substrate, as was indeed anticipated by Strand (1964). This relationship is broken occasionally by erosional rests (pre-Sel erosion) of ophiolitic rocks, usually strongly deformed, at the contact. The relationships are focused on the mountain Svarthovda (UTM 974703), where the basal Sel facies, resting directly on the banded calc-silicates of the Heidal, is a coarse breccia containing blocks (up to 1.5 m) of calc-silicates, psammite, quartzite, granitic gneiss, foliated and non-foliated greenstone and gabbro with subordinate schist matrix. This deposit is some 10 m thick and its lowest 0.5 m is dominated by slabs of calc-silicate rock identical to that of the immediately underlying substrate. The basal facies is succeeded by some 20 m of conglomerate with a quartz-mica schist matrix containing pebbles (up to 0.5 m) of mainly greenstone, gabbro, quartzite and calc-silicate. This is succeeded by an approximately 10 m thick conglomerate which is matrix dominated with isolated 'floating pebbles' of similar type to the underlying deposit and occasional trondhjemite and serpentine pebbles. The matrix is essentially talc-serpentine-magnesite and the deposit is provisionally interpreted as a mass-flow. The deposit is marked as 'serpentine-conglomerate' on NGU's preliminary 1:250,000 map-sheet Årdal (Lutro & Tveten 1988). The 'mass-flow' unit is succeeded by mafic-matrix, green conglomerates with pebbles essentially of greenstone and gabbro (presumably ophiolite derived) and then by a distinctive quartz-pebble conglomerate. The latter has a matrix varying from quartz-schist to schistose quartzite and contains pebbles (up to 10 cm) of mainly vein quartz and quartzite. There are sufficient well-preserved sedimentary structures to identify this as a correct stratigraphic succession from the unconformity.

On the road-section, to the east of the river Skjerva, a polymict conglomerate is well exposed near the base of the Sel (UTM 993693). This conglomerate is clast supported with a quartzitic matrix containing many clastic grains of vein quartz. The conglomerate has a low strain state and contains sub-angular to sub-rounded pebbles and cobbles up to 50 cm (long-axis) dominantly of quartzite and psammite with more occasional clasts of a coarse grained massive garbenschiefer, amphibolite and rare small clasts of chromite-bearing ultramafic rocks. Many of the clasts bear pre-pebble tectonic foliation and examples of pre-pebble folds can be observed. The majority of clasts are of material typical of the Heidal.

These observations show that there are considerable facies variations within the basal part of the Sel series and that the 'serpentine' conglomerate and the 'greenstone' conglomerates and relegated to a part of this interdigitating series of conglomerates and sandstones of petrography varying in relation to the then available locally exposed pre-Sel substrate. The study of the pebble petrography shows that the main source rocks are the Vågåmo Ophiolite and the various rock types within the Heidal series. Occasional pebbles of 'granitic' and 'dioritic' gneisses may well be derived from the gneissic substrate to the Heidal. Many of the pebbles show clear evidence of pre-pebble tectonic fabrics. The basal clastic rocks of the Sel series pass variably up through soft-weathering talc-actinolite schists and garbenschiefer into phyllites, metasandstones, quartz schists and quartzites. Tectonic strains may or may not be reflected in a strong foliation in the serpentine conglomerate, but in the overlying pelitic and semipelitic sequence there is invariably a strong, penetrative foliation attended by pronounced thinning of transposed layering. Between Vågåmo and Otta the ophilitic complex is folded into a tight synclinorium, overturned slightly to the south. The Ordovician cover sequence is restricted therefore to the cores of tight, deep synclines and outcrops as a series of narrow bands. The strong axial plane cleavage and pronounced

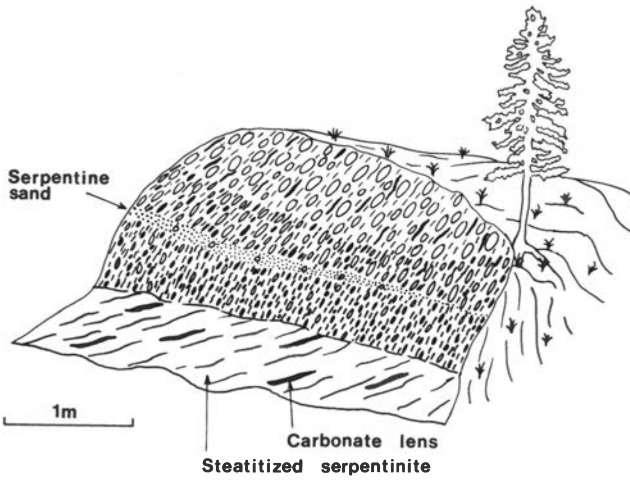

Fig. 4a. Sketch of unconformity formerly seen above quarry at Bolstad.

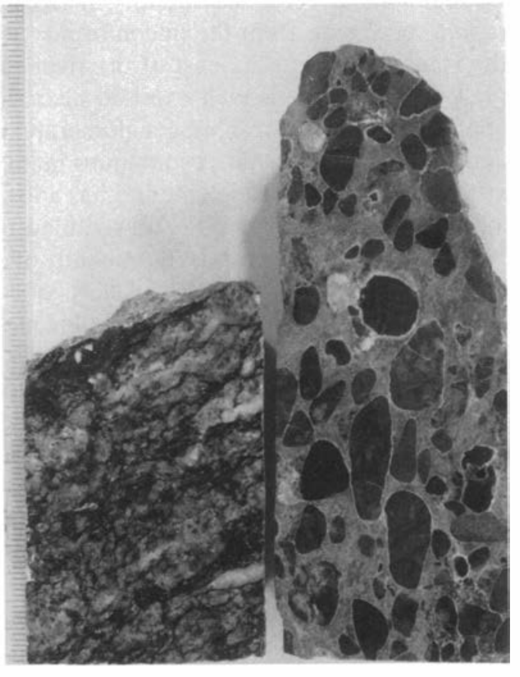

Fig. 4b. Polished drill-core, left-hand part shows foliated serpentinite beneath unconformity, right-hand part shows conglomerate above unconformity. The two pieces of core occur within 25 cm in the corebox. Core diameter = 36 mm. Location shown on Fig. 3a.

layer thinning give this sequence the strong flagginess which makes it commercially attractive as an ornamental and cladding stone.

Mylonite fabrics in the sequences beneath the conglomerate are chiefly confined to the ophiolite-Heidal contact zone and to the base of Precambrian cratonic gneisses which underlie the Heidal series, i.e. the basal thrust zones of nappes. While it is not possible to directly relate the latter thrust to the basal Sel unconformity the mylonites beneath the ophiolite, on the other hand, are certainly pre-Llanvirn in age and related to the primary emplacement of the ophiolites, or a cratonwards shunting during a subsequent phase of deformation. In either case, the ophiolite was already juxtaposed with the miogeoclinal Heidal series by pre-Llanvirn times. The Heidal series itself has a cratonic gneiss substrate, comparable with the Svecofennian basement seen elsewhere in the Baltic Shield. The suspect ophiolitic terrain therefore appears to fit into a scenario in which obduction occurred across the Baltic cratonic margin during the Finnmarkian phase of the Caledonian Orogeny.

The detailed descriptions of the stratigraphy, sedimentology, metamorphism and structural geology will be reported subsequently.

Discussion

The contrasting provincial affinities of late Arenig–early Llanvirn fossils in different parts of the upper Allochthon of the Scandinavian Caledonides has fuelled arguments concerning the significance of the contrast in determining the provenance of their respective outboard and inboard nappes. Until now, the North American affinity of the fossils in the Hølonda Limestone has suggested that the provenance of the outboard nappe of the Trondheim region was adjacent to the Laurentian plate (Gee & Zachrisson 1974; Bruton & Bockelie 1980; Cocks & Fortey 1982; Stephens & Gee 1985). Similarly, the more heterogeneous fossils of the Otta Conglomerate of the inboard nappes, of which it is a part, suggest a source in the eastern Iapetus Ocean (Neuman 1984).

The biogeographic interpretations must now be reconsidered in the light of the new evidence of a major 'terrane-linking' unconformity and pre-late Arenig orogenic deformation. In stark contrast to the weak deformation displayed by the serpentine conglomerate, the competent sequences beneath reveal prominent ductile zones. While this fabric reflects translation of the ophiolite over the Heidal Series, the relationship is one of thrusting rather than obduction, suggesting that it suffered shunting cratonwards during some post-obduction event. The major inter-orogenic unconformity at the base of the Sel Series is seen to mark the end of the Finnmarkian orogenic cycle and the start of the Scandian depocycle. In the pre-Middle Ordovician Finnmarkian tectonostratigraphy the Vågåmo ophiolite is seen as the uppermost element in the nappe stack.

An unconformable relationship similar to that of Otta and the western part of the Trondheim Nappe Complex (Ryan et al. 1980) occurs above most of the recorded Group 1 ophiolite fragments in Norway (Furnes et al. 1985), although the faunal evidence for dating the basal cover sequences is missing or less precise. On Karmøy–Bømlo and Lyngen, for example, limestones up sequence of the basal unconformity yield an Ashgillian age, while in the others the cover sequences have yielded no fossil evidence (Sturt 1984; Sturt et al. 1984). The Upper Arenig–Lower Llanvirn age of the post-orogenic Otta Conglomerate is close to the upper age limit recognised for the final stages of the Finnmarkian orogenic phase, e.g. Late-Middle Arenig.

(A)

(B)

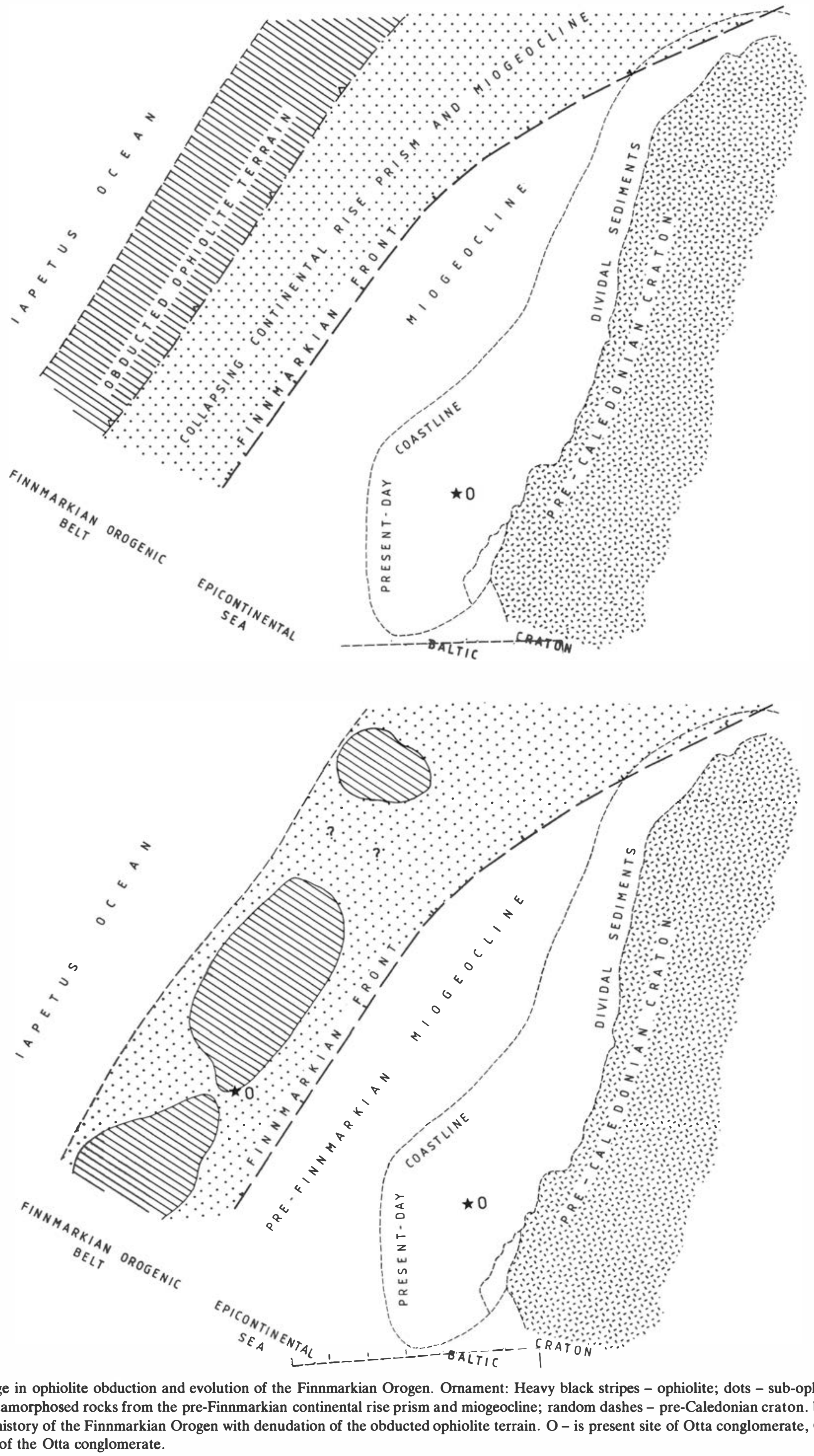

Fig. 5a. Early stage in ophiolite obduction and evolution of the Finnmarkian Orogen. Ornament: Heavy black stripes – ophiolite; dots – sub-ophiolite nappes of deformed and metamorphosed rocks from the pre-Finnmarkian continental rise prism and miogeocline; random dashes – pre-Caledonian craton. b. Later stage in the morphogenic history of the Finnmarkian Orogen with denudation of the obducted ophiolite terrain. O – is present site of Otta conglomerate, O′ proposed site during deposition of the Otta conglomerate.

Table 1. Major and trace elements of metabasalt dykes of the Vågåmo Ophiolite.

	OT1	OT3	OT7	OT4	OT8	OT6	OT9	VG25	OT2	OT5
SiO_2	47.53	48.03	51.32	50.99	51.11	50.97	51.90	47.04	48.88	48.87
Al_2O_3	12.89	12.68	13.72	13.06	13.13	13.46	13.72	13.26	13.66	12.70
TiO_2	1.98	1.80	2.09	1.98	1.78	2.08	2.09	2.60	1.91	2.34
Fe_2O_3	2.58	1.84	2.87	2.33	2.28	3.05	2.87	3.08	4.24	2.43
FeO	11.66	10.83	10.90	11.59	10.26	10.98	10.90	11.26	10.11	12.24
MgO	8.44	7.53	6.99	7.31	7.08	6.99	6.99	6.69	6.54	6.04
CaO	10.79	9.75	9.73	8.96	10.04	9.81	9.73	10.97	10.24	9.54
Na_2O	2.90	3.16	3.17	3.10	2.69	2.70	3.17	2.49	2.82	2.98
K_2O	0.10	0.05	0.08	0.06	0.01	0.10	0.08	0.29	0.03	0.03
MnO	0.24	0.21	0.23	0.26	0.22	0.25	0.23	0.21	0.22	0.28
P_2O_5	0.22	0.19	0.26	0.20	0.17	0.21	0.26	0.30	0.18	0.24
Loi	1.0	2.0	0.6	0.4	0.5	0.6	0.6	1.0	1.5	1.3
Total	100.33	98.07	102.54	100.24	99.27	101.20	102.54	99.19	100.33	98.99
V	402	372	398	415	383	437	426	438	402	429
Cr	167	139	156	109	148	113	157	155	133	88
Co	63	57	57	61	56	60	63	59	59	62
Ni	59	55	46	60	61	54	92	67	68	43
Zn	155	131	129	151	127	122	119	120	111	140
Rb	3	4	4	5	19	4	10	4	3	3
Sr	56	45	73	46	65	82	96	66	85	90
Y	46	43	42	43	39	49	47	54	47	55
Zr	118	108	102	108	107	117	120	169	111	140
Nb	1	nd	nd	nd	3	nd	4	4	1	2

More than twenty localities of detrital serpentinites, generally considered to be of Ordovician age, are known from the Scandinavian Caledonides (Stigh 1979), though with the exception of the Otta–Vågå area stratigraphic constraints on their age are very poor. The only other fossiliferous locality is at Vardøfjället in Swedish Lapland, where five fragments of poorly preserved gastropods of the long-ranging superfamily Maclaritacea have been recorded, and by correlation considered to be of pre-Ashgill age (Holmqvist 1980). Bruton & Harper (1982) emphasize that it is not possible to assign a precise age, in the Ordovician, to these gastropods. We would appeal for caution in age-wise correlation for the many detrital serpentinite occurrences in the Scandinavian Caledonides in view of the general lack of stratigraphic constraints. Although monomictic serpentine conglomerates are a somewhat unusual lithology their presence or absence is controlled by the availability of a suitable local source and presumably also by such factors as climate and depositional regime. That the detrital serpentinite, in the Scandinavian Caledonides, has a range of ages is shown by the serpentine conglomerates stratigraphically above the Stavfjord Ophiolite in western Norway (Skjerlie 1988), where the oldest part of the ophiolite has been dated at 443 ± 3 Ma (Andersen et al. 1990), and by the Svartberg Conglomerate at Røragen which is shown to be of Lower Devonian age (Steel et al. 1985). Detrital serpentinites are not infrequently recorded in the unconformable cover sequences to major ophiolite complexes, e.g. in Oman (Skelton et al. 1990).

At several locations in the Otta–Vågåmo district the unconformable serpentine and polymict conglomerates overstep or come close to overstepping the Ophiolite–Heidal contact. This combined with evidence from conglomerate petrography shows the unconformity to be of 'terrane-linking' type. This to our knowledge is as yet the first instance of this relationship in all the recorded examples of the Ordovician unconformity in Norway, and provides strong additional geological evidence for the relative age of emplacement of the ophiolite across the marginal sequences of the Baltic Craton, i.e. pre-Llanvirn.

In our modelling the emergent edifice of the Finnmarkian orogen would have had opposite shores that faced Laurentia and cratonic Baltica respectively. The intervening landmass could thus have formed a barrier to faunal interchange and migration except where it was breeched by fault breaks or cross-channels (Fig. 5). The Otta Conglomerate contains products of erosion of the Finnmarkian orogen that were deposited on the Baltic-facing shore of the landmass, perhaps in the vicinity of such a break, whilst in our model the Hølonda Limestone would presumably have accumulated on the shore that faced Laurentia. The southern part of the Finnmarkian landmass is considered as having been separated from the main Baltic continent by a broad epicontinental sea in which were deposited Ordovician and Silurian miogeoclinal rocks with characteristic Baltic faunas, now preserved along the orogenic front in Jämtland and in the Oslo region.

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Notes

[1] As yet no formal stratigraphy has been established in this area, therefore the original term 'series' (Strand 1951) will be employed. The Heidal series consists of psammites, quartzites, calc-silicates and various schists which unconformably overlie continental gneissic basement. The silico-clastic rocks are of 'sparagmite' affinity. The Sel series comprise conglomerates, meta sandstones, calc-silicate schists, phyllites and mica schists (Strand 1951).

[2] Since this paper was written the original 'lost' locality, near the Åsåren quarry, where fossils were originally discovered in the 1920s has been relocated (D. L. Bruton, R. Bøe, & R. B. Neumann, pers. comm. 1990).

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