Note – *Notis*

The Tørvikbygd Ophiolite – a newly discovered ophiolite fragment with an unconformable cover sequence in the central Hardanger area, West Norway

TORGEIR B. ANDERSEN, HARALD FURNES, HARALD BREKKE, BRIAN A. STURT & JOHAN NATERSTAD

Andersen, T. B., Furnes, H., Brekke, H., Sturt, B. A. & Naterstad, J.: The Tørvikbygd Ophiolite – a newly discovered ophiolite fragment with an uncomformable cover sequence in the central Hardanger area, West Norway. *Norsk Geologisk Tidsskrift,* Vol. 64, pp. 69–73. Oslo 1984. ISSN 0029-196X.

Diabases from a sheeted dyke complex associated with greenstones, gabbros and ultramafics in the Tørvikbygd area of central Hardanger have typical ocean floor geochemistry. This complex represents a dismembered and strongly deformed ophiolite, the Tørvikbygd ophiolite, and is unconformably overlain by a thick development of metasediments and volcanics of probable Ordovician age. These relationships demonstrate another example of primary basement-cover relationships within the Caledonian nappe sequence in southwestern Norway.

T. B. Andersen, H. Furnes, H. Brekke & B. A. Sturt, Geologisk Institutt Avd. A, N-5014, University of Bergen, Norway. J. Naterstad, Norges geologiske undersøkelse, Oslokontoret, Drammensveien 230, Oslo 2, Norway.

The sequence of Caledonian rocks in the central Hardanger area is part of the upper allochthon of the Scandinavian Caledonides (Roberts et al. 1981). The internal stratigraphical and tectonometamorphic development within this heterogenous complex in the Bergen-Sunnhordland-Karmøy area has received considerable attention in recent years. It has been shown that a major unconformity of Ordovician age separates early Caledonian rock units, including ophiolites from a younger Ordovician-Silurian volcano-sedimentary sequence (Sturt et al. 1983, Brekke et al. in press).

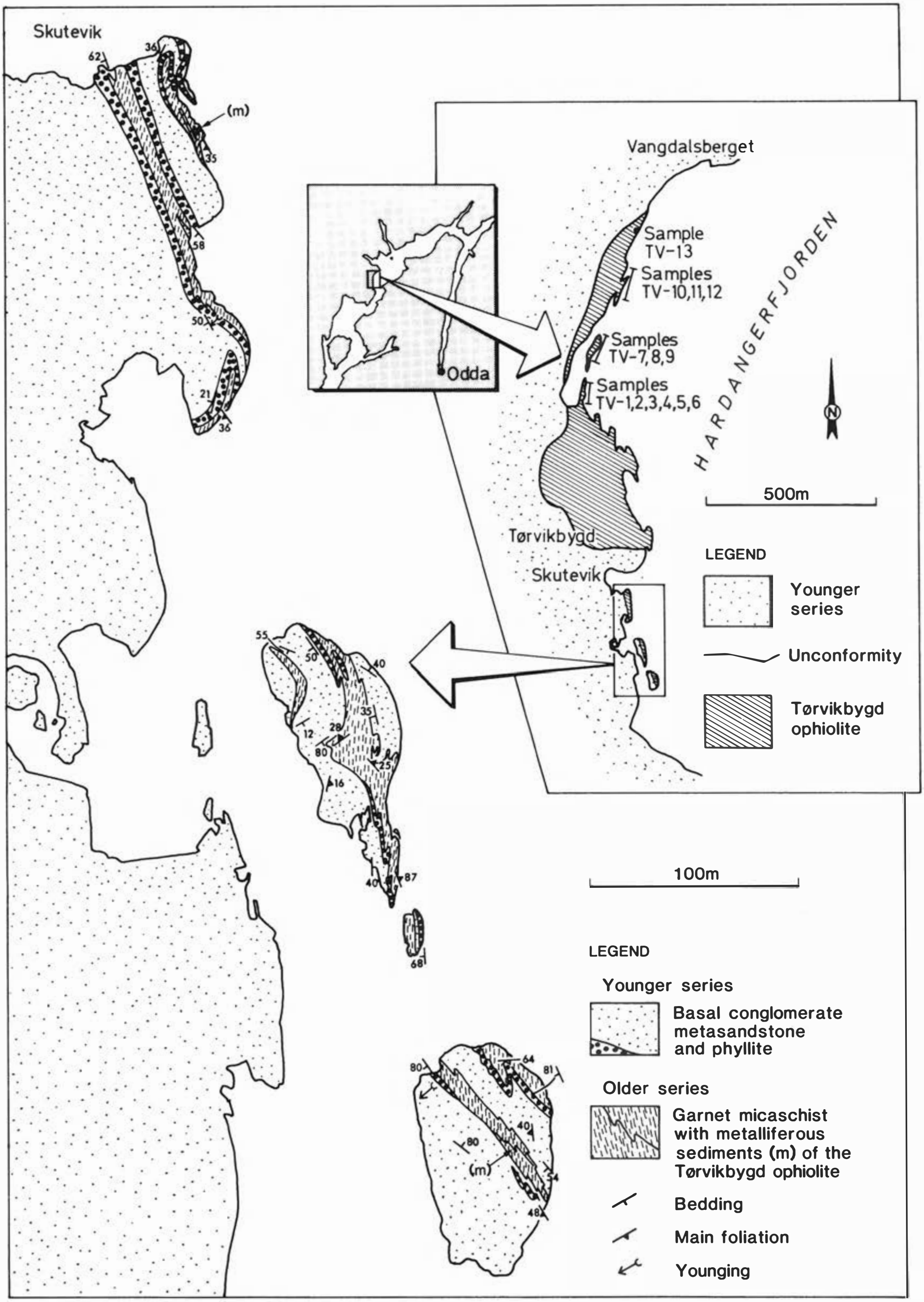
The object of this note is to report on the presence of a highly deformed ophiolitic complex in the lowermost part of the tectonostratigraphic sequence of the central Hardanger region. This complex we propose to call the Tørvikbygd Ophiolite. We also report on the primary stratigraphic unconformity between the ophiolite and an overlying sequence of metasediments and metavolcanics which are, at least in part, of Ordovician age. This discovery provides a basis for a further understanding of the tectonic and stratigraphic development in this area.

The older series, the Tørvikbygd Ophiolite

The rocks of the older series occur in a narrow zone along the northwestern coast of Hardangerfjorden (Fig. 1). They comprise greenstones, gabbros, serpentinized ultramafics and a series of metasediments including micaschists, chert and metalliferous sediments. The primary relationships between these lithologies are rarely preserved, but in some less deformed mega-boudins, original features may still be discerned. In particular this applies to the area between Tørvikbygd and Vangdalsberget, where the greenstones constitute a sheeted diabase complex. The gabbros in this area occur as minor screens between the dykes, and trondhjemites are present as dykes and minor intrusive bodies. The frequency of dykes increases towards the south along this coast section, and the gabbro screens occur mainly in the northern part of this segment. Serpentinites are found as tectonic lenses within this complex. The sheeted dyke complex also occurs at Aksnes a few km to the north of the area shown in Fig. 1, though the state of deformation here is much higher.

The analyzed samples were all collected from the least deformed parts of the sheeted dyke complex along the coast between Tørvikbygd and Vangdalsberget (Fig. 1).

The metasediments of the older series are found on the headland and small islands to the south of Skutevik, and a detailed map of this area is shown in Fig. 1. The metasediments are strongly deformed, and the bedding has been completely transposed. Garnet micaschist is the dominant lithology, though red Mn (garnet)- and


Skutevik
(m)
Vangdalsberget
Sample TV-13
Samples TV-10,11,12
Samples TV-7,8,9
Samples TV-1,2,3,4,5,6
HARDANGERFJORDEN
Odda
500m
Tørvikbygd
Skutevik
LEGEND
Younger series
Unconformity
Tørvikbygd ophiolite
100m
LEGEND
Younger series
Basal conglomerate metasandstone and phyllite
Older series
Garnet micaschist with metalliferous sediments (m) of the Tørvikbygd ophiolite
Bedding
Main foliation
Younging

Fe (magnetite)- rich sediments are found as tightly folded, but continuous layers within the sequence.

The unconformity and the younger series

The contact between the older and younger series represents both a structural and metamorphic break. Clearly cross-cutting relationships at the contact are, however, difficult to observe at the scale of outcrop because of the later polyphasal deformation and transposition. On the map-scale, the younger series directly overlie different rock types in the older complex. In the north they rest directly upon the gabbro and the diabase dyke complex and in the Skutevik area directly upon the older metasediments. This indicates progressive downcutting beneath the unconformity.

Detailed petrographic studies show that the younger series contain two strong foliations (S-1 and S-2) and a later crenulation cleavage (S-3). The S-1 schistosity of the younger series is, however, a secondary planar structure in the older series (Sn + 2), and this schistosity wraps around earlier syn-tectonic, helisitic garnet porphyroblasts in the older rocks (Fig. 2).

Further evidence for a stratigraphic and structural break is obtained from detailed study of the clast petrography in the younger series. The basal conglomerate and grits of the younger series contain clasts derived from the older series. These comprise well rounded pebble sized clasts of gabbro, greenstone, diabase, epidote nodules, trondhjemite and some highly attenuated clasts of metasedimentary origin. These rocks were deformed and metamorphosed prior to their erosion and deposition in the younger series. The basal conglomerate of the younger series is not continuous, but appears to have been developed as lenses and pockets along the contact. The conglomerate is rarely more than a few metres in thickness (not corrected for tectonic strains), and gives way upwards to a thick sequence of metasandstone, phyllites, limestones and metavolcanics. Bedding is locally preserved both in the conglomerate and the gritty lithologies, and primary sedimentary structures (channeling and grading), indicating younging away from the unconformity, have been observed. Primary sedimentary structures can also be observed in the metasandstones and metagreywackes higher up in the sequence, but further studies of these have not yet been carried out.

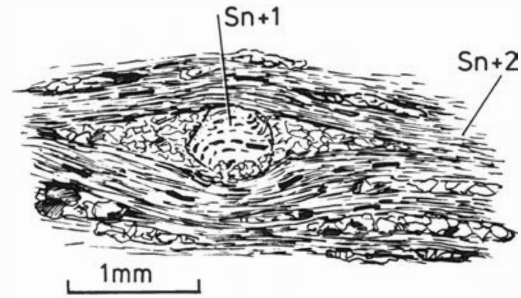


Fig. 2. Helisitic syn-tectonic garnet from the garnet micaschist of the Tørvikbygd Ophiolite with earlier, pre-unconformity foliation (Sn+1) preserved as inclusions in the garnet porphyroblast. Sn+2 in the garnet micaschist is S-1 in the younger series. (Sn refers to pre-unconformity foliations).

At higher stratigraphic levels within the younger series, a complex association of metavolcanics and metasediments occurs (Naterstad & Jorde 1981), of which little detail is presently available.

Geochemistry

Major and trace elements were analyzed by XRF (on glass beads and pressed powder pellets, respectively), using international standards and the recommended values of Flanagan (1973). In the determination of trace elements, only basalt standards were employed in the calibration for the metabasalts, and for the trondhjemites, only granitic rocks were used. The results are shown in Table 1.

Fig. 3 shows the data plotted in various diagrams. In the $FeO^{(t)}$-$FeO^{(t)}/MgO$ and TiO_2-$FeO^{(t)}/MgO$ diagrams (Fig. 3a1, a2), the data points closely follow the trend of abyssal tholeites (A). The close resemblance between the Tørvikbygd metabasalts and modern MORB is

Fig. 1. Detailed geological map of the area south of Skutevik, Tørvikbygd, with simplified map showing the distribution of the Tørvikbygd Ophiolite and the younger series in central Hardanger (key map). The garnet micaschist and metalliferous sediments (m) capping the ophiolite are exposed in tight syn-and antiformal hinges, and the outcrop pattern is the result of interference between two penetrative deformations and a later open folding.

Table 1. Major and trace elements of meta basalt and trondhjeimites from Tørvikbygd.

	Tv1	Tv2	Tv3	Tv4	Tv5	Tv6	Tv7	Tv8	Tv9	Tv10	Tv11	Tv12	Tv13
SiO_2	50.13	48.85	47.13	51.04	70.76	44.41	49.71	44.29	75.20	49.19	49.32	49.71	49.90
Al_2O_3	14.60	15.13	15.20	14.07	11.77	16.28	13.64	13.98	10.64	13.64	14.55	13.45	14.98
TiO_2	1.70	1.60	2.08	1.65	0.91	2.06	2.41	2.82	0.81	2.26	1.71	2.27	1.60
Fe_2O_3	2.50	2.22	1.88	2.22	0.94	2.77	2.45	2.98	0.58	1.40	1.85	1.96	1.99
FeO	7.88	8.78	8.86	8.57	4.28	9.07	9.94	10.62	2.63	9.94	8.86	9.72	8.50
MgO	6.80	7.37	7.72	6.77	2.78	6.60	6.11	7.15	2.67	6.38	7.58	6.55	7.34
CaO	10.36	10.42	11.45	10.40	2.27	11.74	9.07	11.07	1.89	10.25	10.42	10.17	10.27
Na_2O	2.51	2.34	1.93	2.65	3.77	2.55	2.27	2.59	4.00	3.02	3.03	2.88	2.97
K_2O	0.41	0.40	0.26	0.39	0.86	0.41	0.62	0.33	0.27	0.44	0.32	0.51	0.28
MnO	0.20	0.22	0.23	0.22	–	0.24	0.26	0.25	–	0.22	0.23	0.24	0.25
P_2O_5	0.28	0.19	2.23	0.20	0.26	2.36	0.28	2.25	0.25	0.25	0.16	0.40	0.29
Loi	1.49	1.25	1.17	0.95	1.65	1.44	1.39	0.99	1.82	1.85	2.06	1.77	1.41
Total	98.86	98.77	100.14	99.13	100.25	99.93	98.15	99.32	100.7	98.84	100.09	99.63	99.78
V	259	251	276	268	122	263	351	343	101	324	262	340	242
Cr	311	246	329	97	–	197	179	172	–	246	373	242	330
Co	36	38	40	38	–	40	43	40	–	39	39	39	36
Ni	74	96	120	44	–	69	50	48	–	57	87	51	95
Zn	85	145	119	101	44	111	428	119	30	92	122	108	171
Rb	nd	nd	nd	nd	42	7	9	nd	2	nd	nd	1	nd
Sr	148	226	129	225	223	149	84	128	113	148	215	130	183
Y	41	39	43	41	30	47	50	51	33	50	39	50	40
Zr	119	98	131	115	294	129	160	161	366	154	114	153	100
Nb	<4	<4	<4	<4	32	<4	<4	<4	33	<4	<4	<4	<4

further shown in several discriminant diagrams, such as the V/Ti, Ti-Zr-Sr diagrams (Fig. 3b,c,d respectively), where all data plot within the MORB field. In Fig.3e the average contents of Sr,K,(Nb),P,Zr,Ti,Y and Cr have been normalized against average MORB. Except for Nb, which is lower than MORB (for all samples the Nb values are less than 4 ppm, but since at this concentration level the analytical uncertainty is very large, no absolute figure is given), the other incompatible trace elements have concentrations somewhat higher than average MORB. Very low Nb concentrations are a characteristic feature of basalts from marginal basins, and although the Y values of the Tørvikbygd metabasalts are somewhat higher than those of the marginal basin basalts shown here, the possibility should be left open that they may have formed in such a tectonic environment. If so, however, the effect of subduction-related magmatism is small, which may suggest that this part of oceanic crust was remote from a volcanic island arc.

The association of rock types and their geochemistry thus strongly suggest that the older series represents remnants of a highly dismembered ophiolite and its sedimentary cap.

Conclusion

The typical ocean-floor geochemistry, the sheeted dyke complex and the general character of the lithologies in the older series indicate that this represents a highly deformed and dismembered ophiolite complex, the Tørvikbygd Ophiolite.

The dismembered ophiolite was deformed, metamorphosed and deeply eroded prior to the deposition of the younger Ordovician/Silurian (?) series, and the contact between the two complexes represents a major stratigraphic unconformity.

The interpretation and regional significance of these relationships occuring within one of the lowest tectono-stratigraphic units poses an interesting problem for further study and correlation with other areas in western Norway.

Acknowledgement. – We thank M. Adachi for drawing the figures.

Manuscript received November 1983.

IUGS UNESCO

International Geological Correlation Program.
Norwegian contribution no. 65 to project 27 The Caledonian Orogeny.

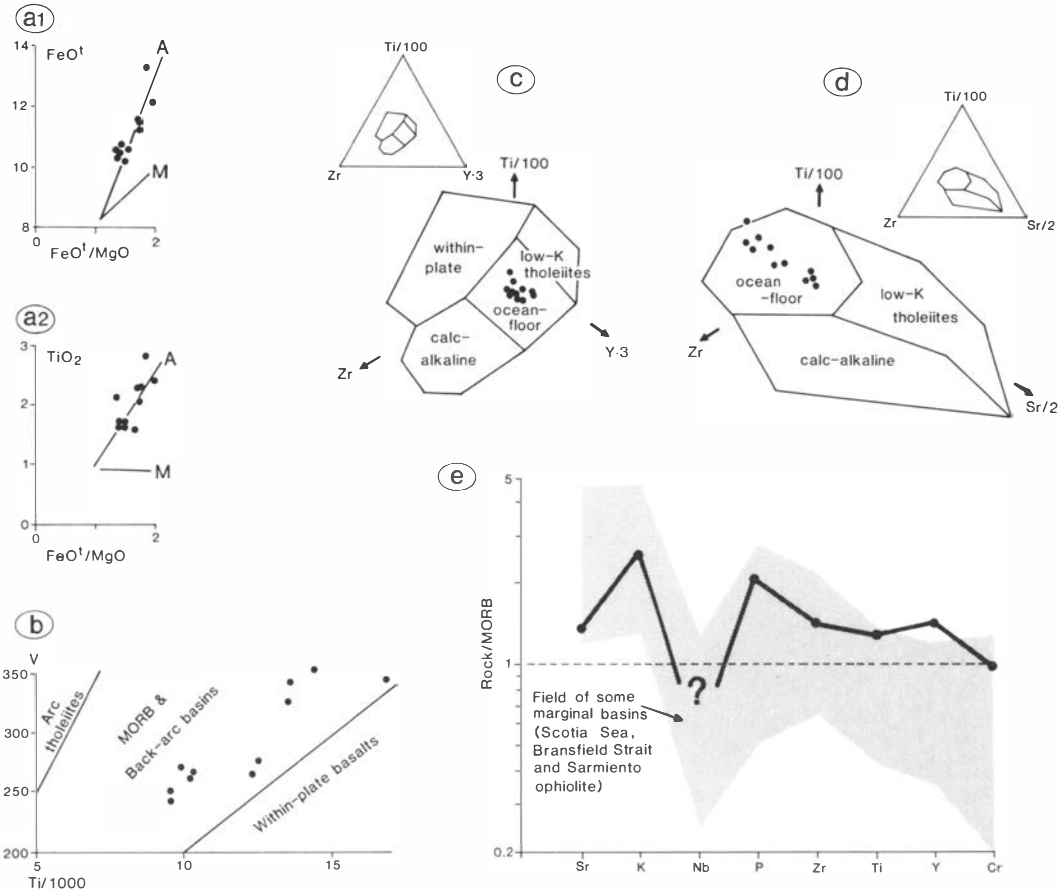


Fig. 3. The Tørvikbygd Metabasalts plotted in various diagrams. A-1 $FeO^{(t)}$ – $FeO^{(t)}$/MgO and A-2 TiO_2 – $FeO^{(t)}$/MgO diagrams showing the trend lines of abyssal tholeiites (A) and the Macauley island tholeiitic series (M) (from Miyashiro 1975). b) V-Ti discriminant diagram (from Shervais 1982). c) Ti-Zr-Y and d) Ti-Zr-Sr discriminant diagrams (from Pearce & Cann 1973). e) Average Sr, K, (Nb), P, Zr, Ti, Y and Cr values normalized to average MORB (Sr 120 ppm, K2O 0.15 %, Nb 4 ppm, P205 0.12 %, Zr 90 ppm, Ti02 1.5 %, Y 30 ppm and Cr 240 ppm; from Pearce 1980). Chemical data from the marginal basins are from: Scotia Sea (Tarney et al. 1977); Bransfield Strait (Weaver et al. 1979); Sarmiento Ophiolite (Saunders et al. 1979).

References

Brekke, H., Furnes, H., Nordås, J. & Hertogen, J. (in press): Lower Palaeozoic convergent plate margin volcanism on Bømlo, SW. Norwegian Caledonides. Tectonic environment. *J. Geol. Soc. London.*

Flanagan, F. J. 1973: 1972-values for international geochemical standards. *Geochim. Cosmochim. Acta 37*, 1189–1200.

Miyashiro, A. 1975: Classification, characteristics and origin of ophiolites. *J. Geol. 83*, 249–281.

Naterstad, J. & Jorde, K. 1981: *Basement-cover relationships in southern Norway – Hardangervidda to Karmøy.* Excursion guide B-6, Uppsala Caledonide Symposium.

Pearce, J. A. 1980. Geochemical evidence for the genesis and eruptive setting of lavas from Tethyan ophiolites. *Proc. Int. Ophiolite Symp. Nicosia* 1979 261–272.

Pearce, J. A. & Cann, J. R. 1973: Tectonic setting of basic volcanic rocks determined using trace element analyses. *Earth Planet. Sci. Letters 19,* 290–300.

Roberts, D., Thon, A., Gee, D. & Stephens, M. B. 1981: *Scandinavian Caledonides.* Tectonostratigraphy (Map) UCS edition.

Saunders, A. D., Tarney, J., Stern, C. R. & Dalziel, I. W. D. 1979: Geochemistry of Mesozoic marginal basin floor igneous rocks from southern Chile. *Geol. Soc. Am. Bull. 90,* 237–258.

Shervais, J. W. 1982: Ti-V plots and the petrogenesis of modern and ophiolitic lavas. *Earth Planet. Sci. Letters 59,* 101–118.

Sturt, B. A., Roberts, D. & Furnes, H. (in press): A conspectus of Scandinavian Caledonian ophiolites. *J. Geol. Soc. London.*

Tarney, J., Saunders, A. D. & Weaver, S. D. 1977: Geochemistry of volcanic rocks from the island arcs and marginal basins. In: *Island Arcs. Deep Sea Trenches and Back-Arc Basins,* Maurice Erving Series, Vol. 1, Am. Geophys. Union, 367–377.

Weaver, S. D., Saunders, A. D., Pankhurst, R. J. & Tarney, J. 1979: A geochemical study of magmatism associated with the initial stages of back-arc spreading. *Contrib. Mineral. Petrol. 68,* 151–169.