Magmatic and detrital pyrrhotite and pentlandite and magmatic troilite from Nordfjellmark, Velfjord-Tosen region, Central Norwegian Caledonides

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Introduction

The metapsammites and conglomerates of the Velfjord-Tosen region rest with a profound stratigraphic unconformity on an ophiolitic substrate (Sturt et al. 1984, Løseth 1985, Thorsnes 1985). The metasediments are rich in sulphides and oxides, both just above the ophiolite contact and higher in the metasedimentary sequence. It was considered by the present authors that these enrichments, at least partly, could possibly represent ophiolite-derived fossil placer accumulations which could be enriched in noble metals (platinum-group elements (PGE) and gold). In 1990 we therefore carried out a reconnaissance survey for PGE and Au in the Nordfjellmark and Nevernes areas. The geology of the actual region, with main emphasis on the tectonostratigraphy, is summarised in Thorsnes & Løseth (1991). The reader is referred to this publication as the maps, etc., therein will be further referred to in the present paper.

PGE and Au survey

The actual ophiolite fragments consist mainly of variably altered mantle harzburgite and dunite with subordinate wehrlite and pyroxenite. A metagabbroic fragment is separated from the ultramafic ones by a thrust fault (Fig.1). Both the ultramafites and the metagabbro are considered as originally belonging to the same basal ophiolitic unit, later dismembered (imbricated) during regional thrusting. The metasedimentary rocks under consideration comprise various schists, psammites, conglomerates and minor marbles (see Thorsnes & Løseth 1991, especially fig.4 and 5).

Both the ophiolite fragments and the overlying clastic sequence were sampled for PGE and Au analyses. The results showed mainly typical background levels with minor anomalies (detection limits were Au: 1 ppb, Pt: 0.5 ppb and Pd: 0.5 ppb). The highest values obtained were Au: 5 ppb, Pt: 12 ppb and Pd: 34 ppb from a metasandstone just above the contact of the Heggefjord ultramafite (fig.5 in Thorsnes & Løseth 1991). The highest Au value of 80 ppb, without anomalous Pt or Pd, occurs in a metapsammite well above the contact to the Gunnardalen ultramafic body (the central, small and very thin ultramafic fragment in fig.4 in Thorsnes & Løseth 1991).

Occurrence of magmatic and detrital sulphides

During microscopic study of the collected specimens, grains of pyrrhotite containing pentlandite lamellae were observed in several samples from the ophiolitic rocks, as well as in a number of samples from the overlying sandstones. In most of the samples, abundant pyrrhotite was present. Microprobe analyses on samples from the Gunnardalen ultramafite and sandstone (Table

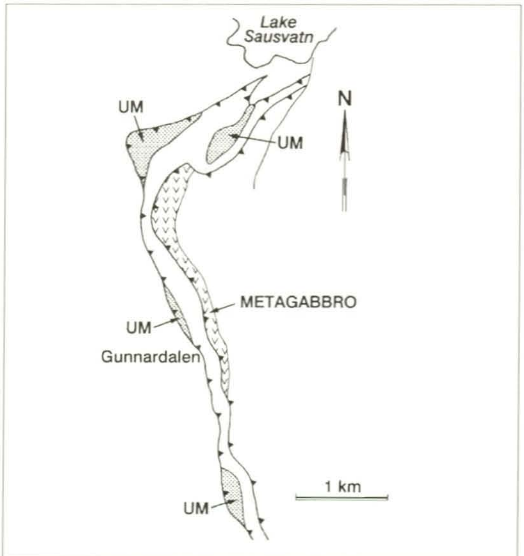

Fig. 1: Simplified sketch map over the Nordfjellmark area, Sausvatn, showing the location of the ultramafic and gabbroic ophiolite fragments. Based on fig. 4 in Thorsnes & Løseth (1991).

1) showed that the high Co-contents are virtually the same in ptl from the metasediments (analysis 13) as in ptl from the underlying harzburgitic substrate (analyses 1, 3, 5 and 7). The Fe content is slightly enriched at the expense of Ni in the metasediment-hosted ptl, presumably relating to diagenetic and/or metamorphic processes in a foreign environment. The Pt-Pd content of the Gunnardalen ultramafite varies from 2.5 - 19 ppb (3 samples), whereas in the sediments above it ranges from 3 - 11 ppb (8 samples) which is commensurate with incorporation of ore grains into a sedimentary unit, but also implies a nearby source. The Au contents in the ultramafite vary from 4 - 8 ppb and those of the sediments are in the range <1 - 80 ppb.

The ultramafite in Gunnardalen consists mostly of strongly altered mantle harzburgite and minor(?) metadunite comprising fine-grained metamorphic olivine. The few microscopically investigated specimens from the body showed it to be unusually rich in very fine-grained magmatic sulphides. Sample 3i-B (Table 1) of a metaharzburgite shows for example ca. 5 % (modal estimate) sulphides (pyrrhotite with minor ptl lamellae) mostly as very small, disseminated grains (<10-500 μm) along the borders of the silicate minerals (metamorphic olivine, bastite, etc.) and in cracks in these. The largest grain observed was measured to 2.5 mm. Pyrrhotite also occurs as drop-shaped inclusions in ca. 3% relatively coarse-grained (up to 2 mm) and partly altered, disseminated chromite in the polished thin-section.

Sample 3i-A of metadunite consists of metamorphic olivine, ca. 1% disseminated chromite and ca. 5% sulphides of which 80-90% are pyrrhotite and 10-20% pentlandite. Most sulphide grains are in the range <10-300 μm, with largest grain ca.800 μm.Such high contents of magmatic sulphides as found in the present case are very rare in the mantle portion of ophiolite complexes. There are, for example, no reports of sulphide enrichments in the mantle portion of the large,

Table 1. Representative analyses of troilite (tr), hexagonal pyrrhotite (hpo), monoclinic pyrrhotite (mpo), pentlandite (ptl) and arsenopyrite (asp) in metamorphosed ultramafic ophiolite rocks (um) and sedimentary overlying metasandstones (sst) from Gunnardalen, Nordfjellmark area, Velfjord-Tosen region, Central Norwegian Caledonides.

sample/ section no.	rock	grain no.	analysis no.	weight-% Fe	Ni	Co	S	As	Total	atomic-% (recalculated to 100 %) Fe	Ni	Co	S	As	Ni/Co	phase analysed
3i-B	um	1	1	30.59	31.19	4.01	33.63	0.00	99.43	24.90	24.10	3.10	47.90		7.77	ptl-lamella
	um		2	60.04	0.58	0.05	39.67	0.00	100.33	46.16	0.43	0.03	53.38		14.33	mpo-host (to ptl-lamella in analysis 1)
	um	2	3	28.99	32.83	4.25	33.06	0.06	99.18	23.76	25.53	3.30	47.40		7.74	ptl-lamella
	um		4	60.77	0.58	0.08	39.69	0.00	101.12	46.44	0.42	0.06	53.08		7.00	po-host, probably mpo
	um	3	5	27.51	31.44	6.85	33.43	0.04	99.26	22.49	24.39	5.31	47.81		4.59	ptl-lamella
	um		6	59.90	0.59	0.09	39.40	0.00	99.99	46.25	0.44	0.06	53.25		7.33	mpo-host
	um	4	7	28.04	32.88	6.14	32.93	0.02	100.00	22.86	25.44	4.75	46.96		5.35	ptl-lamella
	um		8	60.76	0.58	0.10	39.08	0.00	100.51	46.81	0.43	0.07	52.69		6.14	hpo-host
3i-C	um	5	9	29.39	34.57	1.85	32.73	0.00	98.53	24.24	27.06	1.44	47.25		18.79	Ni-rich ptl in vein, showing hex. parting (1.gen.ptl)
	um		10	34.30	31.59	0.53	33.26	0.00	99.68	27.88	24.38	0.41	47.32		59.46	Fe-rich, flameshaped ptl-lamella (2.gen.ptl)
	um		11	61.10	0.31	0.10	38.61	0.00	100.14	47.35	0.23	0.07	52.35		3.29	hpo-host phase
	um		12	63.62	0.09	0.04	36.72	0.00	100.47	49.70	0.07	0.03	50.20		2.33	flame-lamella of tr in host-hpo of analysis 11; the tr hosts in turn the flame-ptl of analysis 10
3D	sst	6	13	31.61	28.60	6.48	32.79	0.10	99.57	25.85	22.20	5.03	46.93		4.41	ptl-lamella; reequilibrated Fe-enriched ptl
	sst		14	61.21	0.33	0.06	39.08	0.00	100.67	47.09	0.24	0.05	52.62		4.80	hpo-host; reequil. Fe-enriched po (originally hpo or mpo)
	sst	7	15	62.12	0.39	0.07	39.33	0.00	101.90	47.28	0.28	0.05	52.39		5.60	fresh hpo in a partly sec. alt. grain; Fe-enrich. (reeq.)
	sst		16	52.22	0.68	0.10	41.99	0.00	94.99	41.30	0.51	0.07	58.12		7.29	alteration product of hpo in anal. 15; strongly Fe-depl.
3H	sst	8	17	36.89	0.24	2.68	23.37	42.53	105.70	32.85	0.21	2.26	36.41	28.27	0.09	subhedral asp-inclusion in po
3i-A	um	9	18	ptl (Fe > Ni); intensity of the strongest Ni-line is ca. 2/3 of that of the strongest Fe-line; qualitative EDS-analysis only.												
	um		19	po: qualitative EDS-analysis only.												
	um	10	20	small grain of Co-Ni-(Fe)-As-S assemblage, i.e. mineral belonging to the cobaltite-gersdorffite solid-solution series; qualitative EDS-analysis only.												

structural formula analysis

1: $(Fe_{4.16}\ Ni_{4.09}\ Co_{0.52})_{8.77}\ S_8$ 2: $(Fe_{0.865}\ Ni_{0.008}\ Co_{0.001})_{0.874}\ S$ 3: $(Ni_{4.31}\ Fe_{4.01}\ Co_{0.56})_{8.88}\ S_8$ 4: $(Fe_{0.875}\ Ni_{0.008}\ Co_{0.001})_{0.884}\ S$
5: $(Ni_{4.08}\ Fe_{3.76}\ Co_{0.89})_{8.73}\ S_8$ 6: $(Fe_{0.869}\ Ni_{0.008}\ Co_{0.001})_{0.878}\ S$ 7: $(Ni_{4.33}\ Fe_{3.89}\ Co_{0.81})_{9.03}\ S_8$ 8: $(Fe_{0.888}\ Ni_{0.008}\ Co_{0.001})_{0.897}\ S$
9: $(Ni_{4.58}\ Fe_{4.10}\ Co_{0.24})_{8.92}\ S_8$ 10: $(Fe_{4.71}\ Ni_{4.12}\ Co_{0.07})_{8.90}\ S_8$ 11: $(Fe_{0.904}\ Ni_{0.004}\ Co_{0.001})_{0.909}\ S$ 12: $[Fe_{0.990}\ Ni_{0.0014}\ Co_{0.0006})_{0.992}\ S$
13: $(Fe_{4.41}\ Ni_{3.78}\ Co_{0.86})_{9.05}\ S_8$ 14: $(Fe_{0.895}\ Ni_{0.005}\ Co_{0.001})_{0.901}\ S$ 15: $(Fe_{0.902}\ Ni_{0.005}\ Co_{0.001})_{0.908}\ S$ 16: $(Fe_{0.711}\ Ni_{0.009}\ Co_{0.001})_{0.721}\ S$
17: $(Fe_{0.99}\ Ni_{0.01}\ Co_{0.07})_{1.07}\ As_{0.85}\ S_{1.09}$

composition of the different members of the pyrrhotite solid-solution series; simplified from Neumann (1985) and Putnis & McConnell (1980)
troilite: $Fe_{1.00}\ S$ miscibility gap at low temp.: $Fe_{0.93-1.00}\ S$ hexagonal pyrrhotite: $Fe_{0.90-0.93}\ S$ intermediate pyrrhotite at higher temp.: $Fe_{0.87-0.90}\ S$
monoclinic pyrrhotite: $Fe_{<0.87}\ S$

well exposed and very well studied Leka ophiolite complex situated some 50 km to the WSW of the Nordfjellmark area (Albrektsen et al. 1991, Pedersen et al. 1993). In this respect the Gunnardalen, and probably also the other three ultramafite fragments in the Nordfjellmark area (fig.4 in Thorsnes & Løseth 1991) resemble somewhat the Cliff locality in the Shetland ophiolite from which a magmatic sulphide concentration has recently been suggested (Lord et al. 1994). However, no chromite segregations, which would probably have acted as a trap for eventual PGEs, have been found in the Gunnardalen fragment. The heaviest (densest) phase found in the ultramafite when scanning over the sections using the SEM was a tiny inclusion of cobaltite-gersdorffite (analysis 20 in Table 1). The densest phase found in the overlying metasediments was a 4 x 5 μm inclusion of arsenopyrite (asp) hosted in pyrrhotite (analysis 17 in Table 1).

Discussion

During the integrated microprobe/SEM study the following magmatic and detrital/metamorphosed sulphide assemblages were found and analysed:
(a) magmatic assemblages: 1: monoclinic pyrrhotite (mpo) - hexagonal pyrrhotite (hpo) - pentlandite (ptl); 2: troilite (tr) - hpo - Ni-rich ptl (ptl-1) - Fe-rich ptl (ptl-2).
(b) detrital and later metamorphosed assemblages: 1: hpo - ptl; 2: hpo - sec. alt. hpo; see Fig.2.
The quantitative analyses (Table 1) and SEM-study permits the preliminary suggestion to be made that both phases in the co-existing Fe-poor mpo/hpo - ptl association are enriched in Fe, depleted in Ni and constant in Co when transformed from the magmatic to the detrital and further diagenetic/metamorphic stages. A probable reason for the observed change in chemical composition seems to be adjustments during reequilibration under diagenesis and/or metamorphic conditions, in a host matrix of quartz, feldspar and biotite.

The presence of clastic sulphide grains in these sandstones is of interest as most sulphides, particulary pyrrhotite, are notorious for being rapidly oxidised under oxygen-rich conditions. The calcareous sandstones in which they occur are marine deposits. The implications of the preservation of such clastic sulphides is presumably the result of erosion of the ophiolitic rocks followed by extremely rapid sedimentation possibly by mass flow movements on unstable slopes. Examples of such preservation of sulphides are known from the literature (e.g. Boyle 1978) and even in ancient fluviatile deposits (Sturt et al. 1994).

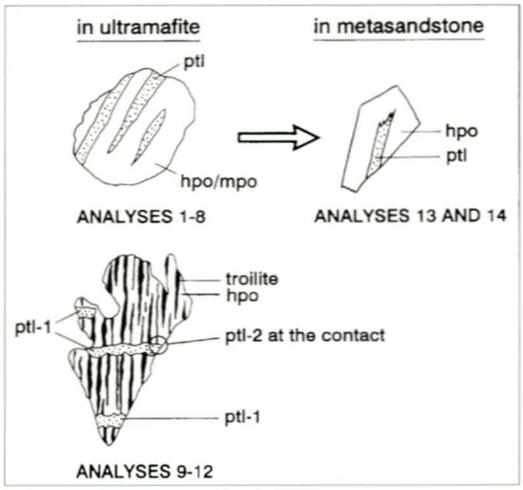

Fig. 2: Sulphide textures observed in samples of ultramafic rocks and metasandstones from Gunnardalen, Nordfjellmark.

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