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A metamorphosed, layered alpine-type peridotite in the Langavat Valley, South Harris, Outer Hebrides

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SUMMARY. A layered alpine-type peridotite, of pre-Scourian age(?), has been metamorphosed in the granulite facies then partially retrogressed to greenschist facies assemblages. Following granulite facies metamorphism of the dunite–harzburgite peridotite, granitization and metasomatism modified the peridotite by adding calcium and generated olivine–tremolite rocks. Anthophyllite-rich rocks developed from localized orthopyroxene-rich zones. The main epoch of serpentinization followed after tremolite formation and removed a portion of the calcium previously added, but with negligible effect upon the original trace-element content. Between tremolite generation and the main period of serpentinization greenschist facies assemblages formed. The layered rocks possess a repetitive, chemical variation normally attributable to basic igneous processes, although they may have formed either by vein metasomatism or by metasomatism of a disrupted layered igneous series. Twelve rock and five mineral analyses are presented, and trace element data for twenty-one rocks.

THE largest ultrabasic intrusion in South Harris is traceable over seven km as discontinuous lenses extending from the Sgeir nan Sgarbh promontory (NF 025950) to Loch Meurach (NG 062878) in the Langavat valley. Seven prominent lenses are intruded into the Langavat metasedimentary series and are transgressive. Between the large lenses (the two largest are approximately 900 × 100 and 400 × 100 m) small outcrops of similar material are common. The large lenses, which are more extensively serpentinized, tend to occur at the extremities of the intrusion. Contact metamorphic phenomena have not been observed and only six outcrops of the contacts were located. Country rocks contiguous with the ultrabasic lenses consist of quartz, plagioclase, and cummingtonite and with increase in the amount of hornblende (Livingstone *et al.*, 1973) pass into typical retrograde metasediments.

Collectively the lenses are characterized by a central zone of olivine–tremolite–serpentine rock, serpentinite, or dunite, which grade into anthophyllite-rich rocks, chlorite schists, or chlorite–actinolite schists. Individual lenses may diverge from the above general pattern. Two striking exceptions are a mica peridotite–harzburgite lens near Loch Dubh Sletteval (NG 055898) and one exhibiting a layered series at Scara Ruadh (NG 055889); the latter forms the main subject of this paper. Petrographic details of the major rock types are given in Table I. For descriptive convenience it is pertinent to note the accessory minerals at this juncture as they are common to most of the rock types tabulated. Disseminated are pyrite, chalcopyrite, an untwinned carbonate, talc, chlorite, and phlogopite. Amphibole-bearing rocks, whether the amphibole constitutes a minor or major portion, contain disseminated cummingtonite.

The layered series. The Scara Ruadh lens consists principally of serpentinite and olivine–tremolite serpentine rocks and approximately one-sixth of the lens, the southern extremity, is layered. The layered series (serpentinite and chlorite/tremolite layers) parallels the western margin and sweeps eastwards, then northwards, to form

TABLE I. *Brief petrographic details of the main rock types*

Rock type	Colour		Grain size	Mineral composition	Notes
	Fresh	Weathered			
Dunite*	dark grey	buff	3 mm	Fo 89·3	Anthophyllite rosettes in hand specimen. Highly acicular anthophyllite and opaque clusters may transgress olivine boundaries.
Harzburgite*	mottled dark grey-black	buff	5–8 cm	Fo 88; En 87	—
Mica peridotite*	dark greenish grey	buff	2–3 mm	Fo 90·5; En 87	Phlogopite may be mantled by pennine
Serpentinites‡	green to black	white	—	lizardite, antigorite, chrysotile	Occasional clouding, tremolite, + anthophyllite, both may be pseudomorphed by serpentine and cloudy pseudomorphs cut by clear chrysotile veinlets
Olivine–tremolite‡–serpentine rocks	mottled dark grey to black	buff	very variable	Fo 85·5	Serpentine may be clouded, opaques very abundant, some tremolite pseudomorphed by serpentine
Anthophyllite† rocks	light grey	buff	very variable	γ 1·625–1·640	Opaques not abundant, anthophyllite derived from orthopyroxene
Greenschist‡ facies rocks	green	reddish brown	Actinolite up to 5 cm	Actinolite, tremolite, chlorite, talc	Opaques not abundant

Approximate frequency of occurrence: * minor, † abundant, ‡ very abundant.
Olivine composition determined by method of Jackson, 1960.
Orthopyroxene composition determined by optical method, γ R.I.

a hook-shaped outcrop. Along the western margin, where the layers are sporadically distributed, they dip approximately 70° westwards and in other regions oppose the paragneiss dip.

Linear intercept measurements in the hook-shaped outcrop region indicate that serpentinite layers constitute approximately 60 % of the layered series. Serpentinite layers range from approximately 10 cm to 2·5 m whereas the chlorite/tremolite layer maximum is 0·6 m. Junctions between layers are sharp. Certain zones within the layered series may be termed 'hybrid layers', which are neither dominantly serpentinite nor chlorite/tremolite layers. In this case the 'banding'[1] is on approximately a 3 cm scale, with bifurcating and re-combining bands. Megascopic evidence for accumulative textures is lacking but would probably have been eradicated by the strong metamorphic overprint. Residual olivine in the serpentinite layers is rare and for the analysed layer (Table II, anal. 5) the olivine (Fo 84·5) is the most fayalite-rich olivine found throughout the Langavat valley ultrabasic lenses.

Lineated chlorite/tremolite layers (the chlorite is akin to kämmererite) contain only a very minor quantity of opaque minerals. Serpentine forms an accessory constituent and residual olivine is very rare.

Chemistry of the peridotite. Seventeen major analyses of twelve rocks and five minerals are detailed in Table II, and trace elements, plus total iron (as Fe_2O_3) for twenty-one rocks in Table III. Major oxide determinations were undertaken by utilizing gravimetric, colorimetric, titrimetric, and X-ray fluorescence methods. All trace elements, except phosphorus, were determined by X-ray fluorescence analysis. Phosphorus was determined according to the neutron activation method of Henderson (1967).

Serpentinite layers are the most iron-rich rocks analysed from the series (Table III) and are different chemically from the chlorite/tremolite layers (Table II, anals. 6 and 7). The former are appreciably lower in SiO_2, Al_2O_3, and CaO than the latter and higher in MgO, total iron, and H_2O.

From Table III it is apparent that the original trace-element concentrations vary little with serpentinization or anthophyllitization. On this basis the Cr, Ni, and Co contents of the serpentinite layers may be assumed to be largely unmodified. A noteworthy point is that the Cr : Ni : Co ratios for the average compositions are identical. Chromium in the serpentinite layers is concentrated in the opaque phases whereas in the chlorite/tremolite layers it must be located in the chlorite since the analysed tremolites (anals. 13 and 14) are low in this element.

The chlorite/tremolite layers are higher in Sr, Mn, and Ti than serpentinite layers with the Sr content of the former closely approaching twice that in the latter. Stueber and Murthy (1966) published strontium abundances of some alpine-type peridotites (2·3–14·7 p.p.m.) and these embrace the Langavat values. The original Sr and Ca contents remain conjectural; however, for twenty-two unmigmatized gneisses from North Harris and Lewis, Tarney *et al.* (1972) obtained average contents of 475 p.p.m. Sr and 3·2 % CaO. On this basis it seems unlikely that strontium accompanied the introduction of calcium into the peridotite. The strontium contents reported in Table III may be close to the original concentrations.

Paragenesis

The layered series. Layering in alpine-type peridotites may result from tectonic and/or magmatic processes (Dickey, 1970) and both tectonic and magmatic-type layers may be present within the same intrusion and possess the same mineralogy and chemistry.

[1] The term 'band' is used to denote either a long narrow chlorite/tremolite or serpentinite unit within a layer of the opposing type rather than an individual layer.

TABLE II. *Analysis of various rocks and minerals from the Langavat Valley peridotite*

Anal. *Sample*	1 NLLA1	2 MLLP	3 MLL	4 LL2	5 LLBS(S)	6 LLBS(A)	7 LLIS(A_2)	8 LB	9 LLIS	10 LL6	11 LL8	12 SNS4	13 Tremolite LL8	14 Tremolite LLBS(A)	15 Antho-phyllite	16 Antho-phyllite	17 MICA MLL
SiO_2	36·37	42·03	36·35	36·52	34·99	47·36	46·22	50·94	38·31	53·43	44·16	45·58	54·56	54·00	58·48	53·16	41·19
TiO_2	0·03*	0·07	0·31	0·05	0·14	0·12	0·06*	0·10	0·11	0·04*	0·24	0·24	trace	0·08	0·03	n.d.	0·37
Al_2O_3	0·69	1·19	5·91	2·94	3·07	5·29	4·87	7·22	10·51	1·96	2·81	14·85	1·49	2·28	0·57	2·95	13·19
Fe_2O_3	2·94	5·92	4·03	7·26	9·03	2·15	0·65	0·61	1·70	1·99	5·37	0·77	0·78	0·76	0·58	4·53	1·54
FeO	6·69	5·93	4·69	2·14	3·67	4·24	4·91	7·11	5·40	6·18	2·95	8·26	2·19	3·48	7·85	3·07	2·53
MnO	0·13	0·20*	0·09	0·09	0·09	0·12	0·20*	0·20	0·15	0·14	0·13	0·11	0·08	0·10	0·27	0·14	0·04
MgO	45·56	37·92	40·33	38·11	36·88	26·93	31·02	22·73	31·76	30·32	30·35	19·01	26·29	26·45	29·25	30·03	27·27
CaO	0·10‡	0·10‡	0·04‡	0·08‡	0·94	6·81	6·93	7·76	2·01	0·36	5·38	6·02	12·53	10·67	0·14	0·28	n.d.
Na_2O	0·05	n.s.	0·22	0·03	0·04	0·20	n.s.	0·36	0·26	0·06	0·18	1·01	0·19	0·17	0·08	0·10	0·77
K_2O	0·01	n.s.	0·70	0·01	0·01	0·03	n.s.	0·04	0·03	0·02	0·03	0·07	0·02	0·02	0·02	0·01	7·06
H_2O^+	5·86	5·89	6·45	11·40	10·48	5·56	4·29	2·64	9·03	4·18	7·24	3·37	2·37	2·22	2·60	4·83	5·36
H_2O^-	0·09	0·14	0·43	0·42	0·33	0·20	0·13	0·02		0·16	0·20	0·08	n.d.	0·06	0·20	0·41	0·50
Cr_2O_3	1·26	1·36*	0·36	1·14	0·78	0·55	0·51*	0·74	1·43	1·34	1·09	0·37	0·13	0·08	0·04	0·52	0·66
	99·78	100·75	99·91	100·19	100·45	99·56	99·79	100·47	100·70	100·18	100·13	99·74	100·63	100·37	100·20†	100·27§	100·48
Ol ≡ Fo	89·3	88·0	90·5	—	84·5	—	—	—	—	—	85·5	—	—	—	—	—	—
Mg/Fe	8·7	6·0	8·7	7·9	5·6	7·8	10·1	5·3	8·2	6·8	6·9	3·8	16·3	11·3	6·2	7·5	12·5

n.s. = not sought. n.d. = not detected. * Trace element result (Table III) converted to oxide. ‡ Calcium determined by X-ray fluorescence analysis. Anals. by A. L. except 15 and 16.

1. Dunite, lens near northern end of Loch Langavat.
2. Harzburgite, lens near Loch Dubh Sletteval.
3. Mica peridotite, lens near Loch Dubh Sletteval.
4. Serpentinite, Scara Ruadh, near southern end of Loch Langavat.
5. Serpentinite layer, Scara Ruadh.
6. Chlorite/tremolite layer, Scara Ruadh (contiguous with serpentinite layer), anal. 5.
7. Chlorite/tremolite layer, Scara Ruadh.
8. Light-coloured band from actinolite–chlorite schists, Scara Ruadh.
9. Chlorite-rich layer, with tremolite, Scara Ruadh.
10. Anthophyllite rock, Scara Ruadh.
11. Olivine–tremolite–serpentine rock, small outcrop north of Scara Ruadh lens.
12. Greenschist facies selvedge; actinolite–chlorite rock, Rudha Sgeir nan Sgarbh.
13. Tremolite from olivine–tremolite rock LL8 (anal. 11).
14. Tremolite from chlorite/tremolite layer LLBS(A) (anal. 6).
15. Anthophyllite, serpentinite, 500 yards SE. of Borve Lodge (Guppy, 1956). Anal. W. F. Waters († includes NiO 0·01, CO_2 0·08).
16. Anthophyllite, lens in serpentinized peridotite, Scara Ruadh (Guppy, 1956). Anal. W. F. Waters and K. L. H. Murray (§ includes NiO 0·12, S 0·18, P_2O_5 0·01 less O ≡ S 0·07).
17. Phlogopite from mica peridotite MLL (anal. 3).

Repetitive, marked chemical disparity between adjacent layers in the Scara Ruadh lens has been detected.

Although the Cr : Ni : Co ratios of the average chlorite/tremolite and serpentinite layers are directly equivalent, the concentration of these elements, and Fe_2O_3, in the

TABLE III. *Trace element data (p.p.m.) and total iron values (as* Fe_2O_3 %) *for the Langavat peridotite and for specimens with contiguous layers from different regions of the layered series. Nos. refer to Table II.*

No.	Sample	Cr	Ni	Co	Sr	Rb	Zn	Mn	Ti	P	Total Fe
1	NLLA1	8800	1890	115	n.d.	n.d.	90	1340	260	40	10·36
2	MLLP	9350	1630	120	9	n.d.	120	1590	535	n.s.	12·50
3	MLL	2950	1150	105	21	150	110	1270	1595	220	9·23
4	LL2	4850	1940	95	n.d.	n.d.	65	1030	230	18	9·63
8	LB	4450	540	65	10	n.d.	55	1480	930	n.s.	8·50
10	LL6	9250	1420	85	n.d.	n.d.	55	1290	345	10	8·85
—	NU6*	6750	1170	85	12	n.d.	65	1540	540	n.s.	10·40
11	LL8	6300	1280	75	20	n.d.	60	1110	380	n.s.	8·64
12	SNS4	3150	520	80	15	n.d.	50	1020	1475	n.s.	9·94
—	LLIS(S1)	7050	1540	105	12	n.d.	55	930	470	n.s.	13·29
—	LLIS(A1)	4850	970	60	22	n.d.	85	1450	910	n.s.	6·74
—	LLIS(S2)	8600	1690	110	n.d.	n.d.	65	670	540	n.s.	12·43
7	LLIS(A2)	3500	810	50	13	n.d.	40	1550	470	n.s.	6·10
—	LLIS(S3)†	4000	1580	115	7	n.d.	80	680	345	n.s.	12·46
—	LLIS(A3)	4150	1080	70	10	n.d.	55	1670	420	n.s.	8·15
5	LLBS(S)	5700	1340	115	n.d.	n.d.	60	1100	470	n.s.	13·10
6	LLBS(A)	4500	860	50	12	n.d.	50	1260	530	4	6·85
—	LLLS(S)	7050	1460	115	n.d.	n.d.	50	830	460	n.s.	12·03
—	LLLS(A)	3700	800	55	12	n.d.	45	1450	475	n.s.	6·53
—	LLIS1(S)	6650	1580	120	6	n.d.	70	830	495	n.s.	13·91
—	LLIS1(A)	3300	790	50	17	n.d.	40	1480	480	n.s.	6·38

n.d. = not detected, detection limit Sr 5 p.p.m., Rb 5 p.p.m. n.s. = not sought. (S1), (S2), etc. = serpentinite layers; (A1), (A2), etc. = chlorite–tremolite layers. * harzburgite with abundant anthophyllite, i.e. transitional towards LL6. † very small sample. Analyst A. Livingstone.

	Cr	Ni	Co	Sr	Rb	Zn	Mn	Ti	P	Total Fe
av. of serpt. layers	7010‡	1531	113	8	—	63	840	463	—	12·87
av. of chlorite–tremolite layers	4000	885	55	14	—	52	1476	547	—	6·79
chlorite–trem./serpt.	0·57	0·58	0·48	1·75	—	0·82	1·75	1·18	—	0·52

Cr : Ni : Co ratio (average serpentinite layer) 4·57 : 1 : 0·07.
(average chlorite/tremolite layer) 4·52 : 1 : 0·06.
‡ value does not include S_3 result.

former is almost half that in the latter. This condition could have been achieved by the original ferromagnesian minerals merely being diluted by a phase deficient in these elements. The chlorite/tremolite layer Ca : Al ratios do not concur with those expected for a peridotite that contained olivine and mainly plagioclase, and imply calcium addition. (In the country rocks cummingtonite cannot be converted into hornblende without calcium addition; Livingstone op. cit.)

The 'norms' of the chlorite/tremolite layers are of a harzburgite type, with minor and almost equal amounts of plagioclase and diopside. If this 'normative' mineralogy is equivalent to the original model mineralogy then the chlorite/tremolite layers should possess trace element levels similar to the harzburgite MLLP: this is clearly not the case. Selective removal of Cr, Ni, and Co (and Fe) to lower the concentrations in narrow, alternating linear regions by metasomatism is an alternative mechanism to dilution by original plagioclase. Carswell *et al.* (1974) described metasomatism in a peridotite near Tafjord, southern Norway, which produced a zoned vein, each zone consisting principally of enstatite, anthophyllite, tremolite, and chlorite (from peridotite to vein centre respectively). For the Tafjord area Carswell (op. cit.) postulated that the country rocks were permeated by elements characteristic of granitization, as is the case for the South Harris rocks. No trace element studies were reported for the altered Tafjord peridotite, although from major chemical changes noted it seems highly probable that the same trace element distributions as those in the Scara Ruadh layers may well be found.

The serpentinite layers are the most iron-rich rocks of the peridotite and iron enrichment is mainly ascribed to their magnetite content. Serpentinization does not basically alter the original bulk composition, including trace-element levels, apart from hydration and conversion of FeO to Fe_2O_3. Olivine from the analysed serpentinite layer is the most iron-rich olivine, showing a 6 mol % Fo decrease over the mica-peridotite olivine. If the peridotite layers were regenerated after serpentinization, then a change in forsterite content is feasible, for regenerated olivine may be richer or poorer in forsterite (Wolfe, 1965; Taubeneck, 1957) than the original olivine. If regenerated olivine became more fayalite-rich it would negate igneous differentiation as a causative agent. The dunite, harzburgite, mica-peridotite, and olivine-tremolite rocks have also been recrystallized and the layered serpentinite olivine is still the most iron-rich, which agrees with the findings of Dickey (1970) for magmatic-type layers. Iron enrichment could be a relict igneous feature or the serpentinite layers have soaked up iron expelled during conversion of adjacent rocks to chlorite–tremolite assemblages.

In conclusion, for the layered series, greenschist facies metasomatic processes could have generated assemblages deficient in Cr, Ni, Co, and Fe. The field and chemical evidence suggests that the chlorite–tremolite layers are another manifestation of vein metasomatism or a metasomatized, disrupted layered igneous series. The type of metasomatism producing sharp mineralogical and chemical contrasts in peridotites, e.g. the zoned ultrabasic balls in Unst (Read, 1934) at Tafjord (Carswell, op. cit.) and Scara Ruadh is little understood. If the Scara Ruadh case is a variation on the vein metasomatic theme then it has produced localized repetition of the process, and metasomatism of this type has mimicked chemical variations normally attributable to basic igneous processes.

Summary of the probable sequence of events for the whole peridotite:

Intrusion (of igneous layered body at Scara Ruadh?) into pre-Scourian oceanic sediments and emplacement during plate-tectonic processes (Garson and Livingstone, 1973).

Scourian granulite facies metamorphism (isochemical) caused recrystallization of peridotite.

Late Laxfordian granitization and metasomatism produced chemical and mineralogical changes in the peridotite.

Development of anthophyllite, mainly from orthopyroxene (Anthophyllite rock $(MgO+FeO)/SiO_2$ value is identical to that of harzburgite orthopyroxene composition).

Addition of SiO_2 and H_2O only—no effect on trace-element content.

Widespread introduction of calcium into peridotite generated olivine–tremolite rocks.

Serpentinization followed after tremolite development.

At this stage appreciable movement of Ca, Si, Mg, and H_2O throughout the peridotite lenses (metasomatic alteration of disrupted igneous layering or production of layered series by vein metasomatism at Scara Ruadh).

Formation of Cr- and Fe-rich opaque phases and magnetite are late stage phenomena of serpentinization.

Greenschist facies rocks are probably contemporaneous with, or slightly post-date, tremolite development.

Concluding remarks. The Langavat valley peridotite would fit into the harzburgite sub-type of alpine-type peridotites of Jackson and Thayer (1972) who have pointed out that layered alpine complexes older than 1200 Myr are exceedingly rare. From petrological evidence the peridotite is certainly older than the last Laxfordian events, 1750–1715 Myr (van Breeman *et al.*, 1971) and may well be pre-Scourian in age.

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