HYDROTHERMAL ALTERATION Of DOLERITE WALLROCK WITHIN THE IBLE SILL, DERBYSHIRE

by

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Summary

The mineralogy, petrology, K–Ar geochronology and mode of occurrence of a zone of altered wallrocks in the Ible Sill, Derbyshire, is described. The chlorite-rich nature of alteration constrasts with the smectite and illite-smectite assemblages typically associated with deuteric or hydrothermal altered basalts in Derbyshire. K–Ar isotopic age determinations and alkali-variations indicate a hydrothermal origin and it is proposed that alteration was effected by hydrothermal brines modified by wall-rock interactions.

Introduction

The Ible Sill outcrops over an area of some 0.25 km^2 on the north side of the Via Gellia in Derbyshire (text-fig. 1). First described by Arnold-Bemrose (1894, 1907), the olivine-dolerite sill was intruded into the Bee Low Limestone of Asbian age (George *et al.*, 1976). A 30 m section of the sill is exposed in the disused roadstone quarry at SK 253568 (Walters & Ineson, 1981). The dolerite is traversed by numerous, randomly orientated veinlets (up to 10 cm wide) infilled with fibrous calcite and a green resinous material, originally described as chrysotile-asbestos by Garnett (1923). A more recent analysis (Sarjeant, 1967) however, indicated a chlorite-smectite intergrowth. These veinlets have no attendant visible wall-rock alteration. However, a zone of pale bleached and altered dolerite up to 1.5 m wide occurs along the base of the upper bench in the quarry. The zone is subvertical and trends east-west; it is associated with a thin, impersistent central fissure. The zone margins are indistinct but a rapid graduation into unbleached dolerite occurs.

The alteration of the dolerite was briefly noted by Garnett (1923) and referred to as 'chlorite–rock'. Walkden (1972) and Walters (1981) have subsequently demonstrated that the majority of previously quoted 'chlorite' occurrences in the basalts of the South Pennines were incorrect and that iron-rich smectites (saponites and nontronites) together with interlayered illite-smectites constitute the dominate clay phases.

Petrology

The unaltered dolerite (table 1 and plate 8 fig. A) is a typical medium-grained ophitic olivine dolerite. Titaniferous augite encloses labradorite laths which form an interlocking groundmass together with minor ilmenite, magnetite and apatite. Euhedral olivine phenocrysts have been pseudomorphed by red and green pleochroic clay aggregates, as shown in plate 8, fig. B. X-ray diffraction analysis of extracted pseudomorphs indicate that they are iron-rich smectites (nontronites and saponites).

In the altered dolerite, the smectite pseudomorphs after olivine are themselves replaced by an apple-green, homogene-ous clay phase which exhibits decreased birefringence and pleochroism relative to the original smectites. Albitised plagioclase representing an earlier replacement phenomena is likewise progressively replaced with increasing alteration. Primary augite is pseudomorphed by an apple green clay phase, with relict grain boundaries marked by concentrations of fine-grained anatase (plate 8, fig. C). Ilmenite and magnetite are altered to aggregates of coarse, euhedral, anatase.

X-ray diffraction analysis of the red and green clay mineral aggregates pseudomorphing the olivine phenocrysts in the altered dolerite indicates the presence of an Fe-rich chlorite. Peaks at 14.5, 7.2 and 3.6Å were unaffected by glycolation but on heating to 550°C for 1 hour, the 7.2Å peak was destroyed and the 14.5Å peak migrated to 14.0Å. The chlorite constitutes in excess of 60% of the altered dolerite, and in this instance the previous designation of a 'chlorite-rock' by Garnett (1923) is confirmed. The dominance of chlorite and the absence of smectites and calcitisation is in direct contrast with the typical deuteric and/or hydrothermal alteration as reported by Walters (1981) in the South Pennine basalts and this locality is therefore considered to have an unusual alteration assemblage, for Ixer (1972) reported the enrichment of K_2O, Fe_2O_3 and CO_2 as well as a reduction in Mg, Na_2O, FeO, MnO in the Matlock Upper Lava next to mineralisation.

Likewise, Ineson (1968) noted that bleached dolerite in the northern Pennine orefield contained carbonate aggregates, anatase, albite, potassium-rich clays, quartz and apatite which preserved the relict texture of the quartz-dolerite. The clay minerals were identified as illite and kaolinite. Major oxides of CaO, MgO, Na_2O and Fe were reduced while CO_2, K_2O and H_2O were enriched in the hydrothermally altered sill. Similarly the minor, or trace elements were redistributed with an overall depletion of Cu, Ni and Sr and an enrichment in Zn, Rb and Ba adjacent to mineralisation.
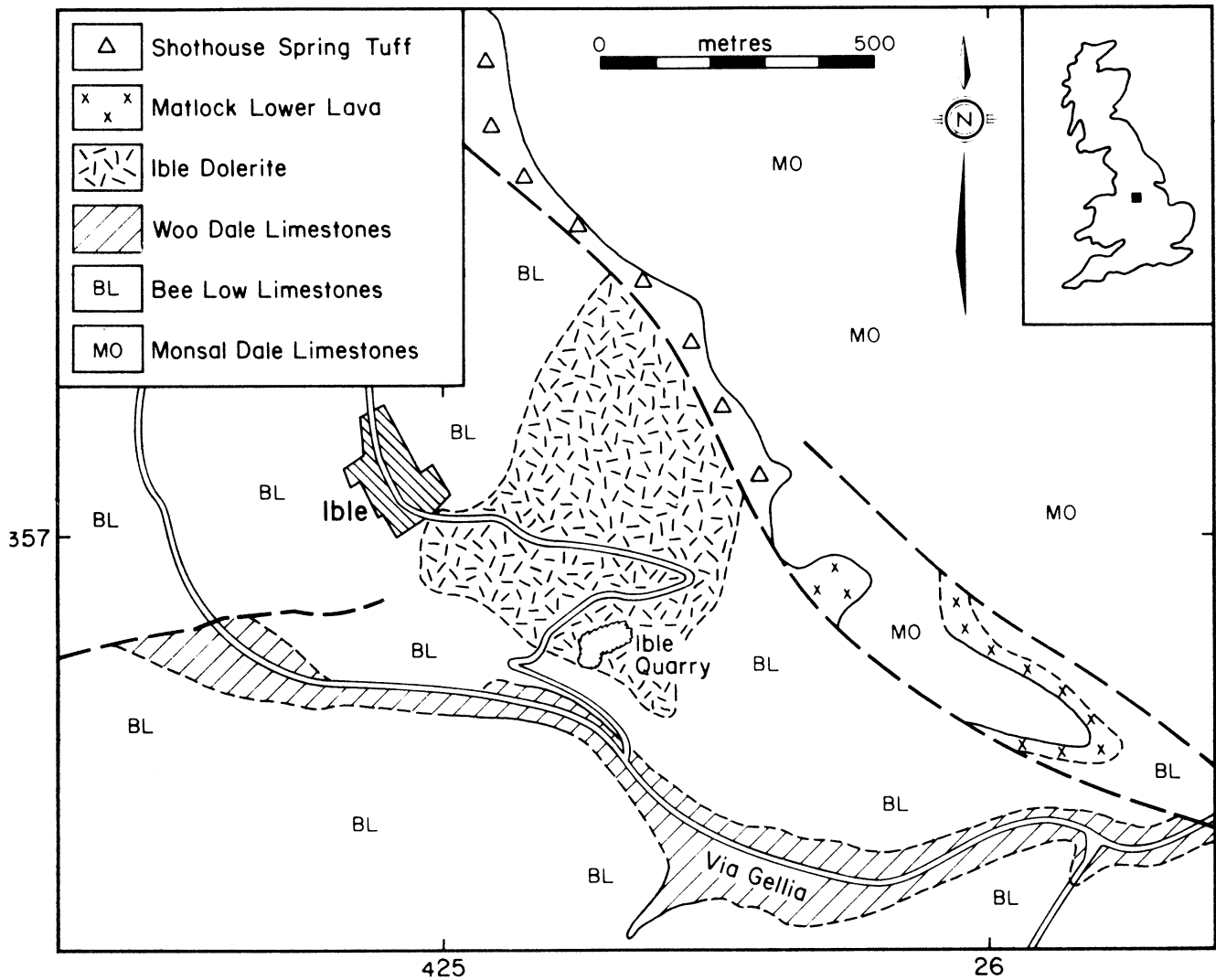
Text-fig. 1.   Geological sketch map of the Ible Sill, Derbyshire

Geochemistry and K–Ar Isotopic Age Dating

Samples which were representative of the transition from unaltered to altered dolerite were analysed by x-ray fluorescence spectrometry and wet chemical methods. The results are shown in table 1. The C.I.P.W. norm of the fresh dolerite (table 2), calculated on an anhydrous basis and with Fe_2O_3 standardised at 1.5% to compensate for the effects of deuteric alteration, indicates that the sill is of a transitional hypersthene–normative nature. The transitional nature is typical

Table 1. **Chemical analyses of the alteration phases of the Ible Sill**

Constituent Wt.%	Sample			
	Is 1	Is 2	Is 3	Is 4
SiO_2	48.76	45.70	44.14	46.40
TiO_2	1.86	1.84	1.75	1.88
Al_2O_3	14.60	16.71	16.09	16.63
Fe_2O_3	4.60	5.51	4.75	4.52
FeO	6.06	6.92	7.43	8.89
MnO	0.16	0.04	0.12	0.21
MgO	8.35	6.81	6.78	7.87
CaO	9.12	2.92	4.03	1.21
Na_2O	2.61	3.28	3.01	2.24
K_2O	0.79	1.17	1.33	2.18
H_2O+	2.36	6.37	6.09	6.49
H_2O^-	1.26	1.26	1.24	1.00
P_2O_5	0.38	0.28	0.26	0.27
CO_2	Trace	1.75	2.28	0.40
SO_3	0.05	0.09	0.06	0.18
Total	100.96	100.65	99.36	100.37
ppm				
Ba	302	168	168	220
Co	81	103	91	107
Cr	358	509	453	473
Cu	81	82	97	89
Ni	242	297	295	272
Pb	28	trace	trace	9
Rb	17	12	12	24
Sr	345	90	99	90
V	182	245	229	231
Y	27	27	24	20
Zn	104	130	128	111
Zr	128	103	101	101

Sample Is 1 – unaltered dolerite
Is 2-4 – progressively altered dolerite

Analyst: S.G. Walters

Table 2 Modal and normative analyses of unaltered (sample Is 1) dolerite at Ible, Derbyshire.

C.I.P.W. Norm* Mode (%)

Mode (%)

Or		4.79	Plagioclase	56.4
Ab		22.68	Clinopyroxene	23.6
An		26.54	Pseudomorphed Olivine	15.0
Di	Wo	7.27	Fe–Ti Oxides	2.4
	En	4.37	Interstitial Clay Alteration	2.6
	Fe	2.51		
Hy	En	11.95		
	Fs	6.85		
Ol	Fo	3.56		
	Fa	2.25		
Mt		2.18		
Al		3.63		
Ap		0.91		
Py		0.11		
Total		99.58	Calculated using Fe_2O,	
%An		53.90	standardised to 1.50%	

Table 3. K–Ar isotopic age determinations on the Ible Sill

Sample	*K_2O%	Radiogenic Argon (mm^3/gm^{-1})	Atmospheric Contamination %	Age (m.y.)
Unaltered dolerite	0.66	$(7.81 \pm 0.07)10^{-3}$	41.3	334 ± 10
Altered dolerite	1.33	$(1.11 \pm 0.01)10^{-2}$	34.0	242 ± 3
Altered dolerite	1.17	$(1.01 \pm 0.01)10^{-2}$	36.0	249 ± 2
Altered dolerite	2.18	$(1.84 \pm 0.01)10^{-2}$	26.8	244 ± 2
Altered dolerite	2.24	$(1.87 \pm 0.01)10^{-2}$	15.7	242 ± 2

*K_2O% are average triplicate analysis

Decay constants: $\lambda_e = 0.581 \times 10^{-10} yr^{-1}$

$\lambda_\beta = 4.962 \times 10^{10} yr^{-1}$

$\dfrac{40\kappa}{\kappa} = 1.167 \times 10^2$ atom.%

of the South Pennine basalt suite (Walters, 1981).

Geochemical alteration of the dolerite has resulted in a depletion in CaO and an increase in K_2O, FeO, Al_2O_3 and H_2O, while only minor variations in the concentrations of SiO_2, TiO_2, P_2O_5, MgO and Fe_2O_3 are noted. The minor amounts of CO_2 and SO_3 confirm the petrological analysis indicating that calcitisation and sulphides, typical products of hydrothermal alteration, are not important. Initial Na_2O enrichment, reflected in the dominance of albite, is subsequently followed by a depletion of Na_2O associated with the secondary replacement of albite by chlorite. A strong relative increase of K_2O over Na_2O during alteration is noted. A depletion of Ba, Sr and Pb is recorded whilst progressive alteration results in an increase or redistribution of Cu, Ni, Cr, V and Zn. Y and Zr exhibit minimal variations between the altered and unaltered dolerite.

The alteration of the Ible Sill, in which chlorite has been developed in contrast to illite/smectite as well as the absence of calcite is at variance with the previously reported petrological analyses of hydrothermally altered basalts in the Pennines (Ineson, 1968, Walters, 1981). As the factors effecting changes in the activity of components in hydrothermal solutions are extremely complex, a discussion on 'typical-trends' is subject to generalisations verging on incorrect statements. For example, the potential to undertake Na or K metasomatism may be present in both magmatic fluids and seawater brines; both of which may have been detected in the South Pennines. Which process actually occurs, i.e. Na or K metasomatism, may depend on factors such as hornblende stability in a nearby magma (Burnham, 1979) or the effective fluid/rock ratio (Seyfried and Bischoff, 1981). However for readers with little or no knowledge of the above, deuteric alteration is often accompanied by hydration, calcitisation and albitisation while hydrothermal alteration results in a depletion of MgO and FeO and an enrichment in CaO, CO_2 and K_2O while TiO_2, P_2O, Zr, Y and to a lesser extent Cr and V remain immobile.

It is emphasised that the authors are **not** suggesting that alkali (Na_2O) metasomatism has effected the Ible Sill, for the increase from 2.61% to a maximum of 3.28% Na_2O cannot be considered to be of a sufficient magnitude to support such a contention.

The alkali enrichment, however, during alteration of the Ible dolerite is considered to be a hydrothermal feature. K–Ar isotopic age determinations (table 3) indicate initial sill emplacement around 334 m.y. (i.e. Lower Brigantian). Alteration occurred around 244 m.y. and this correlates with a hydrothermal episode recognised in the South Pennine Orefield by Ineson & Mitchell (1973).

Origin of Alteration

If the alteration was hydrothermal in origin, the geochemistry and mineralogy are directly opposed to previously reported variations. The stability of chlorite reflects high concentrations of MgO and FeO, whilst calcite (CaO and CO_3) was in unstable equilibrium. The altered zone is also unusual in that the thin, impersistent central fissure contrasts with the 'veinlet-swarms' accompanying typical hydrothermal alteration in basalts (Walters & Ineson, 1980). Garnett (1923) indicated that the central fissure and its attendant alteration diminished in size and died out with increasing height up the quarry face.

The restricted nature of the channelway may suggest that the hydrothermal flow approached conditions of stagnation and allowed extensive wall-rock interactions to occur and the previously reported depletion and enrichment of major and trace elements associated with hydrothermal alteration in the South Pennines were partially reversed. Thus FeO depleted during wall rock alteration at lower levels in the Sill resulted in a gradual enrichment in the restricted flow of hydrothermal fluids within the fissure and the eventual stability of chlorite as an alteration phase. Similarly, trace elements depleted at lower levels may have been concentrated in the stagnated hydrothermal fluids. The bulk geochemical characterisation of the hydrothermal fluid, i.e. a saline brine capable of H^+, Na^+ and K^+ metasomatism (Rodgers, 1977) were not significantly modified by the extensive wall-rock interactions. As previously indicated, such an hypothesis is very tentative and the variations may have been due to an interplay of numerous conditions.

Conclusions

The geochemistry, mineralogy and mode of occurrence of the zone of alteration in the Ible Sill has not been recorded elsewhere in the South Pennines. K–Ar isotopic age determinations, however, suggest a hydrothermal origin. Extensive wall-rock interactions involving the restricted flow of hydrothermal fluids are envisaged and resulted in the geochemical modifications recorded.

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Explanation of Plate 8

Plate 8, Fig. A.   Unaltered dolerite, Ible Quarry. Ophitic titaniferous augite (pale grey) encloses labradorite laths and anhedral Fe–Ti oxides. Pseudomorphed olivine phenocrysts exhibit characteristic outlines and preservation of internal cracks (plane polarised light) scale bar = 1 mm.

Plate 8, Fig. B.   Pseudomorphed olivine phenocryst. Primary olivine is replaced by homogeneous (green) pleochroic smectites. Original internal cracks are outlined by (red) pleochroic smectites (plane polarised light) scale bar = O.5 mm.

Plate 8, Fig. C.   Altered dolerite. Primary augite is pseudomorphed by (apple green) chlorite with concentrations of anatase at relict grain boundaries. Albitised plagioclase is partly replaced by chlorite along cleavages. Ilmenite and magnetite are altered to aggregates of coarse, euhedral anatase (plate polarised light) scale bar = O.5 mm.

Plate 8
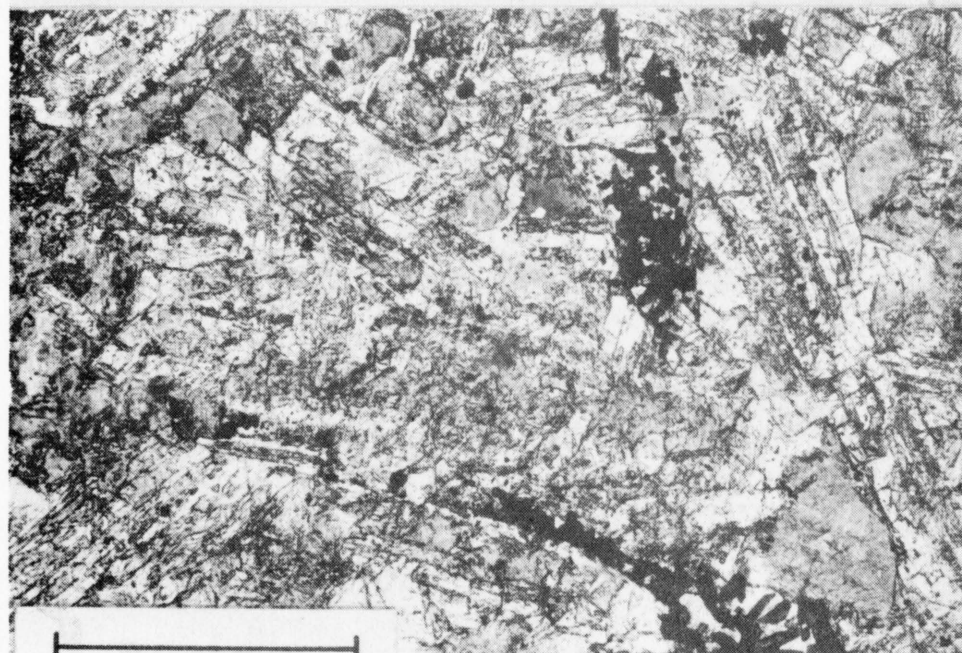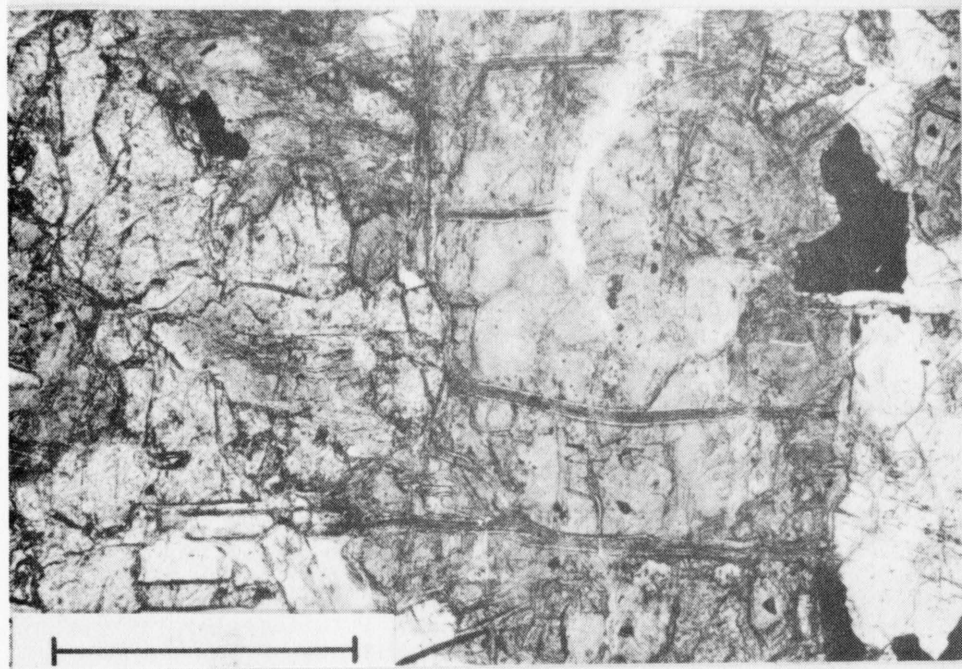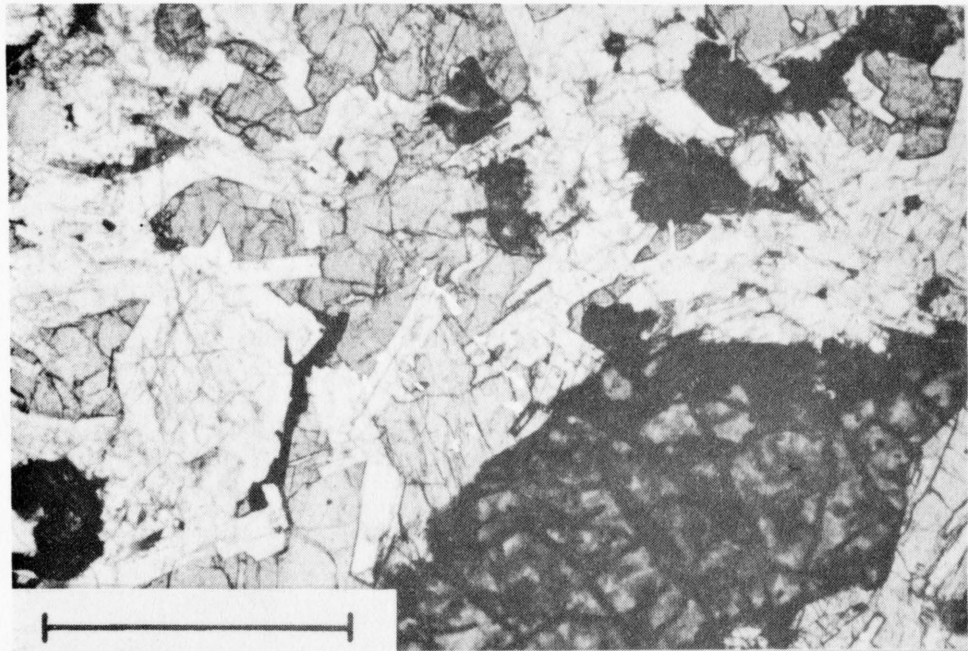
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