THE PETROGRAPHY AND GEOCHEMISTRY OF THE POTLUCK SILL, DERBYSHIRE, ENGLAND

by

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Summary

The Potluck Sill is one of three sills that outcrop in northern Derbyshire. It is an ophitic olivine dolerite. Mineralogical determinations have shown the composition of olivine to range from $Fo_{72}-Fo_{63}$, plagioclase to range from $An_{65}-An_{45}$ and augite to range from Mg_{44-40} Fe_{24-11} Ca_{45-34}. Other major primary minerals include titanomagnetite and ilmenite. Minor amounts of analcime, natrolite, aluminous chromite, pyrite and chalcopyrite are present. Clays of the smectite group are the most important product of alteration of the ferromagnesian minerals. New geochemical data show there to be little variation in the 'unaltered' sill.

Introduction

A number of olivine dolerite sills are intruded into the Carboniferous Limestone of the South Pennines. These include the Bonsall and Ible Sills in the southern half of the South Pennines and the more numerous sills of the northern half that include the Potluck, Peak Forest, Mount Pleasant, Tideswell Dale and Waterswallows Sills (text-fig. 1).

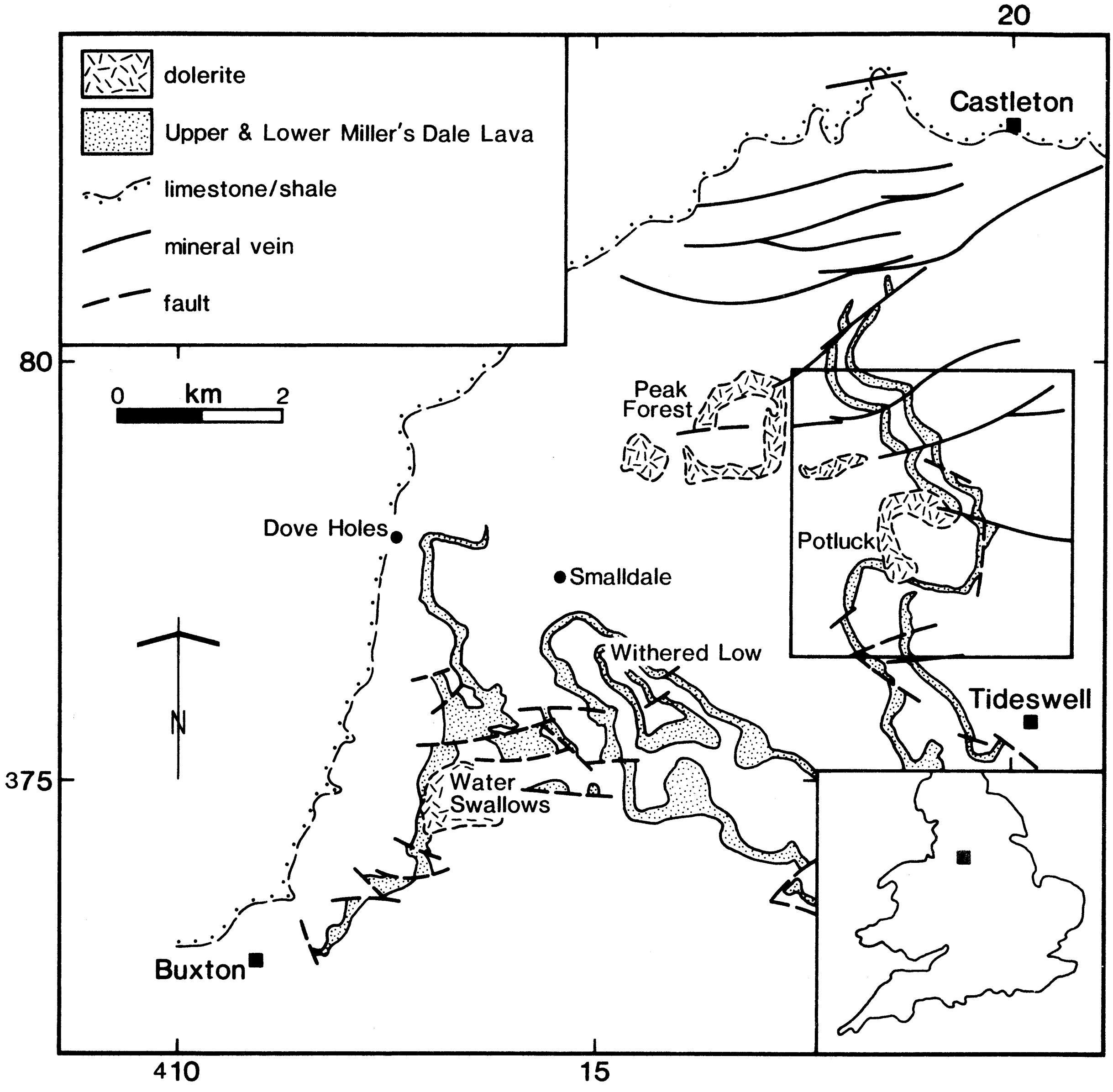
The Potluck Sill occupies part of Tideswell Moor (south of Castleton) (text-fig. 2) and is close to two other sills, i.e. the larger Peak Forest and the smaller Mount Pleasant Sill. Exposures of the sill are very poor, with the major surface occurrence being at Pittle Mere (SK 13647833). There are no clear contacts between the sill and the surrounding limestones and lavas. The main evidence of its extent is to be found in outcrop and mine dump debris as well as in auger material. Although the area of the sill, which is of the order of 0.5 km^2, can be estimated fairly easily there is some uncertainty about its thickness. Green *et al.* (1887) reported a minimum thickness of 600 ft (183m) of 'toadstone' at Black Hillock Shaft (SK 14107822) but Stevenson and Gaunt (1971) suggested that the shaft followed a feeder to the sill and hence was unrepresentative. Walters and Ineson (1980) indicated that where Tideslow Rake has intersected the sill, the dolerite is present to a depth of 146.3m.

Arnold-Bemrose (1894; 1907) identified the sill as an ophitic olivine dolerite and described in detail the alteration of the olivine (1894, p.613-20). More recently, Stevenson and Gaunt (1971) described the sill as being a coarse ophitic olivine dolerite comprising phenocrysts of altered forsterite-rich olivine and calcic plagioclase set in a groundmass of labradorite (An_{63} Ab_{37}) and augite with accessory orthopyroxene, ilmenite and magnetite. Walters and Ineson (1980) have described the hydrothermal alteration of the sill that has converted the dolerite to a 'white rock' similar to the White Whin of the North Pennines and consisting of kaolinite, calcite and albite.

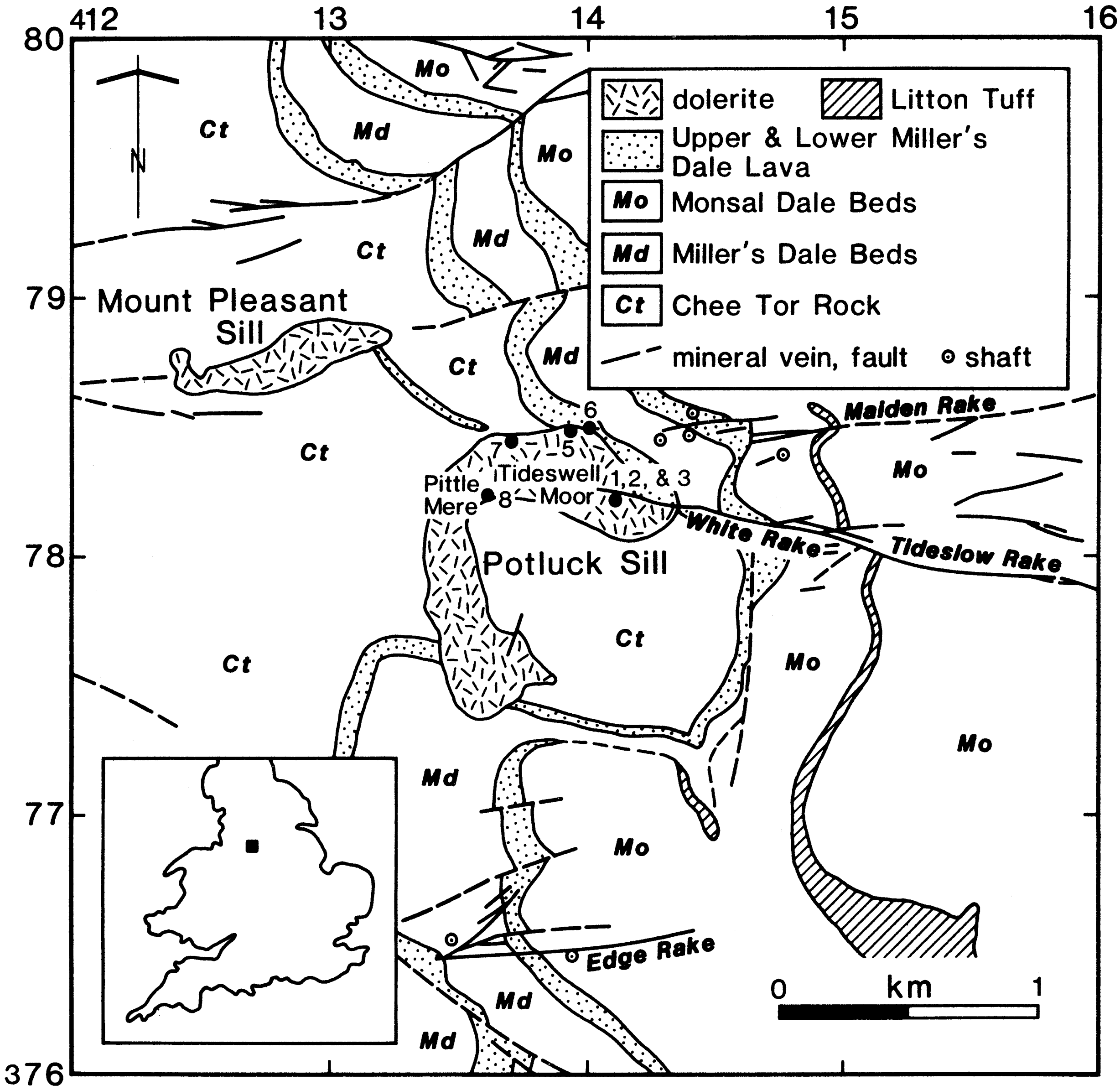
The present study of the Potluck Sill which incorporates mineralogical, petrographical and geochemical studies forms part of a more comprehensive study of the igneous activity of the South Pennines.

Techniques

Hand specimens of the Potluck Sill were collected to include all the various rock types. Most of the specimens were, however, from loose boulders. Multiple thin sections and one polished section of each specimen were prepared for petrographical studies using transmitted and reflected light. These techniques were supplemented by X-ray diffraction analysis which assisted in the identification of some of the secondary minerals.



Text-fig.1 Sketch map of the northern dolerite sills of Derbyshire.



Text-fig.2 Sketch map of the Potluck Sill

Electron probe microanalyses were made of some of the primary silicates and to positively identify the alteration products of the olivine. X-ray fluorescence analysis was used to analyse the material for both major and minor elements.

Petrography

In common with other Derbyshire sills, the Potluck Sill displays a number of different doleritic textures, which include the coarse ophitic dolerite described by Stevenson and Gaunt (1971) (plate15, fig. A); subophitic dolerites, and finer grained dolerites with an intergranular texture of clinopyroxene and plagioclase. Although no distinctive marginal facies of the sill is seen, a finer dolerite occurs at (SK 13777850) (Samples PL 71 & PL 72) close to the northern boundary of the intrusion. This dolerite has some petrological differences from the main dolerite. In hand specimen this dolerite is a dark blue-green fine grained rock with dark green phenocrysts of olivine or its pseudomorphs up to 3mm in length. No other phenocrysts are visible to the naked eye nor are amygdales seen. Weathering of the dolerite produces a 1-3mm thick brown limonitic crust.

The ophitic dolerite comprises olivine and rare plagioclase phenocrysts (1-3mm in length) set in a medium to coarse grained groundmass of unoriented plagioclase laths up to 1mm in length and ophitic plates of augite up to 3mm diameter. In the intergranular dolerite similar size olivine and plagioclase phenocrysts (1-3mm in length) are set in a groundmass of small plagioclase laths and subhedral augite crystals. Modal analysis for the dolerite types are given in table 1.

Table 1 Modal analyses of the Potluck Sill

	A	PL1	PL2	PL52	PL51	PL62	PL61	PL72	PL71	PL81	PL82
Olivine	1.1	4.08	0.00	3.1	1.9	2.4	6.6	0.8	1.3	1.9	3.0
Olivine Pseudomorphs	6.8	13.82	22.07	14.6	16.3	9.5	15.0	17.0	15.1	14.1	14.4
Augite	18.3	19.11	18.55	20.5	22.1	21.8	19.4	21.6	22.7	22.3	19.9
Plagioclase Laths		36.15	24.25	23.6	26.1	23.5	31.9	25.6	23.4	22.7	27.0
Altered Plagioclase Laths		1.64	2.19	3.0		2.0		4.1		1.7	
Plagioclase Groundmass	67.8	12.78	20.27	19.7	26.7	26.0	20.5	18.0	27.9	24.8	29.3
Altered Plagioclase Groundmass		7.12	4.85	7.0		6.5		7.2		4.0	
Opaques	1.5	3.35	5.00	3.6	4.0	7.0	3.4	2.1	3.2	3.9	3.5
Clay Matrix	4.5	1.89	2.19	1.8	2.3	1.1	3.0	1.7	4.4	2.4	2.1
Analcime	-	0.06	0.16	1.3	0.7	0.1	0.2	1.7	1.6	1.0	0.6
Thompsonite	-	-	-	0.9	-	0.1	-	-	0.2	-	0.2
Natrolite	-	-	-	1.0	-	0.1	-	-	0.3	0.7	0.1
Amphibole	-	-	-	-	-	-	0.1	-	0.1	-	-
Biotite	-	-	0.47	-	-	0.1	-	-	-	-	-
Calcite Veins	-	-	-	-	-	-	-	-	-	0.4	-
Limonite Veins	-	-	-	-	-	-	-	-	-	0.3	-
Counts		1640	1280	1150	1240	1200	1230	1200	1160	1140	1150

A—Stevenson and Gaunt (1971)

PL.1 & PL.2	SK 14107820	PL.71 & 72	SK 13777850
PL.51 & 52	SK 13937842	PL.81 & 82	SK 13657834
PL.61 & 62	SK 13947845		

Olivine occurs as euhedral to subhedral phenocrysts (up to 3mm in length) or as collections of smaller subhedral crystals (up to 2.5mm in diameter) associated with augite. These phenocrysts of olivine are often very altered. Finer grained olivine (up to 0.1mm in length) is totally pseudomorphed. Relict fresh phenocrystic olivine has a large 2V ($2V_\gamma \approx 90$) that suggests a composition close to the Mg end member forsterite (Stevenson & Gaunt, 1971) and similar in composition to the olivines from other Derbyshire Sills, notably Bonsall Sill (Smith *et al.*, 1967). Electron probe microanalyses, however, indicate that the relict fresh olivine has compositions that range from $Fo_{63}Fa_{37}$ to $Fo_{72}Fa_{28}$; but that mainly lie close to $Fo_{68}Fa_{32}$ (table 2).

Table 2 Electron microprobe data for Potluck pyroxenes and olivines

	1	2	3	4	5	6	7	8	9
		Pyroxenes					Olivines		
SiO_2	51.7	51.5	49.8	50.8	37.9	38.1	38.0	38.7	37.1
TiO_2	1.3	1.0	1.4	1.6	-	-	-	-	-
Al_2O_3	1.7	3.0	2.1	2.4	-	-	-	-	-
FeO	10.0	6.8	10.0	9.3	27.6	31.5	28.1	24.9	29.0
MnO	0.2	0.1	0.2	0.2	0.4	0.5	0.4	0.3	0.4
MgO	14.3	14.9	13.6	14.1	34.1	29.8	34.0	36.9	33.9
CaO	20.2	21.1	20.6	21.0	0.3	0.2	0.3	0.3	0.3
Na_2O	0.4	0.4	0.5	0.4	-	-	-	-	-
Cr_2O_3	-	0.6	-	0.1	-	-	-	-	-
NiO_2	-	-	-	-	0.2	0.1	0.1	0.2	0.2
Total	99.8	99.4	98.2	99.9	100.5	100.2	100.9	101.3	100.9
Number of ions on the basis of 6 oxygen (pyroxenes)/4 oxygens (olivines)									
si	1.936	1.914	1.014	1.904	1.007	1.032	1.007	1.007	1.005
Ti	0.035	0.028	0.041	0.044	-	-	-	-	-
Al	0.076	0.130	0.098	0.107	-	-	-	-	-
Fe	0.313	0.212	0.320	0.291	0.614	0.715	0.623	0.541	0.638
Mg	0.797	0.825	0.775	0.787	1.353	1.202	1.346	1.428	1.333
Ca	0.812	0.838	0.844	0.845	0.008	0.007	0.008	0.007	0.007
Na	0.026	0.029	0.036	0.027	-	-	-	-	-
Mn	0.008	0.005	0.008	0.007	0.008	0.011	0.008	0.007	0.010
Cr	-	0.017	-	0.002	-	-	-	-	-
Ni	-	-	-	-	0.003	0.003	0.002	0.004	0.003
				Atomic Ratios					
Mg	42.0	44.0	40.0	41.0	69.0	63.0	68.0	72.0	68.0
Fe	24.0	11.0	16.0	15.0	31.0	37.0	32.0	28.0	32.0
Ca	34.0	45.0	44.0	44.0	-	-	-	-	-

Samples 1-4: Individual Ophitic Pyroxenes Samples 5-9: Individual Olivines in Relict Microphenocrysts
Potluck Sill coarse ophitic dolerite PL1 Black Hillock Mine (SK 141782)

Typically, olivine encloses 10–40μm rounded to euhedral crystals of a spinel that semiquantitative analyses show to be an aluminous chromite. The spinel shows zoning with a lighter reddish-brown margin of magnetite up to 10μm in width. The chromite is randomly distributed throughout the olivine crystals but often occurs as collections of five or six crystals. Even when the olivine is totally replaced the enclosed chromite remains unaltered.

Plagioclase feldspar is found as large phenocrysts, as unoriented lath-shaped crystals and as coarser groundmass plates. Knots of plagioclase phenocrysts, in total up to 1.5–2mm in length, consist of four or five equant crystals that characteristically display complex multiple twinning and some zoning. The cores of the phenocrysts show a fine grained myrmekitic intergrowth with augite that appears to have an ophitic relationship with the plagioclase. In addition the plagioclase carrys inclusions of ilmenite (20–60μm) and more abundant skeletal crystals of titanomagnetite (20–100μm in diameter) that themselves contain ilmenite lamellae. The phenocrysts show zoning and this is especially well seen in their inclusion-free 100–200μm wide margins. Although many phenocrysts have sharp edges some show strong resorbtion as do similar phenocrysts from the nearby Mount Pleasant Sill. However, much of the plagioclase occurs as unoriented lath-shaped (0.1–0.6mm in length) twinned but poorly zoned crystals. Although there is a compositional range from $An_{45}-An_{65}$ most laths have a composition of $An_{58}-An_{62}$ that is similar to the value of An_{63} given by Stevenson and Gaunt (1971). The most calcic labradorite ($An_{65}Ab_{35}$) occurs as lath-shaped inclusions within the plagioclase phenocrysts. Alteration of the labradorite laths is variable but typically the cores of the feldspar are replaced leaving fresh margins. A later feldspar occurs as coarser plates 0.2–0.8mm across, it is strongly zoned and is simply twinned and has lower refractive indices than the labradorite laths. It is often intensely altered to green clay minerals, analcime and zeolite minerals, with the alteration having been initiated along the feldspar cleavage.

Augite occurs as ophitic crystals up to 3mm across, as phenocrysts up to 1mm across or as microphenocrysts 0.25mm long that often surround olivine phenocrysts. In one section a 1mm diameter gas-bubble is infilled with euhedral augite crystals which have an equant habit in the centre surrounded by radiating prismatic pyroxenes. The augite is pale pink in colour, very faintly zoned, and weakly pleochroic. Electron probe microanalyses (table 2) show the ophitic pyroxene to be augite but with significant amounts of Na and Ti. The analyses are very similar to those given for the diopside-titanaugites from igneous rocks of the Duffield borehole (Harrison, 1977). Minor amounts of othopyroxene have been reported as an accessory mineral (Stevenson & Gaunt, 1971).

Trace amounts of a red-brown rhombic amphibole are associated with laths of ilmenite. The amphibole is possible a Ti-rich barkevikite or kaersutite. In addition zircon and biotite occur in minute amounts within the coarse plagioclase plates.

Ilmenite is the most common opaque mineral. It forms lobate laths that range in size from 60×5μm up to 1mm in length. The laths are intergrown with pyroxene and labradorite crystals, and often enclosed within a narrow rim of titanomagnetite 5−10μm in width. Lesser amounts of ilmenite occur as 40−100μm equant crystals, as small cores (10−20μm) to euhedral magnetite crystals (40−200μm) or as irregular patches up to 60μm in diameter of blebby ilmenite. The ilmenite is generally very fresh with only a little alteration to rutile along the edges of the laths or as 5−20μm patches.

Titanomagnetite like the ilmenite is intergrown with the pyroxene and feldspar. It forms euhedral octahedral crystals 10−100μm in size or larger subhedral crystals (0.2—0.5mm in diameter). Many crystals have a core of ilmenite or contain thin ilmenite lamellae (1−2μm in width) oriented along the (111) planes of the host titanomagnetite. Magnetite crystals from the unusual fine-grained facies of the dolerite (PL7) are distinctive in that they show distinct but gradual zoning, with a core of grey spinel (10−15μm in diameter) surrounded by magnetite 20μm in width and finally with small 5μm long ilmenite laths. These crystals occur intergrown with pyroxene and are not found in the olivine crystals. All specimens of the dolerite have a generation of magnetite that occurs as poorly crystalline aggregates (30−100μm in diameter) of individuals 2−5μm in size. These aggregates occur about ilmenite laths or are isolated in the groundmass. The individual magnetite grains are cemented by chalcopyrite and lesser amounts of bornite together with traces of pyrite. Typically the magnetite has totally oxidized to haematite. The main generation of magnetite is commonly oxidized to blue haematite (although the martite texture is absent) or less commonly to rutile as small 2−3μm patches or to sphene as 5−10μm wide rims.

Although the Potluck Sill is one of the least altered dolerites of the South Pennines it has undergone alteration with the growth of a number of new minerals including clays, zeolites and sulphides. Primary olivine is intensely altered and so too is plagioclase feldspar (most notably the platey groundmass feldspar) and titanomagnetite, whereas clinopyroxene and ilmenite are largely unaltered. (see plate15, figs. B & C and plate16, fig. A).

Arnold-Bemrose (1894) distinguished two types of alteration of the olivine phenocrysts which he called 'Potluck pseudomorphs' and 'Peak Forest types'. The former included red and green alteration products that were optically homogeneous and pleochroic and the latter green products that were homogenous, fibrous and often yellow-green in colour. He noted that both types were found in the same specimen and that the material was 'mica-like'. A detailed investigation of this material by Walters (1981), has shown it to be an Fe-rich nontronite (a variety of smectite-clay) and his results are given in table 3 together with other analyses of comparable material.

This smectite is itself replaced by calcite and/or silica in the more altered specimens of the sill. The carbonate has an iron stained rim that may reflect the original iron content of the previous smectite. In addition, small grains of chalcopyrite and pyrite (1−4μm) occur in the very centre of the altered fractures that typically cut across the olivine crystals, and very thin fibres ≤ 1μm wide of chalcopyrite lie in parallel with the clay minerals.

Clay minerals, (the chlorite of Arnold-Bemrose (1894) and Stevenson and Gaunt (1971)) analcime and zeolite group minerals are found in the interstitial areas bounded by plagioclase laths and augite crystals. These minerals may represent a late stage residual product of the melt or the alteration of such products. Such a late stage occurrence of analcime and zeolites together with alkali feldspar and sodic pyroxene is common in the teschenites of the West Midlands for example the intrusion of Pouk Hill (Ixer, 1981), and from the Duffield Sill (Harrison, 1977). However the small amounts of analcime and zeolite (as shown by the modal analyses in table 1), the absence of accompanying alkali feldspars and pyroxenes, and the textural evidence showing that the secondary minerals replace the platey plagioclase feldspars, all suggest that these minerals are the products of alteration.

Although both X-ray diffraction of the whole rock samples and electron probe microanalysis of the olivine pseudomorphs both suggest that smectite clays are the most dominant group, both illite group clay and kaolinite are present. Walters and Ineson (1983b) suggest that this dominance of smectite is a characteristic of all the basalts and dolerites of the South Pennines except for a few unusual examples. The clays are light to dark green or yellow and fibrous to vermicular and characteristically form a thin rim (20μm wide) enclosing analcime or zeolites.

Table 3 Electron microprobe analysis of smectite in the Potluck Sill and comparable analyses

<table>
<tr><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><td>SiO_2</td><td>42.8</td><td>45.7</td><td>43.05</td><td>39.11</td><td>46.83</td><td>43.98</td><td>45.12</td></tr>
<tr><td>TiO_2</td><td>-</td><td>-</td><td>-</td><td>0.18</td><td>0.64</td><td>0.16</td><td>0.23</td></tr>
<tr><td>Al_2O_3</td><td>4.1</td><td>4.0</td><td>6.40</td><td>3.29</td><td>8.92</td><td>10.15</td><td>5.13</td></tr>
<tr><td>Fe_2O_3</td><td>-</td><td>-</td><td>17.86</td><td>31.49</td><td>7.87</td><td>7.85</td><td>11.14</td></tr>
<tr><td>FeO</td><td>28.9*</td><td>28.3*</td><td>0.10</td><td>0.96</td><td>4.88</td><td>5.32</td><td>4.77</td></tr>
<tr><td>MgO</td><td>7.9</td><td>8.3</td><td>4.46</td><td>8.05</td><td>11.08</td><td>18.02</td><td>17.06</td></tr>
<tr><td>CaO</td><td>2.0</td><td>1.9</td><td>2.92</td><td>2.28</td><td>2.78</td><td>2.78</td><td>0.21</td></tr>
<tr><td>Na_2O</td><td>0.1</td><td>0.1</td><td>-</td><td>-</td><td>1.71</td><td>-</td><td>2.68</td></tr>
<tr><td>K_2O</td><td>-</td><td>-</td><td>-</td><td>-</td><td>1.93</td><td>-</td><td>0.85</td></tr>
<tr><td>H_2O^+</td><td rowspan="2">14.2**</td><td rowspan="2">11.7**</td><td rowspan="2">29.93</td><td rowspan="2">16.27</td><td>5.39</td><td>9.24</td><td rowspan="2">13.60</td></tr>
<tr><td>H_2O^-</td><td>6.81</td><td>6.24</td></tr>
<tr><td>Total</td><td>100.0*</td><td>100.0**</td><td>104.72</td><td>101.63</td><td>98.84</td><td>103.74</td><td>100.79</td></tr>
</table>

1. and 2: Microprobe analyses, red pleochroic alterations of olivine—Potluck Sill (Walters, 1981). (PL.1. SK141782).

3. Fe-rich nontronite in altered basalt (Weaver & Pollard, 1973).

4. Average of five 'iddingsite' analyses (Ross & Shannon, 1925).

5. Mixed nontronite/saponite infilling vesicle in basalt (Scheidegger & Stakes, 1977).

6. Saponite in altered basalt (Weaver & Pollard, 1973).

7. Saponite in altered basalt (Seyfried *et al.*, 1978).

* Total iron as FeO

** Total H_2O calculated by subtraction of other oxides from 100%, may include small but significant values of TiO_2 and K_2O.

Analcime is anhedral to euhedral and often more abundant than the zeolites. It occurs as small rounded amygdales 100–200μm in diameter, as interstitial infilling, as thin veinlets or together with the other secondary minerals it replaces plagioclase. Some analcime looks altered and is cut by calcite veinlets. The presence of analcime in the intrusive rocks of the South Pennines has previously been noted by Tomkeieff (1928) from Calton Hill, and by Ixer (1972) from the Bonsall Sill. Its occurrence in the Potluck Sill together with the recognition of analcime-bearing amygdules (up to 1mm in diameter) from Peak Forest suggests it to be a widespread but minor component of the intrusive rocks. All optical identifications of analcime were confirmed by X-ray diffraction work (see plate16, figs. B & C).

Two types of zeolites occur, often together with analcime and enclosed within a thin rim of clay minerals. The earlier zeolite is clear, has a R.I. close to 1.540, first order birefringence and a radiating acicular habit. The properties are similar to those of thompsonite (but also of chalcedony). The second zeolite also has a radiating habit of more tabular crystals, and is natrolite. Zeolites are previously unrecorded from the South Pennine intrusive rocks and the present study could only recognise natrolite from the nearby Peak Forest Sill in addition to its presence in the Potluck Sill.

Very minor quantities of sulphides are present in the dolerites. The most abundant is chalcopyrite, with pyrite being locally common. Chalcopyrite occurs associated with the alteration of olivine, cementing the aggregates of late spongy magnetite or as small (2–40μm) subhedral to euhedral crystals that often rim ilmenite and magnetite. Chalcopyrite is found associated with bornite and idaite and is altered to rims of bornite, idaite or covelline and is oxidized to limonite. Bornite and idaite (2–3μm) are intergrown with the chalcopyrite that cements the magnetite, both occur as thin veinlets cementing fractured pyrite and both are altered to covelline.

Pyrite too is found in minor amounts except for the specimens PL71 & PL72 where it is the most abundant sulphide. Usually, pyrite forms small crystals up to 5µm in size within olivine pseudomorphs, or as 5–20µm in diameter cubes, it is enclosed in chalcopyrite. In PL71 however, larger 10–100µm diameter skeletal crystals are common and reach a maximum size of 350µm. These crystals enclose magnetite. The crystals are often fractured and are healed by bornite and idaite. Pyrite is extensively oxidized to limonite.

Weathering of the dolerites has had little effect. It has oxidized the sulphides to limonite and limonitically stained the silicate minerals.

Geochemistry

Very few geochemical data have been published on the olivine dolerite intrusive rocks of the South Pennines and this is in contrast to the more abundant data on the more alkaline intrusives of both the West Midlands and the East Midlands Coalfields.

Table 4 presents six new analyses of the Potluck Sill together with one of the highly altered bleached sill from Black Hillock Mine. Table 5 presents the CIPW norms for the six fresher specimens. These six analyses show there to be little significant variation in both major and minor element chemistry and this reflects the petrographical similarity of the specimens. There is however a slight difference between specimens PL 1 and 2 and specimens PL 5 and 8, in that the former two have slightly higher SiO_2, Al_2O_3 and K_2O contents and have quartz in their norms whereas the latter four have olivine.

More obvious trends can be seen when the bleached dolerite PL3 is compared to the fresher dolerites. The extreme alteration of the dolerite is seen to be accompanied by a substantial loss of total iron and MgO; significant loss of SiO_2, Al_2O_3 and Na_2O and by some reduction of TiO_2, MnO and P_2O_5. There is however, a dramatic increase in CaO and CO_2 and some increase in K_2O and total water. This change in major element chemistry reflects the change to the new minerology of the bleached sill which is calcite and quartz accompanied by kaolinite, smectite and albite. The trace elements show a general reduction and this is especially true for Ba, Sr, Co, Ni, Cu and Zn.

Only Cr shows a slight reduction and this is seen petrographically by the continued presence of chromite within calcite pseudomorphs after olivine.

Similar geochemical trends were reported from the hydrothermally altered Whin Sill (the Black Whin altering to White Whin) by Wager (1929) and Ineson (1968). In addition, the mineralogy of the North Pennines White Whin and the altered Potluck Sill are similar with carbonation and albitization being very important in both. However, the clay mineralogy is different, with illite-kaolinite occurring in the White Whin and kaolinite-smectite in Potluck. This variation may reflect the interstitial orthoclase in the unaltered Whin Sill (Dunham & Kay, 1965) as opposed to smectites at Potluck.

Conclusions

The present petrological study of the Potluck Sill, has confirmed that the sill is composed of olivine-dolerite. Detailed mineralogical studies of the primary silicates show the clinopyroxene to be augite that is less titaniferous (TiO_2 < 1.6 wt.%) than its optics might indicate. Similarly the relict olivine analyses show that the olivine is more fayalitic ($Fa_{28}-Fa_{37}$) than previous optical determinations have suggested (Stevenson & Gaunt 1971). The primary opaque mineralogy is a simple one of titanomagnetite, ilmenite and chromite, with haematite and copper and iron sulphides as common secondary minerals.

The later mineralogy is more complex and consists of clay minerals, zeolites and analcime, with average modal amounts of 2.9% clay ('chlorite') 1.0% analcime and 0.2–0.3% zeolites. The presence of analcime from Potluck Sill and nearby Peak Forest Sill and its known occurrence from Bonsall Sill and Calton Hill suggests that it may be a common accessory mineral for the olivine dolerites. The occurrence of natrolite has only been recorded from Potluck and Peak Forest Sills. The greater abundance of analcime than has previously been supposed suggests closer similarities to the more alkaline dolerites that surround Derbyshire. However, the occurrence of late stage alkaline pyroxene, amphibole and feldspars that are typical of the alkaline dolerites appears to be absent from Potluck Sill. The geochemistry shows that the 'fresh' olivine dolerites all have very similar major and minor element abundances, and no clear indication of any differentiation trends could be seen in the limited material available. With extreme alteration, the olivine dolerite is converted to a rock that approximates to an impure limestone that is similar to the alteration of the 'Black Whin' to 'White Whin' of the northern Pennines.

Table 4 Chemical analyses of the Potluck Sill

	PL 1	PL 2	PL 3	PL 5	PL 6	PL 7	PL 8
SiO_2	48.74	48.62	40.31	47.47	47.24	47.60	47.39
TiO_2	1.86	1.89	1.43	1.77	1.88	1.72	1.68
Al_2O_3	14.73	15.17	10.51	13.86	13.79	13.75	13.78
Fe_2O_3	4.21	4.17	0.71	4.04	2.80	3.86	3.80
FeO	6.58	5.32	0.32	7.55	8.59	7.66	7.82
MnO	0.17	0.12	0.10	0.18	0.17	0.17	0.18
MgO	8.09	6.65	0.52	9.42	9.98	9.30	9.57
CaO	8.94	9.68	22.96	8.24	8.55	8.05	8.52
Na_2O	2.67	3.00	0.78	2.94	2.52	2.80	2.80
K_2O	0.80	0.86	0.89	0.71	0.68	0.71	0.64
H_2O^+	2.43	2.30	3.26	3.29	3.10	3.20	3.40
H_2O^-	0.95	1.54	0.49	-	-	-	-
P_2O_5	0.30	0.30	0.21	0.25	0.26	0.24	0.23
CO_2	0.13	0.57	18.32	0.62	0.11	0.05	0.13
SO_3	0.04	0.04	0.28	-	-	-	-
Total	100.64	100.23	101.09	100.34	99.67	99.11	99.94
Ba	285	259	82	223	207	294	269
Co	88	81	32	-	-	-	-
Cr	303	379	293	353	366	349	348
Cu	80	86	15	85	84	77	98
Ni	219	275	50	224	245	231	240
Pb	17	7	6	6	10	9	10
Rb	17	15	9	23	16	17	20
Sr	358	402	100	409	310	290	342
V	175	196	155	206	197	204	196
Y	30	25	19	23	22	26	22
Zn	97	74	6	102	95	96	103
Zr	133	130	88	111	109	105	103

Samples: 1 Potluck Sill coarse ophitic dolerite
Black Hillock Mine—SK 141782 (Waters 1981)
2 Potluck Sill, ophitic dolerite from Black Hillock Mine. (Walters 1981)
3 Potluck Sill, altered dolerite (bleached white) with calcite, kaolinite and albite. Black Hillock Mine. (Walters 1981)

Samples: 5 SK 13937842
6 SK 13947845
7 SK 13777850
8 SK 13657834

Table 5 C.I.P.W. norms of the Potluck Sill.

		PL1	PL2	PL5	PL6	PL7	PL8
Q		0.87	1.11	-	-	-	-
Or		4.73	5.08	4.20	4.02	4.20	3.78
Ab		22.59	25.39	24.88	21.32	23.69	23.69
An		25.85	25.39	22.53	24.31	22.85	23.14
Di	(Wo	6.91	8.63	6.98	6.85	6.48	7.36
	(En	4.95	6.53	4.84	4.50	4.43	5.01
	(Fs	1.34	1.23	1.57	1.87	1.54	1.78
Hy	(En	15.20	10.04	10.05	11.08	13.05	10.24
	(Fs	4.11	1.89	3.26	4.61	4.53	3.63
Ol	(Fo	-	-	6.00	6.51	3.99	6.02
	(Fa	-	-	2.14	2.99	1.52	2.35
Mt		6.10	6.05	5.86	4.06	5.60	5.51
Il		3.53	3.59	3.36	3.57	3.27	3.19
Ap		0.70	0.70	0.58	0.60	0.56	0.54
Py		0.08	0.08	-	-	-	-
Total		96.96	95.71	96.25	96.29	95.71	96.24

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Explanation of plates 15 and 16

Plate15, Fig. A.

Typical ophitic dolerite texture shown in the Potluck Sill. Smectite pseudomorphs after olivine (dark areas) occur in a coarse groundmass of un-orientated plagioclase and ophitic plates of augite up to 3mm in diameter. Plane polarised light. Black Hillock Mine Shaft (SK 14107822).

Plate15, Fig. B.

Calcitised and albitised Potluck Sill dolerite with veining. The relict textures of the coarse ophitic dolerite (Plate No.15, fig. A) are preserved, dark areas represent coarse carbonate replacement of olivine phenocryst pseudomorphs. Pittle Meer (SK 13647833).

Plate15, Fig. C.

A plagioclase phenocryst showing a core that contains abundant augite (dark grey) and iron-titanium oxides (black) and is surrounded by an inclusion free rim. Cross-polars. Spec. PL.81 (Table 1).

Plate16, Fig. A.

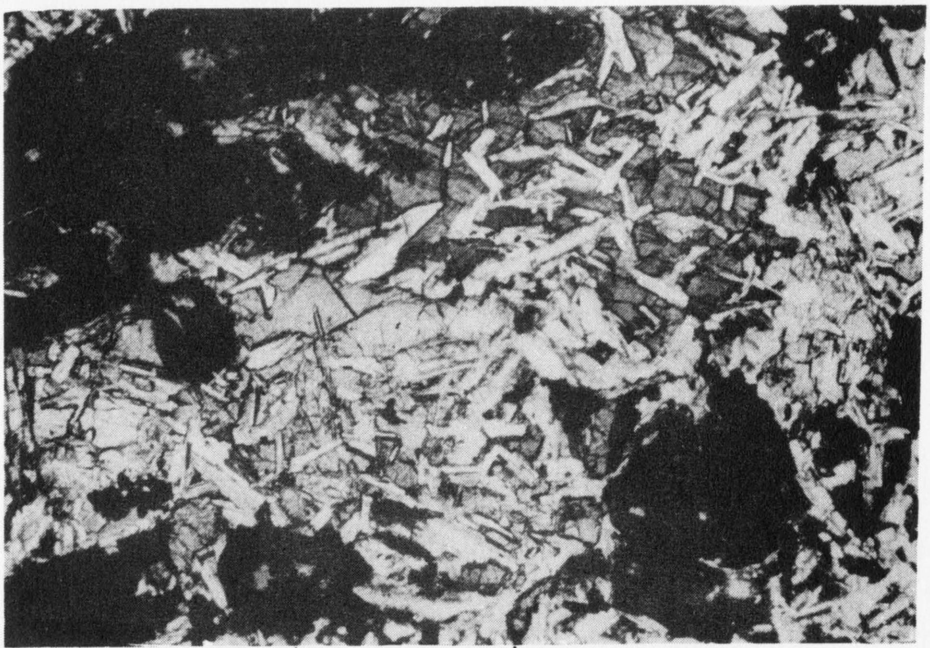
Radiating prismatic augite crystals within fine grained dolerite that shows altered olivine microphenocrysts and an intergranular texture of plagioclase laths and augite. Cross-polars. Spec. PL.51 (Table 1).

Plate16, Fig. B.

Interstitial analcime (right, colourless) and fibrous zeolite (left grey) together with groundmass plagioclase (colourless with cleavage). Both the analcine and zeolite have a thin 'chlorite' rim. Plane polarised light. Spec. PL. 71. (Table 1).

Plate16, Fig. C.

Subophitic dolerite containing an altered olivine pseudomorph (upper left) and rounded analcime (colourless centre). Plane polarised light. Spec. PL 51 (Table 1).



A

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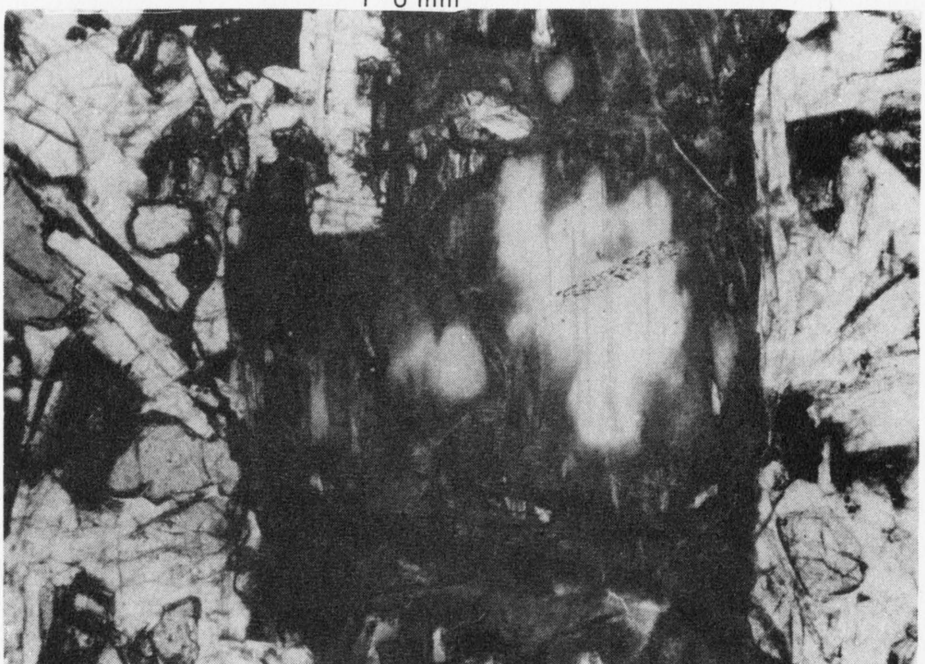

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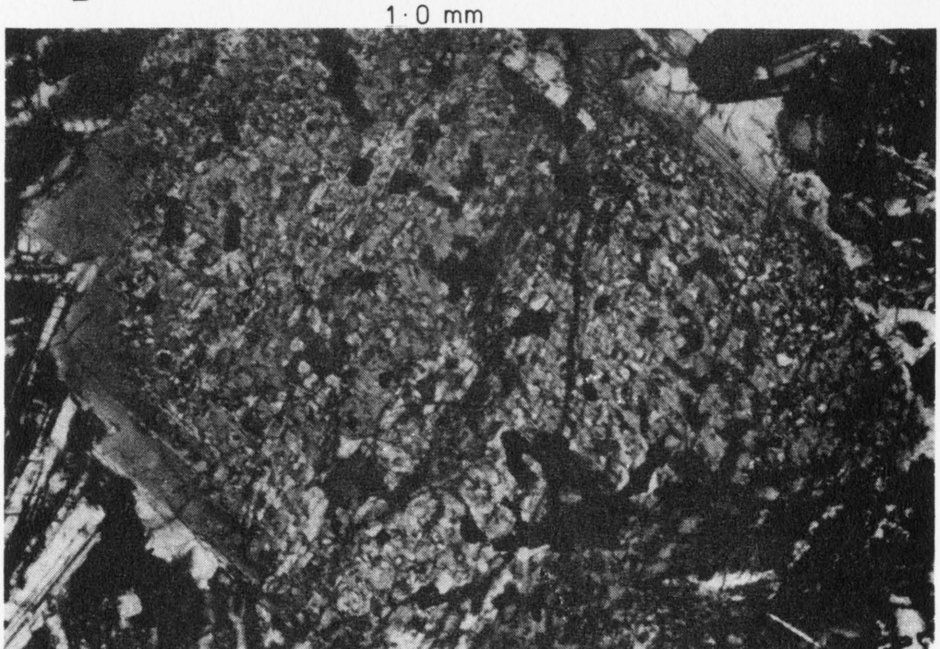

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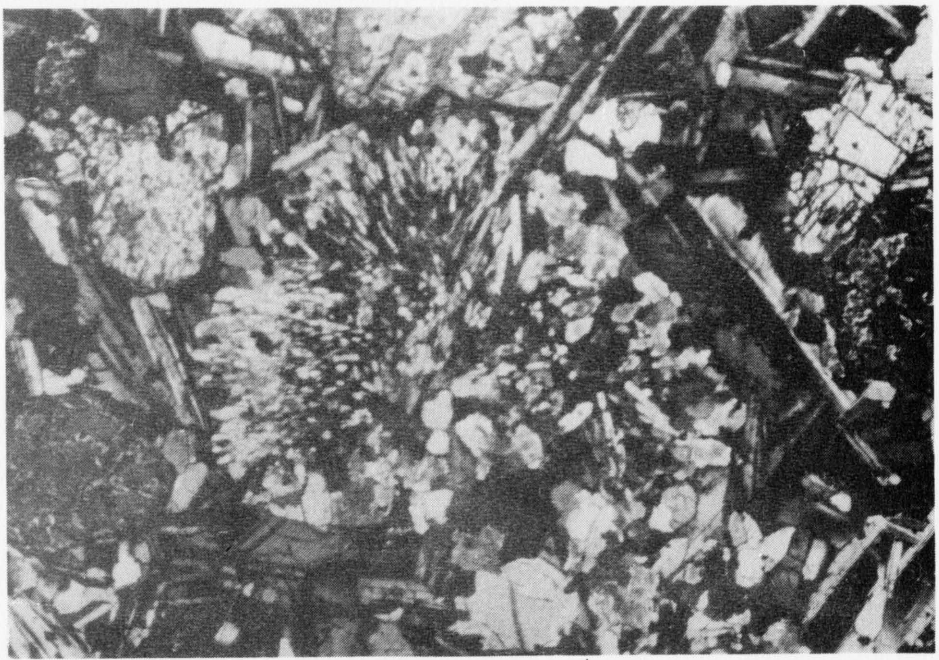

A

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B

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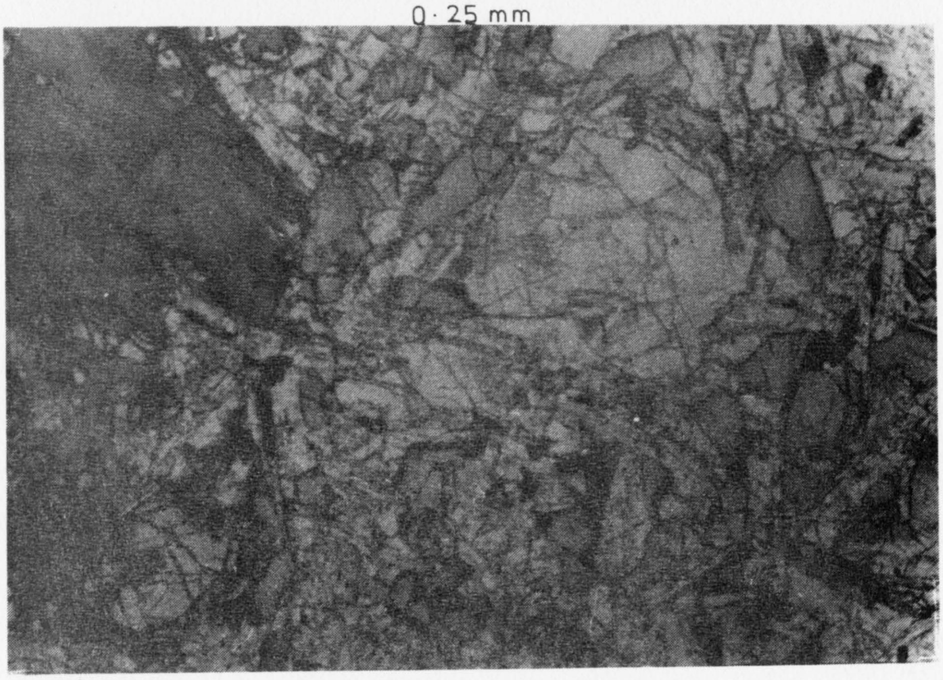

C

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