Read at the Annual Conference of the Ussher Society, January 1995

TALC-CARBONATE ALTERATION OF SOME BASIC AND ULTRABASIC INTRUSIONS IN CORNWALL.

M. R. POWER AND P. W. SCOTT

Power, M.R. and Scott, P.W. 1995. Talc-carbonate alteration of some basic and ultrabasic intrusions in Cornwall. *Proceedings of the Ussher Society,* **8,** 392-397.

Carbonatised basic and ultrabasic intrusive bodies are common in Cornwall. At Greystone, a basic sill shows alteration assemblages from albite-calcite to albite-dolomite through to dolomite-quartz, magnesite-quartz and talc-dolomite. Chlorite is ubiquitous. Dilution by carbonate has an important effect on the observed chemical variations. Ratios of trace elements show that Sr is mobile and Zr, Ti, Y, and Nb are essentially immobile. There is no evidence for differentiation of the sill, the observed mineral assemblages being controlled by hydrothermal alteration. Enrichment in As is closely related to the carbonatisation and the alteration is most likely a result of reaction with CO_2 -rich hydrothermal fluids possibly associated with the cross course mineralisation. Relict magmatic minerals are present at both Duporth and Polyphant and similar alteration assemblages, talc-dolomite-chlorite, are formed. Neither of these two bodies shows differentiation.

M. R. Power and P. W. Scott, Camborne School of Mines, University of Exeter, Redruth, Cornwall, TR15 3SE.

INTRODUCTION

Numerous basic and some ultrabasic bodies occur throughout Cornwall, many of which show well developed carbonatisation (Clayton, 1993). The more massive basic bodies frequently show fractionation (Morton and Smith, 1971; Floyd *et a1.,* 1993). Three bodies in particular have been studied; the metadolerites at Greystone and Duporth; and the ultrabasic complex at Polyphant (Figure 1). Intrusive relationships are apparent at Greystone and Duporth, both of which have a sill-like nature. Polyphant, however, is a fault-bounded, sheet-like body with a thickness of around 30 m (Chandler *et al.,* 1984). Variable alteration is pronounced in all three bodies with mildly chloritised and albitised material being progressively carbonatised to form carbonate and talc-rich assemblages.

The primary aim of this research was to determine why the intrusions have been differentially altered. It was hoped that it would be possible to determine whether the variable alteration seen in these bodies was due to variations in the original rock chemistry (due to differentiation), or due to different degrees of alteration of a homogeneous body.

The Greystone [SX 365 806] sill has been intruded into organic-rich, Lower Carboniferous cherts and shales. Pillowed tops to the sill have been identified (Turner, 1982) and interpreted as being due to high level intrusion into wet sediments. Extensive faulting and fragmentation of the sill has occurred as a result of its close proximity to the Greystone thrust which crops out immediately above it. This has produced thrust ramping of the sill both parallel to and perpendicular to the thrust direction (Turner, 1982). As a result the rock relationships are disguised. A cross-course vein cuts the body along with several minor quartz and carbonate veins and may have significance to the alteration process.

At Duporth [SX 036 513], a minor sill intruded into Lower Devonian, Meadfoot Group sediments (showing a thickness of approximately 20 m) is exposed in the sea cliffs. Extensive faulting has locally given the rock a pronounced tectonic fabric. Alteration is most pronounced in association with these shear zones. The Duporth sill is the type locality of the mineral duporthite (Collins, 1877) which has been re-appraised and found to be a fine intergrowth of talc and chlorite (Scott and Power, 1995).

Ultrabasic rocks of the Polyphant complex (well exposed in New Quarry, [SX 262 8221] are associated with a thrusted unit of Devonian and Carboniferous sediments which have been involved in thin-skinned thrust tectonics (Isaac *et al.,*1983) and may lie several kilometres north of their original position.

SAMPLES, PETROGRAPHY AND PARAGENESIS.

A suite of samples was collected from each of the three bodies and graded according to the alteration seen in thin section. Samples with relatively unaltered plagioclase were assumed to be the least altered whilst those containing significant talc were classed as the most altered. Determination of the major mineral phases was carried out using X-ray diffraction, optical and scanning electron microscopy with qualitative energy dispersive analysis (SEM).

Greystone: Five distinct assemblages can be recognised, the critical minerals being: albite-dolomite, albite-calcite, dolomite-quartz, magnesite-quartz and talc-dolomite. Chlorite is present throughout.

Albite-calcite assemblage: Large (>2 mm) relict plagioclase feldspar crystals with well-preserved lamellar twinning are common. They show mild alteration to sericite and carbonate (calcite).

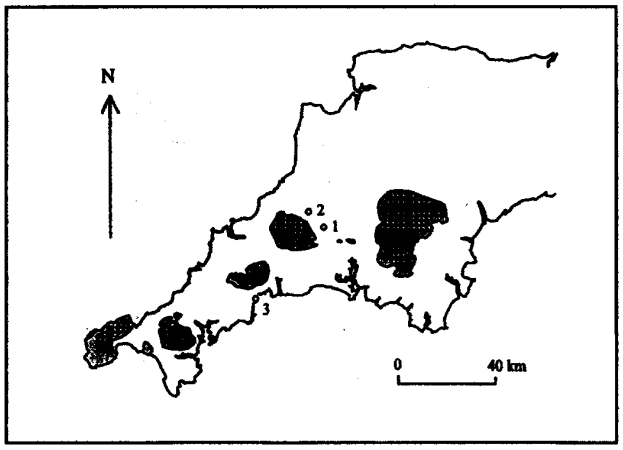

Figure 1: Simplified geological map of Cornwall showing localities and their proximity to the Cornubian granites (dotted). 1 - Greystone, 2 - Polyphant, 3 - Duporth.

	Greystone																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Species	A,C	A,C	A,C	A,C	A,C	A,C	A,D	A,D	A,D	A,D	A,D	A,D	A,D	A,D	D,Q	D,Q	D,Q	M,Q	M,Q	M,Q	M,Q	M,Q
SiO_2	48.88	45.84	45.04	42.04	43.89	45.91	38.33	38.57	41.76	40.37	45.08	46.08	44.61	41.55	39.2	38.9	36.09	35.87	33.06	35.44	33.16	31.45
TiO_2	2.62	3.25	3.02	2.11	2.7	1.53	3.01	1.22	3.83	3.01	2.97	2.58	2.69	0.93	3.28	0.8	0.96	0.91	0.85	0.98	0.98	1.06
Al_2O_3	16.25	18.99	18.52	16.23	17.09	19.04	17.5	11.81	15.63	12.3	16.28	14.84	15.77	13.02	16.61	7.4	9.55	7.23	7.06	7.02	7.29	8.21
Fe_2O_3	11.58	11.68	10.89	12.17	12.54	8.89	11.97	11.71	15.73	13.26	12.51	10.21	13.04	12.8	12.32	13.1	13.87	11.25	12.81	11.72	12.76	12.13
MgO	4.78	6.04	7.25	5.2	5.29	4.23	6.4	12.93	8.6	5.81	6.4	5.8	6.71	13.61	6.26	15.1	16.66	20.06	19.22	18.93	19.48	19.26
CaO	2.27	2.7	3.3	5.97	4.76	4.39	5.41	5.3	2.89	7.89	2.69	4.45	3.39	4.95	7.25	8.37	6.22	3.24	3.27	3.86	3.46	4.94
Na_2O	3.89	2.45	2.39	3.14	3.1	4.59	0.22	1.24	1.56	1.14	2.04	0.58	2.18	1.71	0.11	0.01	0.01	0.01	0.01	0.01	0.01	0.01
K_2O	1.5	1.61	2.51	0.93	1.61	2.86	3.76	0.63	0.8	1.71	1.22	1.86	1.03	0.03	2.68	0.01	0.04	0.05	0.04	0.04	0.06	0.04
P_2O_5	0.49	0.6	0.51	0.57	0.53	0.62	0.42	0.66	0.75	0.7	0.66	0.62	0.59	0.09	0.59	0.07	0.08	0.17	0.11	0.12	0.13	0.16
L.O.I.	4.82	6.14	5.78	10.9	6.62	5.9	12.1	15.3	7.89	13.2	7.72	10.7	8.2	9.13	11	16.11	15.6	20.1	22.4	20.7	21.5	21.6
Total	97.08	99.3	99.21	99.26	98.13	97.96	99.12	99.37	99.44	99.39	97.57	97.72	98.21	97.82	99.3	99.87	99.08	98.89	98.83	98.82	98.83	98.86
Ba	537	440	270	323	358	537	600	56	254	470	358	448	269	90	66	17	405	23	18	38	10	40
Nb	37	39	33	33	38	34	30	33	25	23	60	58	50	10	11	5	5	13	8	9	9	10
Zr	185	267	212	230	188	176	216	215	179	174	271	238	242	74	102	73	73	96	68	78	72	92
Y	18	29	27	26	25	28	37	31	26	26	27	32	23	8	14	6	9	10	8	10	9	10
Sr	219	331	234	501	200	254	333	401	202	334	100	144	149	165	205	225	220	173	130	140	127	257
Zn	121	108	68	137	129	100	87	65	97	73	178	158	157	101	93	84	81	70	77	86	94	100
Ni	27	50	72	66	21	10	42	54	49	63	79	179	64	475	188	367	322	329	302	316	336	327
Mn	2323	2110	2550	2580	2788	2323	2680	4030	3990	5360	2323	3563	2865	1549	3070	2926	2330	1460	2980	2950	3510	2010
Cr	248	122	130	104	186	186	80	94	111	135	248	186	248	867	1450	1720	2220	1400	1300	1400	1390	1530
As	<2	<2	<2	<2	4	<2	<2	<2	6	15	45	44	15	3	20	311	108	144	283	300	269	127
S	1800	100	<100	200	1900	1100	300	500	<100	500	2600	1000	600	<100	300	7200	700	200	<100	100	<100	200

	Greystone								Duporth				Polyphant									
	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
Species	M,Q	M,Q	M,Q	T,D	T,D	T,D	T,D	T,D	PA	T,D	T,D	T,D	P,S	P,S	P,S	P,S	P,S	T,D	T,D	T,D	T,D	T,D
SiO_2	36.39	34.84	35.53	34.51	40.2	42.5	40.32	40.66	35.1	41.22	36.5	43.23	38.39	38.08	38.09	38.19	38.26	37.27	42.12	35.66	35.7	34.6
TiO_2	0.81	0.93	0.8	0.67	0.75	0.64	0.86	0.68	1.25	2.03	0.9	1.51	0.72	0.68	0.73	0.69	0.72	0.67-	0.71	0.65	0.7	0.66
Al_2O_3	8.02	8.77	7.28	6.96	7	6.2	7.11	7.04	10.77	14.38	7.18	10.84	5.39	5.35	5.37	5.85	5.4	5.42	5.51	5.08	5.26	5.72
Fe_2O_3	12.2	12.66	13.33	13.39	15.6	13.5	14.6	16.08	16.94	16.34	20.93	14.33	13.95	14.13	13.97	13.88	14.39	13.39	14.11	13.62	13.85	13.1
MgO	18.62	18.81	18.03	19.42	21.6	22.6	24.14	25.32	21.09	14.38	21.22	14.77	26.8	26.86	26.99	27.18	27.45	23.38	24.91	21.64	21.24	22.3
CaO	4.03	3.41	3.2	7.6	3.58	3.25	2.58	2.7	0.07	0.66	0.3	6.05	3.91	4.45	4.2	4.14	3.06	4.89	1.64	7.08	6.82	6.26
Na_2O	0.02	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.57	0.05	0.16	1.33	0.15	0.13	0.14	0.12	0.15	0.03	0.04	0.03	0.01	0.01
K_2O	nd	nd	nd	0.03	0.01	0.01	0.04	0.04	0.08	nd	0.1	0.04	0.27	0.27	0.3	0.3	0.28	0.2	0.01	nd	nd	nd
P_2O_5	0.12	0.13	0.12	0.06	0.07	0.05	0.1	0.05	0.01	0.42	0.15	0.3	0.9	0.14	0.14	0.13	0.12	0.11	0.11	0.12	0.15	0.12
L.O.I.	19	19.5	19.6	16.1	11.03	11.1	9.06	6.19	11.5	8.17	10.7	6.23	9.03	8.7	8.94	8.77	8.72	13.4	8.91	14.5	13.9	15.4
Total	99.21	99.09	97.91	98.75	99.85	99.86	98.82	98.77	98.25	98.61	99.17	99.23	99.36	99.45	99.53	99.9	99.16	99.18	98.57	98.96	98.18	98.73
Ba	90	90	nd	38	15	11	41	45	179	90	nd	269	179	90	90	90	nd	nd	90	90	nd	90
Nb	12	13	11	3	3	4	7	3	17	31	11	24	17	15	15	15	13	12	10	13	11	13
Zr	70	72	61	64	53	60	61	46	89	160	59	130	54	51	53	50	47	47	44	45	48	75
Y	7	8	8	8	7	7	7	7	8	12	10	12	7	7	8	7	7	5	2	4	5	5
Sr	153	96	105	330	143	144	89	94	10	13	7	140	40	51	49	49	31	123	58	99	95	646
Zn	136	145	167	66	63	73	64	67	145	223	116	212	87	79	89	84	100	90	83	90	102	90
Ni	966	1060	1080	376	399	370	410	369	1300	500	1500	800	1400	1300	1360	1290	1340	1320	1430	1350	1300	1140
Mn	1549	1626	1471	4300	1107	1331	930	1480	1781	5808	3872	2323	1704	1781	1781	1859	1781	1704	697	1781	1471	1549
Cr	929	867	929	1500	1664	1737	1490	1350	62	2600	929	1857	1671	1610	1671	1610	1610	1610	1733	1486	1486	1548
As	224	352	370	68	43	57	<2	6	2	59	2	2	2	2	2	2	8	49	2	163	228	137
S	100	200	2900	1200	5900	800	400	500	1000	<100	900	400	100	400	200	300	<100	<100	<100	<100	<100	<100

Table 1: Results of XRF analysis of samples from Greystone, Duporth and Polyphant. Species refers to the key mineral phases: A-albite, C-calcite, D-dolomite, Q-quartz, M-magnesite, T-talc, P-pyroxene, S-serpentine. Major oxides expressed as a percentage; trace elements in ppm. LOI = loss on ignition; nd = below detection limits.

No other primary magmatic phase remains. Chlorite is abundant as a product of the alteration of pyroxene. Large spherical aggregates of TiO_2 are finely intergrown with chlorite; the textures observed are possibly due to alteration of titaniferous pyroxene. No fresh pyroxenes have been identified in any of the samples.

Albite-dolomite assemblage: Progressive alteration gives rise to this assemblage. Plagioclase feldspars are significantly more altered with only minor amounts remaining; carbonate and sericite are proportionally more abundant. Chlorite and dolomite are common with lesser amounts of quartz.

Dolomite-quartz assemblage: Complete recrystallisation of the rock has occurred; no relict phases or textures remain. Chlorite is abundant as are sparry dolomite crystals.

Magnesite-quartz assemblage: Extensive carbonatisation has produced an assemblage of coarsely crystalline magnesite, quartz, chlorite and dolomite. Analysis of the magnesite by SEM shows that it contains significant amounts of iron and is therefore the variety breunnerite.

Talc-dolomite assemblage: Silicification has produced an assemblage of talc, chlorite, dolomite and minor quartz.

Sulphide phases include jamesonite, galena, chalcopyrite, pyrite, pyrrhotite, pentlandite and cobaltian gersdorffite. They are most common in the carbonate rich samples, particularly the magnesite-quartz assemblage.

A clear progression is apparent from the albite-calcite to the albite-dolomite assemblage with increasing carbonatisation. However, the paragenetic sequence becomes confused with increasing recrystallisation of the rock and it is unclear if the dolomite-quartz, magnesite-quartz and talc-dolomite assemblages are sequential.

Duporth: Both plagioclase and pyroxene of magmatic origin are present as relict material. The pyroxene is frequently overgrown by tremolite. No olivine or serpentine minerals are present and, as a result, the description of the Duporth "picrite" (Ussher *et al*., 1909) is inappropriate. Talc, chlorite and dolomite are the main alteration phases with the talc forming spherical aggregates giving the rock a spotty appearance in hand specimen. Veins of siderite are common throughout, often associated with talc-chlorite veins.

Polyphant: Alteration of the ultrabasic rock is very localised; relatively unaltered material lies within a metre of highly talcose rock. Only two assemblages have been identified.

Pyroxene-serpentine: The least altered samples show an as-

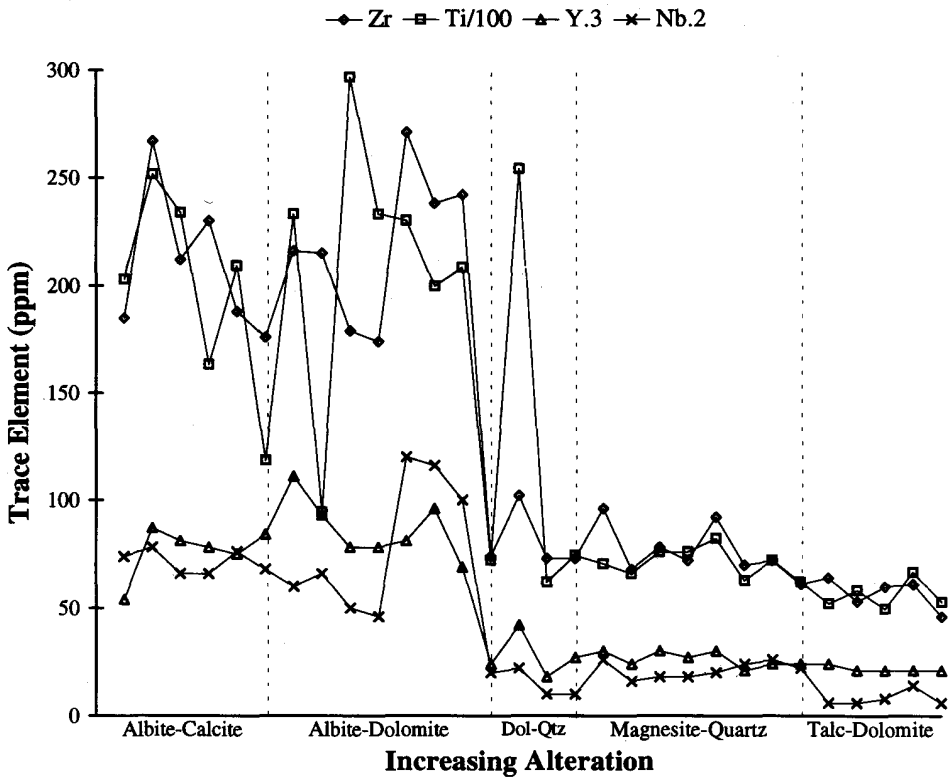

Figure 2: Data from Greystone. Behaviour of immobile elements with increasing degrees of alteration.

semblage of pyroxene (diopside), chlorite, serpentine (antigorite) and amphibole (magnesio-hornblende). Olivine has been completely serpentinised with antigorite pseudomorphing it. Poikilitic textures remain with pyroxene oikocrysts surrounding chadacrysts of olivine (now antigorite). Magnetite occurs as a product of the serpentinisation process. Brown amphiboles are common and have been attributed to high temperature hydrous equilibrium crystallisation (Floyd and Rowbotham, 1982). Relatively high concentrations of Al, now resident in chlorite, suggest that plagioclase may have occurred as a primary phase.

Talc-dolomite: The assemblage of altered rocks is primarily talc and chlorite with dolomite; talc appears to form after antigorite whilst chlorite and dolomite form after pyroxene and amphibole.

In all three bodies, talc and magnesite appear to be mutually exclusive. This is unusual as in the majority of talc-carbonate deposits, magnesite is the predominant carbonate phase. The absence of magnesite in association with talc may be due to the high chlorite (and thus aluminium) content taking up much of the available magnesium; excessive calcium (released during the albitisation process) may also be a contributory factor. Both of these factors could be due to the relative abundance of plagioclase in the protolith. Basic rocks are therefore more likely to give a talc-dolomite alteration assemblage when altered rather than the talc-magnesite that is produced as a result of the alteration of ultrabasic bodies.

GEOCHEMISTRY

X-ray fluorescence spectrometry, using a Phillips PW1400, was used to analyse major, minor and trace elements. The results are given in Table 1. The widest variety of alteration is present at Greystone and the bulk of the analyses are from that locality.

Greystone: SiO_2 and Al_2O_3 decrease markedly with increas- ing alteration whilst MgO shows a strong enrichment with alteration. Zr, Ti, Nb and Y show a strong depletion with alteration (Figure 2), conversely, Cr and Ni values markedly increase in the more altered samples (Figure 3). Arsenic is strongly enriched in the dolomite-quartz and magnesite-quartz assemblages (Figure 3). Although some hydrous minerals are present, the loss on ignition generally reflects the carbonate content. Dilution of the rock by carbonate may, at least partly, explain the trends of elements observed as the carbonate rich rocks are depleted in a number of elements.

Using immobile trace elements, it should be possible to establish whether or not differentiation has taken place. The elements Ti, Y, Zr, Nb and Sr have been found to be immobile during low grade regional metamorphism (Pearce and Cann, 1973; Winchester and Floyd, 1976) and can be used to show differentiation trends (particularly Zr and Ti). A Ti-Zr plot reveals a distinct trend with the more altered talc-dolomite and magnesite-quartz assemblages depleted in both Ti and Zr (Figure 4). Similar trends have been identified in other metabasites around Cornwall and interpreted as due to differentiation (Chandler and Isaac, 1982). However, dilution of the rock by carbonate will give similar trends. The relative mobility of elements can be shown using ternary diagrams. On the Zr-Ti/100-Sr/2 plot of Pearce and Cann (1973), there is a wide scatter of points with the most altered assemblages enriched in Sr indicating that, as noted by Smith and Smith (1976), Sr is mobile during carbonate alteration. Little scatter of points is apparent in the graphs of Zr-Ti/100-Y.3 (Pearce and Cann, 1973) and the scatter is unrelated to mineral assemblage (Figure 5). In fact, the scatter of points is most pronounced for the relatively unaltered, albite-dolomite assemblage. Consequently, Zr, Ti, and Y appear to be immobile even in the most altered samples. The immobility of Ti in these rocks conflicts with Hynes (1980) and suggests that Ti is not always mobilised by fluids with high Xco_2.

Assuming Nb is also immobile, a graph of $\log Zr/TiO_2$-$\log Nb/Y$ will show fractionation trends. The Nb/Y ratio represents an index of alkalinity which is constant for a single magma source, whilst the Zr/TiO_2 ratio represents a differentiation index which increases with fractionation (Winchester and Floyd, 1977). Figure 6 shows that there is slight variation in the Zr/TiO_2 ratio and again this is unrelated to mineral assemblage. This indicates that, if differentiation had taken place during crystallisation of the greystone sill, then the more basic

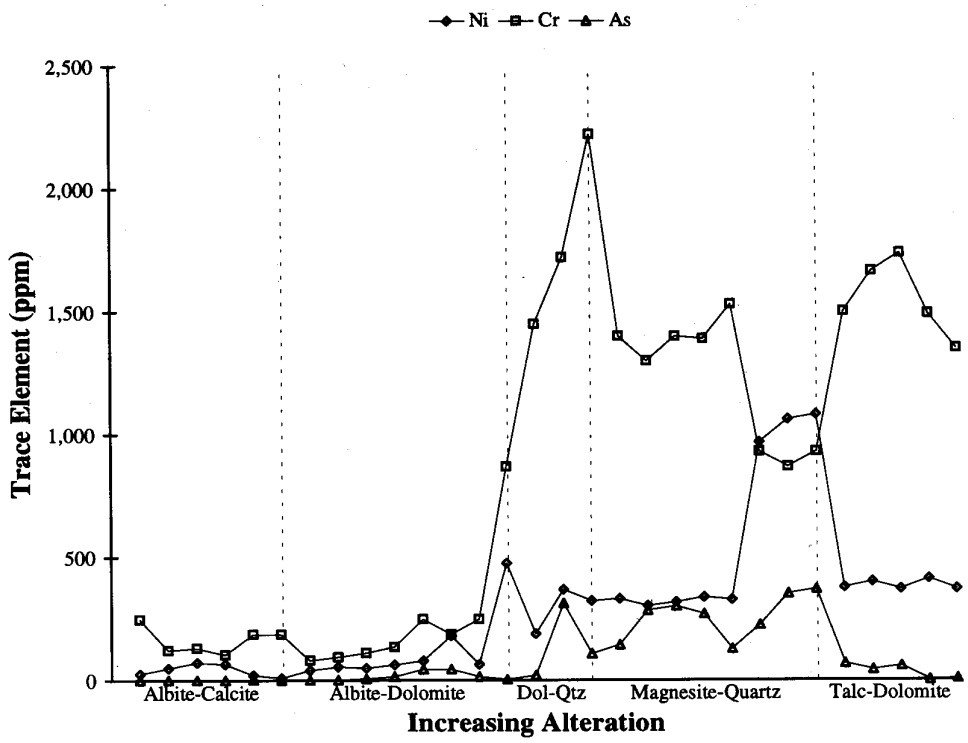

Figure 3: Data from Greystone. Trace element enrichment in the most altered samples.

fractions are no more susceptible to alteration than the more acidic fractions. It is more likely that the scatter is due to slight mobility of Ti and/or Zr.

Turner (1982) noted that a number of sills are present at Greystone and it is possible that more than one sill has been sampled. However Nb/Y ratios are approximately constant indicating that, even if more than one body has been sampled, the sills are likely to be closely related genetically.

Both Ni and Cr show distinct concentration in the more altered assemblages and are indicative of a differentiation trend. However, Ni is a common constituent of sulphide phases and may have been introduced, or concentrated, by alteration processes. As chromium rich phases have not been identified, Cr is expected to be resident in chlorite or at low concentrations in sulphides. It therefore seems likely that both Ni and Cr have been introduced to the system and are unlikely to be due to primary fractionation of the Greystone sill.

Strong enrichment of arsenic in both the dolomite-quartz and magnesite-quartz assemblages, combined with the decreased abundance of Ti and Zr indicates that As is closely related to the carbonatisation (and therefore the dilution) event. Samples collected from the contact between the sill and the country rock show no particular enrichment in As or carbonate showing that the alteration is not due to interaction with fluids directly derived from the surrounding

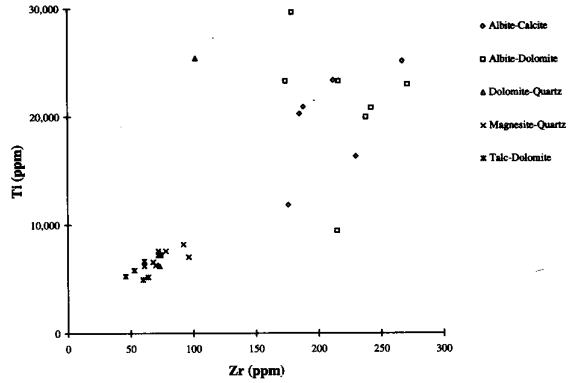

Figure 4: Binary plot displaying the strong depletion in Ti and Zr with alteration. Data from Greystone.

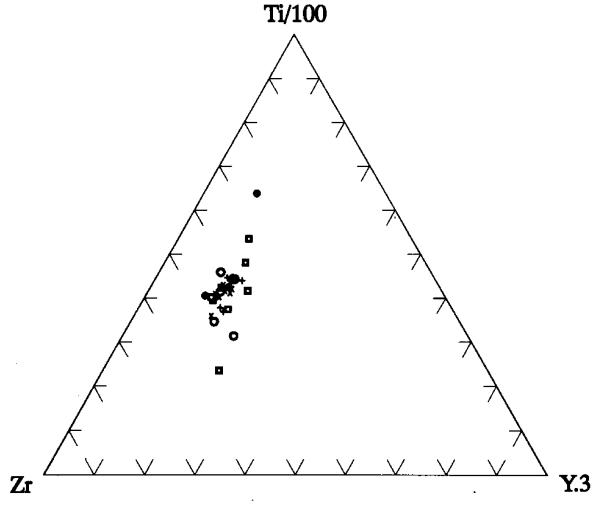

Figure 5: Zr-Ti/100-Y.3 plot (after Pearce and Cann, 1973). Limited mobility of elements. Scatter of points is unrelated to mineral assemblage. O = albite-calcite; □ = albite-dolomite; • = dolomite-quartz; × = magnesite-quartz; + = talc-dolomite. Data from Greystone.

sediments as suggested by Turner (1982). The presence of As in the basic body is therefore interpreted as a result of As and CO_2 rich hydrothermal activity. The lack of any clear evidence for differentiation coupled with the concentration of As in the carbonate rich assemblages suggests that the variable alteration is a result of differences in hydrothermal fluid activity and chemistry rather than any magmatic differentiation process.

Duporth: Limited data from the sill at Duporth shows that Sr is mobile whilst Ti, Zr, and Y remain largely immobile. No obvious differentiation trends have been identified and again the alteration is likely to be controlled by factors external to the intrusion. Minor enrichment in As is present in one rock but sulphide phases are not common.

Polyphant: Chemical variation between the different assemblages at Polyphant is less pronounced. Generally, there are lower amounts of MgO and a higher L.O.I. in the talc-dolomite assemblage, but overall, less carbonate is present than at Greystone. As with Greystone, the ratios of Zr:Ti:Sr and Zr:Ti:Y (Pearce and Cann, 1973) confirm that Sr has a large degree of mobility whilst Y is immobile. Zr:Ti:Y ratios are closely grouped even in the talc-dolomite assemblage. No differentiation trends are indicated by Zr/TiO_2:Nb/Y ratios. Ni and Cr also show no significant variation, supporting the idea that the body was homogeneous prior to alteration.

The data from Greystone and Duporth lie in the within-plate basalt field of Pearce and Cann (1973) supporting the findings of Floyd (1984) and Floyd *et al*. (1993). Ni-Cr data from Polyphant suggest a MORB affinity (conflicting with Floyd *et al*., 1993) indicating that the body may be related to the ophiolitic Menage Formation mélange, as proposed by Barnes (1985).

TIMING AND NATURE OF THE CARBONATISATION

Carbonatisation in the rocks of Greystone is closely linked to the formation of disseminated As-Ni-Co sulphides (gersdorffite, pentlandite and arsenopyrite). This is reflected by the overall enrichment in As and Ni with increasing carbonatisation. U-Co-Ni-Bi-As-Ag mineralisation is typical of late-stage, cross course mineralisation (Pattrick and Polya, 1993). Fluids associated with cross course mineralisation are typically highly saline and contain compressed gases, probably CO_2 or low-order hydrocarbons (Rankin *et al.,* 1982). The alteration seen at Greystone therefore, may well be related to fluids associated with the cross course that cuts the sill. Complex sulphides containing Cr have been identified in veins of this type (Pattrick and Polya, 1993) implying that the fluids can be enriched with respect to Cr. This may explain the high Cr concentrations in the most altered rocks. Although cross courses in general are fairly minor features, visible wall rock alteration can extend to well over 10 m from the vein. Examples of cross courses with particularly large metasomatic haloes (well over 10 m in width) are present at Perranporth and Porthleven *(pers. comm.* A. Alexander, 1995).

Similar As-Ni-Co mineralisation to that at Greystone has been identified in tuffs and volcanic rocks in south Devon, and has been attributed to exhalative hydrothermal activity (Leake *et al.,* 1985). Hydrothermal activity of this type can have a massive, lensoidal or a disseminated nature (Pattrick and Polya, 1993). As an alternative explanation it is possible that this type of hydrothermal activity was responsible for the carbonatisation event and could be a source for As and sulphides.

As there is no particular enrichment in As, Ni or Cr at Polyphant and Duporth, the processes causing the alteration are likely to be different.

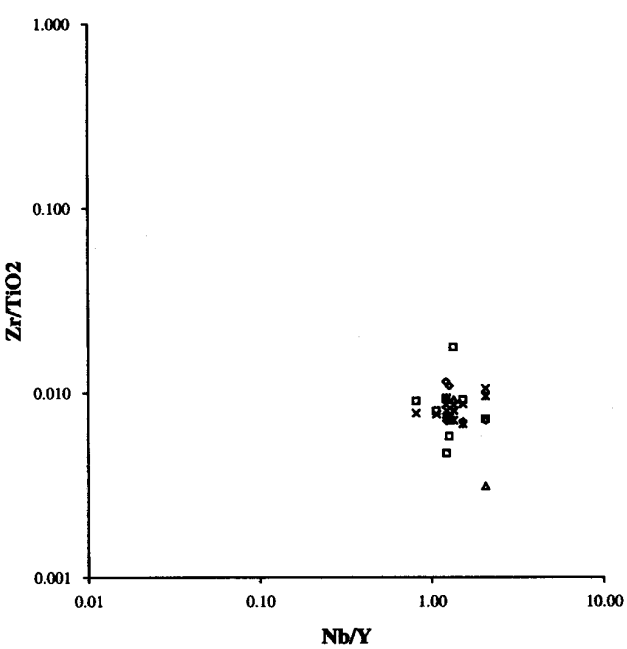

Figure 6: Limited variation in Zr/TiO_2 ratio indicates little differentiation has taken place. Symbols as in figure 4. Data from Greystone. Diagram after Winchester and Floyd (1977).

CONCLUSIONS

The igneous bodies at Greystone, Polyphant and Duporth all show variable alteration from minor chloritisation through to major carbonatisation and talcification. A paragenetic sequence can be established. Trace elements show that the variation in concentration of elements is due to dilution effects caused by the carbonatisation event. There is no evidence for differentiation in any of the three bodies. The composition and activity of the alteration fluids appear to have controlled the type of alteration mineral assemblage produced. Enrichment of As in altered rocks at Greystone is indicative of hydrothermal activity and may be linked to the cross course that cuts the intrusion.

ACKNOWLEDGMENTS

We wish to thank L. Sear for the XRF analysis; C.M. Bristow for suggestions and ideas; A.J. Ball for his help and expertise in using the SEM; and ECC Quarries (now CAMAS Aggregates) for access to their quarry. Duporth Holiday Village kindly allowed access to their private beach. M.R.P. acknowledges support for his Ph.D. research from C.S.M. Trust.

REFERENCES

BARNES, R. P. 1985. Discussion of papers on the Hercynian back arc marginal basin of south-west England (a reply). *Journal of the Geological Society,* London, **142**, 927-9.

CHANDLER, P., DAVEY, R. F., DURRANCE, E. M. and JADY R. J. 1984. A gravity survey of the Polyphant ultrabasic complex. *Proceedings of the Ussher Society,* **6,** 116-20.

CHANDLER, P. and ISAAC, K. P. 1982. The geological setting, geochemistry and significance of lower Carboniferous basic volcanic rocks in central south-west England. *Proceedings of the Ussher Society,* **5,** 279-288.

CLAYTON, R. E. 1993. Basalt carbonatisation and its implications for antimony mineralisation in north Cornwall. *Proceedings of the Ussher Society,* **8,** 105-111.

COLLINS, J. H. 1877. Note on Duporthite, a new asbestiform mineral. *Mineralogical Magazine,* **1**, 226.

FLOYD, P. A. 1982. Chemical variation in Hercynian basalts relative to plate tectonics. *Journal of the Geological Society,* London, **139,** 505-20.

FLOYD, P. A. and ROWBOTHAM, G. 1982. Chemistry of primary and secondary minerals in titaniferous brown amphibole-bearing greenstones from north Cornwall. *Proceedings of the Ussher Society,* **5,** 296-303.

FLOYD, P. A., EXLEY, C. S. and STYLES, M. T. 1993. *Igneous rocks of south-west England.* Chapman and Hall, London.

HYNES, A 1980. Carbonatization and mobility of Ti, Y, and Zr in Ascot Formation metabasalts, SE Quebec. *Contributions to Mineralogy and Petrology,* **75,** 79-87.

ISAAC, K. P. 1985. Discussion of papers on the Hercynian back arc marginal basin of south-west England. *Journal of the Geological Society,* London, **142,** 927-9.

ISAAC, K. P., CHANDLER, P., WHITELEY, M. J. and TURNER, P. J. 1983. An excursion guide to the geology of central South West England: report on the field meeting to West Devon and East Cornwall, 23-31 May, 1982. *Proceedings of the Geologists Association, London,* **94,** 357-376.

LEAKE, R. C., BROWN, M. J., SMITH, K. *et al.* 1985. Volcanogenic and exhalative mineralisation within Devonian rocks of the South Hams district of Devon. *Mineral Reconnaissance Program Report,* **79,** British Geological Survey, 90 pp.

MORTON, R. D. and SMITH, D. G. W. 1971. Differentiation and metasomatism within a Carboniferous spilite-keratophyre suite in SW England. *Mineralogical Society of Japan, Special Paper,* **1,** 127-132

PATTRICK, R. A. D. AND POLYA, D. A. 1993. *Mineralisation in the British Isles*. Chapman and Hall

PEARCE, J. A. and CANN, J. R. 1973. Tectonic setting of basic volcanic rocks determined using trace element analyses. *Earth and Planetary Science Letters,* **19,** 290-300.

RANKIN, A. H., ALDERTON, D. H. M., THOMPSON, M and COULTER, J. E. 1982. Determination of uranium:carbon ratios in fluid inclusion decripitates by inductively coupled plasma emission spectroscopy. Mineralogy Magazine, **6,** 179-86.

SCOTT, P. W. and POWER, M. R. 1995. Duporthite: A mixture of talc and chlorite. *Proceedings of the Ussher Society,* **8,** 445

SELWOOD, E. B. and THOMAS, J. M. 1986. Variscan facies and structure in central south-west England. *Journal of the Geological Society,* London, **143**, 199-207.

SMITH, R. E. and SMITH, S. E. 1976. Comments on the use of Ti, Zr, Y, Sr, K, P and Nb in the classification of basaltic magmas. *Earth and Planetary Science Letters,* **32,** 114-120.

TURNER, P. J. 1982. The anatomy of a thrust: a study of the Greystone Thrust Complex, east Cornwall. *Proceedings of the Ussher Society,* **5,** 270-278.

USSHER, W. A. E., BARROW, G., MACALISTER, D. A. and FLETT, F. S. 1909 . *Geology of the country around Bodmin and St. Austell with notes on the petrology of the igneous rocks.* Memoir of the British Geological Survey of Great Britain. pp. 49- 51.

WINCHESTER, J. A.and FLOYD, P. A. 1976. Geochemical magma type discrimination: application to altered and metamorphosed basic igneous rocks. *Earth and Planetary Science Letters,* **28,** p. 459-469.

WINCHESTER, J. A. and FLOYD, P. A.1977. Geochemical discrimination of different magma series and their differentiation products using immobile elements. *Chemical Geology,* **20,** 325-343.