ALKALI METASOMATISM FROM CORNUBIAN GRANITE CUPOLAS

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The distribution of the alkali elements Li, Na, K, Rb and Cs in the aureoles surrounding two buried and four partly exposed granite cupolas are described. Most of the aureole rocks are pelites with subordinate metabasalts (greenstones) and sparse quartzite. Petrographic evidence indicates that metasomatic processes continued after the peak of contact metamorphism. There is a consistent geochemical pattern to both pelites and greenstones, with elevated concentrations of Rb and Cs in the inner aureole (to 500 m from granite) and lower concentrations outside this zone. In some aureoles this general pattern is also reflected in the K and Li distributions. The degree of alkali enrichment depends upon the composition of the core granite. The patterns are consistent with and partly reflect the mineralogical changes observed.

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INTRODUCTION

The emplacement of granite magmas into the middle crust causes a variety of effects within their surrounding country rocks. These are well illustrated in South-west England, where contact metamorphic hornfels and spotted slate aureoles are accompanied by pegmatites, skarn and granite-related hydrothermal mineralisation. Contact metamorphism is generally considered to involve reactions that take place in more or less closed chemical systems, isolated from chemical interaction with the granite magma, heat conduction providing the sole impetus. However, this view can be misleading in that there is evidence for pervasive metasomatism as distinct from the obvious processes such as fracture-controlled hydrothermal alteration and mineralisation.

This paper considers evidence for the extent of chemical interaction between granites and their contact aureoles in the particular setting of the roofs of granite cupolas emplaced into a low to very low grade metamorphic pelitic terrane. It presents analytical results for rock samples from traverses across aureoles which surround some minor granite cupolas, with emphasis on data for the alkali elements, Na, K, Rb, Cs and Li, in the context of lithological and mineralogical variation in the rocks. Because of the potentially widespread distribution of alkali metasomatism around such cupolas we compare the data for some aureoles with "background" slates from the same region.

The alkali elements show a similarity in chemical properties and their geochemical behaviour. K and Na are major elements in common rocks where they are mostly hosted within major minerals: potash feldspars and micas for K, plagioclase for Na. Rb is a trace element which seldom forms essential minerals but commonly replaces K in micas and feldspars and is, in particular, enriched in late stage hydrothermal minerals. Within co-existing potash feldspar and mica, in both igneous and metamorphic rocks, the Rb concentration is almost always higher in the micas. This is considered to be due to the slightly greater ionic size of Rb^+, compared to K^+ (Heydemann, 1969), which leads to preferential incorporation at the 12-fold co-ordination sites of the micas. The geochemical properties of Cs are closest to Rb but, because of the absence of Rb minerals, the largest concentrations of Cs are found within K minerals and, again, micas display higher values than co-existing feldspars.

ALKALIS IN THE GRANITES

The trace alkali concentrations in Cornubian granites are higher than the world-wide average. Exley *et al*. (1983) proposed three major granite types (A, B and C) with two further variants derived from these by metasomatic alteration. B-type granites represent 90% of the exposed plutons by volume and are represented in this study by the Redmoor, Bosworgey and Hemerdon cupolas. The less widespread C-type granites (Castle an Dinas, Cligga Head and St Agnes) are more evolved, have characteristically higher Rb and Cs and usually higher Li. Table 1 summarises data for the granites

The Na_2O levels are fairly typical (Exley *et al*., 1983) but are reduced by greisenisation which, in particular, affects the samples from Hemerdon, Bosworgey and St Agnes. The granites show higher levels of K_2O than associated background slates (Table 3) with values typically greater than 4.5% and, as expected, tending to increase with greisenisation. However, the less evolved Hemerdon granite displays lower values of about 3% K_2O. Rb values are much higher in the granites than in background slates, ranging from over 450 ppm, in the Redmoor and Hemerdon granites, to over 1000 ppm for the Castle-an-Dinas Granite. Cs concentrations in granites are also relatively high, although in the Redmoor and Hemerdon samples they are only slightly higher than in background slates from St Columb Major. The more representative of two Cligga Head Granite samples, KB2044, is surprisingly low in Cs, differing markedly from the other evolved type-C cupolas sampled.

ALKALIS IN THE COUNTRY ROCKS

The extent of change in concentration of any element with proximity to the cupola margin can depend upon several factors, not the least being differences in mobility. For example, Cs may migrate farther than Rb and the distance to true sedimentary background levels will consequently vary. Of the aureoles studied, it is likely that only Redmoor and Hemerdon were sufficiently well sampled to provide a complete traverse through the aureole. All of the other aureole traverses were incomplete, some because they extended an insufficient distance from the contact (Bosworgey) or because samples were only available from the outer part of the aureole (Castle-an-Dinas). Other traverses were affected by lithological inhomogeneity, as at Cligga Head, where there are sandstones and chert rich pelites, and at St Agnes, where sandstones occur at the contact and also about 500 m from the contact. At Hemerdon, in addition to pelitic rocks, a collection of greenstones provided reasonable coverage of the inner aureole, but only one further greenstone sample was available, and that at 1500 m.

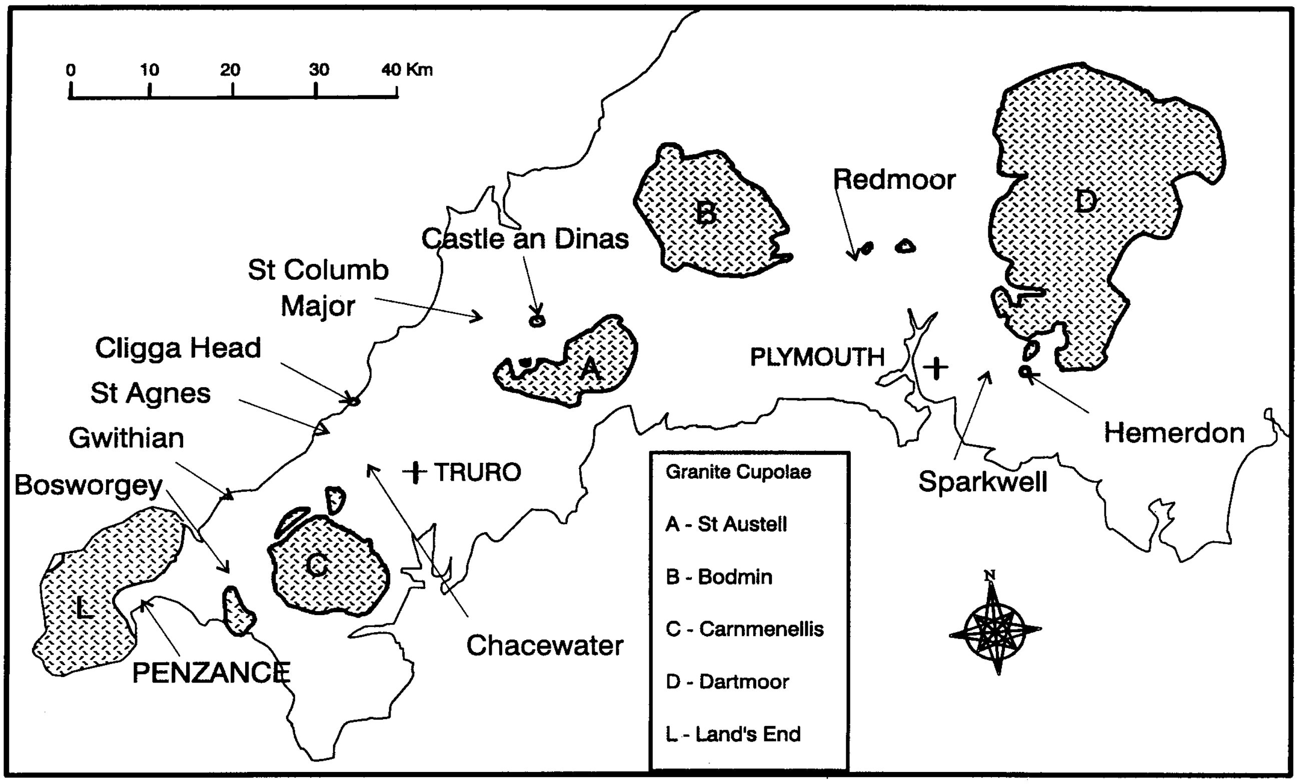

Figure 1 . *Location diagram.*

Pelite samples were collected from two background areas (no evidence of contact metamorphism) thought to be representative of the specific geological environment in which the cupolas were emplaced. These were at least 2.5 kilometres from the nearest granite outcrop and, as far as can be judged, a similar distance from a buried cusp or ridge. Samples from west Cornwall (Gwithian, Chacewater and Truro) relate to both the Bosworgey and St Agnes aureoles, whereas those from near St Columb were considered to represent background to the Cligga Head and Castle an Dinas aureoles.

A further group of fresh pelitic borehole samples was available from an area of weak mineralisation at Sparkwell, near Hemerdon. These may have been affected by alkali metasomatism from related mineralisation. All reported high alkali element concentrations and the rocks were concluded (Beer and Ball, 1986) to have suffered low grade W and Sn mineralisation (Sn, mean 17±12 ppm, maximum 43 ppm, and W, mean 7±6 ppm, range 0-21 ppm).

Table 3 summarises the analytical data for these background samples. The concentrations are close to those encountered in average pelitic rocks, with low levels of Cs, K/Rb close to 200 and variable K and Na contents. However, one sample from the St Columb group displayed anomalously high Cs (169 ppm) and Rb (313 ppm), with consequently low values of K/Rb and K/Cs. This has not been explained, the concentrations of Sn and W being unexceptional.

THE REDMOORE AUREOLE

Two principal zones of metamorphism were distinguished petrographically in the Redmoor aureole, comprising an outer zone of spotted, phyllitic rock, and an inner zone of coarser, banded hornfels. Beyond these, at more than 900 m from the granite contact, textures more typical of background "Killas" are present. In the outer aureole zone, the pelitic aureole rocks display a striking lepidoblastic texture in which muscovite flakes display a very high degree of orientation generally parallel with bedding. In the inner zone, within 400 m, the phyllitic rock gives way to coarser textures in which overgrowth by discordant biotite flakes has partially obscured the muscovite foliation. In addition, K-feldspar replaces the contact metamorphic muscovite and also forms non-orientated porphyroblasts. Thus, an early lepidoblastic muscovitic assemblage preceded formation of the non-orientated higher grade minerals which represent the peak of contact metamorphism.

At least four styles of subsequent metasomatic alteration can also be identified in the aureole and the granite. These include kaolinisation and sericite-chlorite alteration (which may affect the alkali distributions) as well as formation of tourmaline±fluorite. In addition, a late (post-biotite) generation of non-orientated white mica, present within granite and out to at least 250 m out from the contact, is interpreted as of metasomatic/hydrothermal origin.

The geochemical data (Figure 2) reveal generally low values of soda in the inner part of the aureole, i.e. up to 600 m, and higher values, possibly approximating to background, in the outer aureole. One exception to this was a sample with 1.42 % Na_2O, but this also contains 84 ppm Sn and may be accompanied by localised mineralisation with tourmalinisation. All the Na_2O concentrations are substantially lower than those in the granite.

K_2O is highest within about one km from the granite, declining to background levels beyond. Although the data are variable there is an overall decline with distance from the contact, close to which the values are actually higher than in the granite.

A well-developed zone of high Rb concentrations (>500 ppm; Figure 2), corresponding with the biotite zone, extends to about 500 m from the contact, with lower values outside this of about 200 ppm. Rb values in the innermost part of the aureole are twice those in the granite. This distribution is reflected in the K/Rb ratios. Although showing substantial scatter, the inner part of the aureole (to 300 m) exhibits low values of K/Rb similar to those of the granite, with even lower ratios in the innermost part. Beyond about 600 m the ratio, at about 175, is constant and approximates to background.

Notably high Cs concentrations were observed in the pelites close to the granite contact, exceeding those of the granite itself by a factor of ten or more (compare with Bowler (1958) for the Tregonning –

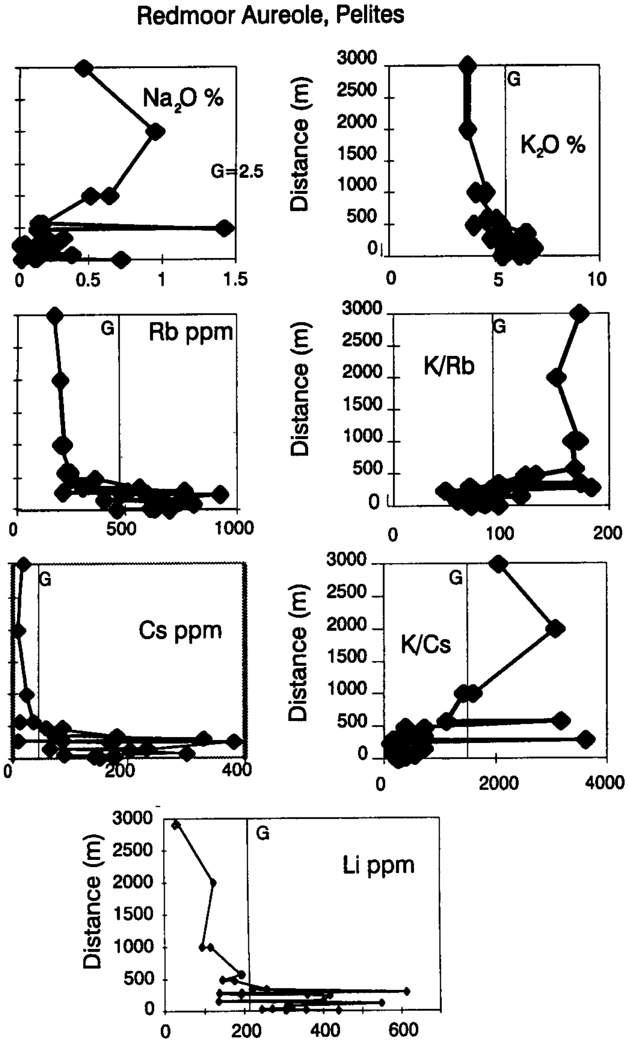

Figure 2. *Distribution of alkalis through the Redmoor aureole. G represents the average granite composition.*

Godolphin contact). The values decline to about background levels at 500 m. There is an equally clear pattern for K/Cs with low values in the inner part of the aureole (to 300-500 m) and values similar to the background slates in the outer part. This observation is tempered by a small number of erratic high values for this ratio close to the contact. Finally, the Li distribution displays a pattern that is almost identical to K_2O, Rb and Cs.

THE HEMERDON AUREOLE

There is an overall similarity to Redmoor in the alkali element distribution of the Hemerdon aureole. Samples were only available to 800m, but geochemical patterns are reasonably clear.

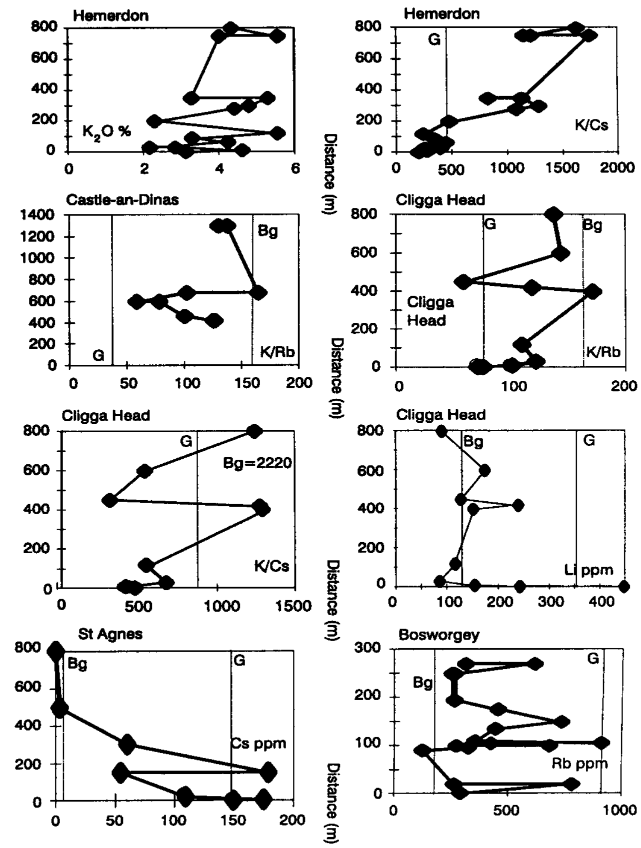

Figure 3. *Distribution of alkalis and ratios through selected examples of aureoles. G is the average granite composition, whilst Bg is the mean background level. Siliceous samples are circled.*

Some pelites samples from the outer part of the aureole were not analysed for Na_2O, yet as at Redmoor the highest Na_2O contents occur in the more distal samples. The low soda values in the inner aureole are higher than the mean granite concentration, which is affected by greisenisation. There is some suggestion of an increase in K_2O with distance from the contact (Figure 3). Although this is different to the Redmoor aureole, the patterns for Rb, Cs, K/Cs and K/Rb show similar distributions.

Analyses of greenstones sampled between 14 and 210 m from the granite are summarised in Table 2, where they are compared with the one sample from 1500 m. They were not comprehensively analysed for Na, and do not indicate a consistent pattern for this element. The greenstones do however display elevated K_2O close to the contact, much higher than in the granite, and even the most distant sample has a high value. K-metasomatism in greenstones close to granites is well known (Tilley, 1935; Hawkes, 1958; Floyd and Lees, 1972). The present data are also consistent with the findings of Floyd (1973), who showed that greenstones in contact zones of granites are enriched in both K and Rb, with lower K/Rb ratios (see also Figure 4). The

Table 1

	Redmoor		Hemerdon		Castle an Dinas		Cligga Head		St Agnes		Bosworgey	
	Average	St Dev	Average	St Dev	Average	St Dev	KB2044	KB2061	Average	St Dev	Average	St Dev
Na_2O	2.52	0.75	0.09	0.02	2.57	0.74	3.21	0.01	0.93	0.95	0.79	0.64
K_2O	5.36	0.79	3.04	0.55	4.59	0.53	4.78	5.47	4.46	1.13	6.39	0.97
Rb	477	63	491	49	1011	215	563	813	820	192	882	174
K/Rb	93	3	51	5	38	21	70	56	46	9	61	9
Cs	32	7	58	18	100	44	47	66	150	78	89	14
Li	213	24	no data	no data	1220		353	745	662	225	157	15

Table 1. *Average and standard deviations (St.Dev) for analytical data from the granites.*

sample from 1500 m has a higher level of Cs than would be expected of a basic igneous rock however.

THE CASTLE-AN-DINAS AND CLIGGA HEAD AUREOLES

The petrography of samples from these aureoles indicate rocks in which pervasive alteration has obliterated earlier biotite-grade contact metamorphism. The presence of tourmaline suggests that metasomatising fluids were B-enriched, in addition to Sn and W.

At Castle-an-Dinas, moderately high geochemical concentrations of Sn and W (Beer and Ball, 1986) indicate low grade mineralisation throughout the aureole. However, it was not possible to sample the inner part of the aureole owing to lack of exposure. No systematic pattern was observed for Na_2O, whose values are close to background and much lower than in the granite. Although the distribution patterns for K_2O, Rb, Cs are irregular (Figure 3) their concentrations also fall within the background range, distinctly lower than those in the granite and also lower than in the weakly mineralised Sparkwell area. There is, nevertheless, a modest increase in K/Rb from below 100 close to the contact to about 140 at beyond 500 m. Values greater than 50 ppm Cs were observed, irregularly, to about 600 m, and there is an indistinct pattern for K/Cs (average 880±434, close to values recorded at Sparkwell).

The data were tested statistically in two ways in comparing the aureole with the background (Table 3). Firstly, all of the data for the aureole are compared with the St Columb background samples. Both one way analysis of variance and a non-parametric analogue, the Kruskal-Wallis Test, show that there are significant differences between the two data sets for Li, K/Rb, K/Cs and, possibly, Cs. Secondly, when samples beyond 600 m are included within the background the data still show similar differences, except for Cs.

The data from the Cligga Head aureole show no consistent pattern for Na_2O and K_2O, probably because of the presence of siliceous sediments, especially in the inner part of the aureole. Significantly higher levels of Rb, Cs, Li, K/Rb and K/Cs occur in the aureole samples when compared with the St Columb background samples (Table 3). The high values of Rb (<439 ppm) in the inner part of the aureole are lower than in the granite, though in general higher than in the background pelites, despite the inhomogeneity in the sampling media. Erratic, high values for Cs were observed throughout the aureole. Low values of K/Cs (<500) occurred close to the granite, with higher values (>1000) at a greater distance. Moderately high Li concentrations (Figure 3) observed at about 400-700 m from the contact, as at Castle-an-Dinas, are lower than those in the immediate contact samples. Henley (1974) noted a marked increase in this aureole, not only of Cs and Rb, but also S, As and Sn, towards the granite contact.

THE ST. AGNES AND BOWSWORGEY AUREOLES

Petrographically, the samples from St. Agnes resemble those from Castle-an-Dinas and Cligga Head, with however the presence of fluorite additionally suggesting introduction of F during metasomatism. The Bosworgey samples are more similar to those from Redmoor in their style of metamorphism and alteration.

The geochemical patterns in the St Agnes aureole, as at Cligga Head, are confused by the presence of highly siliceous rocks close to the contact (Figure 3). It is not possible to recognise any consistent pattern in K_2O or Na_2O content, both being close to background and granite values. However, Rb is higher than background and much lower than in the granite. Cs shows the clearest pattern for all the alkali elements, with high values (>50 ppm) extending to about 300 m from the contact (Figure 3). Half of the samples exhibit Cs contents higher even than the granite. At distances greater than 400 m the values fall to background. K/Cs exhibits a pattern similar to that observed in the Redmoor and Hemerdon aureoles, low values (<1000) extending to at least 300 m from the contact beyond which the ratio increases. Li displays moderately high concentrations between about

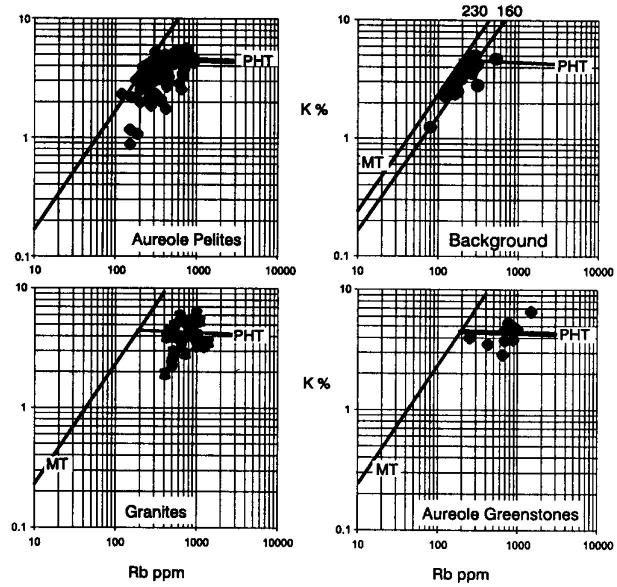

Figure 4. K/Rb scattergrams for aureole pelites, background slates, granites and aureole greenstones. MT is the main trend for igneous rocks (K/Rb - 230), and PHT is the pneumatolytic hydrothermal trend (after Shaw, 1968). A value of K/Rb about 160 is that generally accepted for unaltered sedimentary rocks (Heier, 1968). In practise, however, the average background K/Rb is between 190 and 200 (see text). Both aureole pelites and greenstones fall between the two zonal categories.

400 and 700 m from the contact, but levels are near background close to, and again at more than 700 m from the contact.

As at Castle-an-Dinas, the data from St Agnes were tested statistically in two ways to compare the aureole with the background (Table 3). Firstly, when all the samples (to 800 m from granite) were compared with background, highly significant differences were observed for Rb, Cs, K/Rb and K/Cs, and significant differences for Li and Na_2O. When, secondly, samples beyond 500 m were included with the background, similar relationships were again observed with the exception of Na_2O, for which no significant difference was noted.

In the Bosworgey aureole, it was only possible to obtain samples of drill core from less than 300 m from the granite and also at about 1000 m. When the 1000 m samples were included with the aureole then highly significant differences were observed (Table 3) for Na_2O, Rb, Cs, Li, K/Rb (Figure 3) and K/Cs. When the 1000 m samples were included with the background samples then a highly significant difference was observed for all of the alkali elements. The Li content of the Bosworgey granite is particularly low and the values in the aureole even lower (Tables 1 and 3). Ball and Basham (1984) have shown that in the Bosworgey granite, at least, the main host for the Li is late stage sericitic micas.

SUMMARY AND DISCUSSION

Several examples of alkali migration into aureoles from granite have been described. For the Tregonning-Godolphin granite, Stone and Awad (1988) showed that aureole rocks within about 10 m of the contact were significantly higher in K_2O, Cs, Rb and Li than samples from outside that limit. Cs enrichment extended further into the aureole. The value of K/Rb was 169 beyond 10 m but substantially lower within the 10 m zone.

Mitropoulos (1982) showed that Rb enrichment extended barely 10 m from the contact of the Lands End Granite, while K/ Rb ratios in the more distal zones lay between 190 and 200. Floyd and Leveridge (1987) and Shail and Floyd (1988) similarly reported 'background' K/Rb values between 190 and 200 for both pelitic and arenaceous members of turbidite units from the Gramscatho beds.

Table 2

	Average	St Dev	RMD23
Na_2O	0.09	0.06	
K_2O	5.46	1.35	4.87
Rb	828	294	251
K/Rb	57	14	161
Cs	337	168	24
K/Cs	175	130	1684

Table 2 . *Comparison of analytical data for 9 greenstone samples within 200 m of the Hemerdon contact with one background sample (RMD23).*

Oosterom *et al* (1984) have examined the aureole of the W-Sn bearing Panasquiera granite cupola in Portugal. Shales consisting of quartz-chlorite-albite-sericite assemblages are converted by contact metamorphism into hornfelsic biotite-chlorite-cordierite schists. High levels of Rb and Li were observed in the pelitic hornfelses, ranging from 490 to 155 ppm Rb (background 155 ppm), and 500 to 75 ppm Li (background 55 ppm).

In the English Lake District, the Crummock Water aureole (Cooper *et al.,* 1988) provides an example in which contact metamorphism, expressed as bleaching, induration and chloritic spotting, is accompanied by statistically significant higher levels of K and Rb. The aureole, underlain by a concealed granitic intrusion, is also notable for the presence of fracture-controlled tourmalinisation over the crest of this granite. In this same area, Roberts (1983) described metasomatic potassium enrichment of semi-pelitic Skiddaw Group hornfels in contact with the Skiddaw Granite.

Wodzicki (1972) investigated the theoretical basis for metasomatism by igneous intrusions. He considered that element migration takes place by a combination of hydrodynamic flow and intergranular diffusion. The main requirement for the first is that the rock should be permeable, and that fluid pressure should be greater than the confining pressure. The direction of flow would be governed by pressure gradients, which are likely to be greater vertically than laterally for high level intrusives. Although unmetamorphosed mudstones are relatively impermeable, the presence of fracture or slatey cleavage and microscopic veinlets would render aureole rocks more generally permeable.

For intergranular diffusion, each constituent could move independently, the direction of movement governed by the activity gradient. Intergranular diffusion is governed by factors such as compositional and thermal gradients and the diffusion characteristics of the individual elements. However a simple chemical diffusion model does not explain all of the observations, for instance the numerous cases where elemental abundances are greater in the inner aureole than in either granite or background. The distribution of many of the elements e.g. K, Rb and Cs appears to be entirely consistent with the observed mineralogy. Thus Rb and Cs contents are high in rocks juxtaposed to the pluton and characterised by the main K mineral being a feldspar, but are appreciably lower than in portions of the aureole characterised by micas.

From the present work, it is apparent that the overall degree of metasomatic enrichment is dependent upon the composition of the associated granite. Higher levels of Rb, Cs and Li are found in the aureoles around those granites that themselves have the highest Rb, Cs and Li contents. All of the cupolas selected for the present study are either mineralised with stockworks or veins (Hemerdon, Cligga Head and Castle-an-Dinas), or are at or close to "Emanative Centres" of mineralisation (Dines, 1956). Beer and Ball (1986) described the distribution of Sn and W in these aureoles. They concluded that there was a general pattern in which an exo-contact zone of moderate Sn and W values extending to 20-50 m from the granite is succeeded outwards by variably higher metal levels to a distance of 500-800 m, beyond which the levels fell rapidly to background concentrations.

The presence of high trace alkali concentrations in zones with enhanced Sn and W suggests a similar origin, and hydrothermal transmission of late stage fluids soon after emplacement of the granites is suggested. The more extensive metasomatism in these aureoles than that observed the Tregonning-Godolphin and Lands End granites (Stone and Awad, 1988; Mitropoulos, 1982) may have resulted simply from greater fluid transport within the roof zone as compared to the walls of intrusions.

At Bosworgey, there is no evidence for systematic K metasomatism in the inner part of the aureole. All the aureole rocks have K concentrations close to background despite an appreciable concentration contrast between granite and background slate. It is possible that few sites for additional mica development were available and there was no further sink for K migrating outwards following granite emplacement. However, there is petrographic evidence of considerable recrystallisation of the micas in the aureole rocks, and although there is no increase in K content there is an appreciable increase in the Rb and Cs, which were presumably taken up by the recrystallising micas. Similarly, at Hemerdon the pelites are relatively depleted in K close to the granite yet the Rb and Cs contents are much higher than might be expected from the K content alone. In contrast, where the chemistry of the rock is suitable for growth of additional mica (as opposed simply to recrystallisation), then the K content can increase substantially and may even exceed the associated granite value. For instance the Hemerdon greenstones and the Redmoor pelites all show development of biotite and muscovite close to the contact and this is reflected in enhanced whole rock K values. Rb and Cs contents are also very high in the outer part of the inner aureole.

Statistically highly significant differences were observed for K_2O, Rb, K/Rb, Cs, K/Cs and Li, but not for Nap, between the weakly mineralised samples from Sparkwell and the other background sedimentary rocks from West Cornwall and St Columb (Table 3). Rb has been proposed as an indicator element for mineralisation by a number of workers (e.g. Al-Atia, 1975) in particular for relatively high temperature mineralisation, such as Sn and W veins, and in some cases it may indicate lower temperature Pb/Zn mineralisation.

CONCLUSIONS

Textural evidence for continuing metasomatic recrystallisation in sedimentary (and metabasaltic) contact aureole rocks surrounding granite cupolas in Southwest England is in accord with geochemical evidence provided by the alkali elements (in addition to Sn and W). Mobilisation of alkalis into the late-stage aqueous fluid from the granite, which then migrates through the aureole and allows these elements to become fixed during mineralogical changes, provides a plausible mechanism to explain the observed elemental distributions. Each granite cupola is of smaller volume than the alkali-enriched aureole, in which the concentrations of Rb and Cs, and in some cases Li and K also, may exceed those of the granite. The lateral extent of Cs enrichment may be the result of the Cs ion being more poorly hydrated than the other alkalis (Floyd, 1967; Stone and Awad, 1988) and consequently able to migrate with greater ease. It is also likely that this ion is less readily taken up into the 12-fold co-ordination site in micas than Rb. Finally, it is worth noting that in this study the use of ratios of diadochous elements (i.e. K/Rb, K/Cs) overcomes some of the problems in interpreting the geochemistry that arise from lithological variation among the aureole samples, provided that fluid flow rates are similar and similar mineralogical readjustment takes place. Where more homogeneous pelites are involved, raw Rb and Cs concentrations alone appear sufficient to indicate the proximity of granite.

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	Aureole			Background			Kruskaal-Wallis Test		Analysis of Variance	
	Mean	S.D.	Range	Mean	S.D.	Range	T	Prob.	F	Prob.
Sparkwell area compared with background										
		n=9			n=17					
Na2O	0.4	0.09	0.29-0.53	0.7	0.55	0.01-1.43	1.46	0.227	2.74	0.1104
K2O	4.95	0.41	4.37-5.77	3.91	1.1	1.53-6.14	6.881	0.009	7.43	0.0115
Rb	306	85	262-527	188	56	79-313	11.88	0.001	18.78	0.0002
Cs	67	46	36-180	20	37	nd-169	14.098	0.000	8.06	0.0089
Li	183	54	121-307	128	38	42-209	7.292	0.007	9.6	0.0048
K/Rb	139	19	91-154	175	26	91-203	12.233	0.000	13.26	0.0012
K/Cs	759	260	266-1127	3499	2852	169-11811	12.721	0.000	8.12	0.0091
Castle an Dinas aureole compared with background										
		n=9			n=7					
Na2O	0.5	0.22	0.25-1.00	0.85	0.7	0.1-1.8	0.63	0.427	1.845	0.1960
K2O	2.97	1.06	1.07-3.98	3.73	0.71	2.02-4.98	1.235	0.266	2.6	0.1290
Rb	215	58	151-297	201	52	161-313	0.07	0.791	0.244	0.6290
Cs	31	14	21-59	37	58	5-169	5.8	0.022	0.093	0.7450
Li	86	37	52-145	120	24	92-166	3.05	0.081	4.703	0.0480
K/Rb	113	32	58-164	159	35	91-196	5.67	0.017	7.28	0.0170
K/Cs	661	434	317-1549	2220	1984	169-6456	4.71	0.030	3.933	0.0670
Castle an Dinas Aureole <600m compared with background										
		n=5			n=11					
Na2O	0.63	0.211	0.48-1	0.65	0.61	0.01-1.8	0.927	0.335	0.005	0.9430
K2O	2.63	1.3	1.07-3.98	3.6	0.64	2.65-4.98	1.415	0.234	0.424	0.0590
Rb	213	66	151-297	207	52	160-313	0.029	0.836	0.036	0.8852
Cs	31	16	21-59	35	46	5-169	1.697	0.191	0.047	0.8310
Li	78	34	52-137	111	32	56-166	2.39	0.126	3.41	0.0860
K/Rb	98	30	58-126	149	33	91-196	6.497	0.011	9.207	0.0090
K/Cs	789	472	317-1376	1774	1671	169-6455	3.083	0.079	1.619	0.2240
Cligga Head aureole compared with background										
		n=7			n=7					
Na2O	0.31	0.26	0.06-0.94	0.85	0.7	0.1-1.8	1.995	0.169	4.06	0.0630
K2O	4.09	1.31	1.31-5.31	3.73	0.71	2.02-4.98	1.482	0.223	0.38	0.5449
Rb	299	85	188-439	201	52	161-313	5.179	0.023	6.44	0.0237
Cs	51	20	26-81	37	58	5-169	5.67	0.017	0.45	0.5129
Li	175	106	84-447	120	24	92-166	1.01	0.315	1.57	0.2311
K/Rb	114	32	58-170	159	35	91-196	5.179	0.023	6.46	0.0235
K/Cs	749	378	310-1290	2220	1984	169-6456	5.672	0.017	4.79	0.0462
Compares St Agnes aureole samples <800m with background										
		n=9			n=11					
Na2O	0.3	0.15	0.02-0.55	0.62	0.42	0.03-1.43	3.9	0.048	4.58	0.0463
K2O	4.11	3.53	2.5-6.1	4.02	1.31	1.43-6.14	0.013	0.909	0.02	0.8858
Rb	353	122	157-531	180	59	79-291	9.24	0.002	17.32	0.0006
Cs	85	70	n.d-178	8.7	5.8	n.d.-19	5.547	0.019	13.07	0.0020
Li	194	80	111-339	153	54	42-209	3.608	0.058	4.7	0.0439
K/Rb	105	41	57-161	184	13	161-203	13.577	0.000	37.61	0.0000
K/Cs	4986	1098	118-3938	7841	9169	1326-11311	5.37	0.020	0.4	0.5361
St Agnes aureole samples within 500m compared with background										
		n=6			n=14					
Na2O	0.35	0.115	0.19-0.39	0.53	0.42	0.03-1.43	0.206	0.650	0.86	0.3661
K2O	4.12	1.43	2.48-6.1	4.04	1.27	1.43-6.14	0.027	0.869	0.02	0.8884
Rh	394	98	237-531	200	86	79-435	9.313	0.002	19.56	0.0003
Cs	121	55	54-178	9.6	9.2	n.d.-35	12	0.001	57.17	0.0000
Li	226	79	153-339	132	41	42-209	8.333	0.004	12.42	0.0024
K/Rb	92	42	57-161	173	27	141.203	9.313	0.002	27.39	0.0001
K/Cs	376	265	118-707	9205	10879	1297-11311	12	0.001	3.83	0.0661
Bosworgey aureole to 1000m compared with background										
		n=26			n=11					
Na2O	0.198	0.17	0.022-0.243	0.62	0.42	0.03-1.43	9.756	0.002	19.18	0.0001
K2O	4.21	1.16	2.65-6.45	4.02	1.31	1.43-6.14	0.001	0.974	0.18	0.6750
Rb	381	196	120.29	180	59	79-291	15.9	0.000	10.92	0.0022
Cs	94	67	36-49	8.7	5.8	n.d.-19	22.56	0.000	17.69	0.0002
Li	148	111	n.d.-370	153	54	42-209	1.797	0.180	0.2	0.6622
K/Rb	108	49	48-193	184	13	161-203	11.943	0.001	25.6	0.0000
K/Cs	517	330	120-1340	7841	9169	1326-11311	21.952	0.000	17.2	0.0002
Bosworgey aureole samples to 300m compared with background										
		n=22			n=15					
Na2O	0.18	0.17	0.022-0.22	0.54	0.38	0.03-0.22	12.436	0.000	15.07	0.0004
K2O	3.82	0.8	2.65-4.58	4.62	1.52	1.53-6.39	4.168	0.041	4.37	0.0438
Rb	401	208	120-310	205	66	79-289	13.665	0.000	12.36	0.0012
Cs	102	69	46-77	19	20	n.d-51	22.109	0.000	20.33	0.0001
Li	90	12	n.d.-77	188	104	42-318	12.42	0.000	11.19	0.0025
K/Rb	93	36	48-123	176	12	161-183	22.695	0.000	93.67	0.0000
K/Cs	404	178	121-643	6054	8335	792-12690	26.053	0.000	10.24	0.0029

Table 3. *Summary statistics for the various aureole rocks compared to background. F is the mean square ratio (F Test). T is the Kruskal - Wallis test statistic. Prob. is the significance level of F and T. Significance levels >95% (<0.05 Probability) are emboldened. See text for further discussion.*

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