Read at the Annual Conference of the Ussher Society, January 1993

THE GEOCHEMICAL EXPRESSION OF STRUCTURAL DOMAINS BETWEEN MOUSEHOLE AND NEWLYN, SOUTH-WEST CORNWALL

M. K. DURKIN

Durkin, M. K. 1993. The geochemical expression of structural domains between Mousehole and Newlyn, south-west Cornwall. *Proceedings of the Ussher Society,* **8,** 99-104

Invasion by late-stage Rb-bearing fluids of the metasedimentary aureole between Mousehole and Newlyn appears confined to fracture-assisted conduits. Penetration was facilitated by a short-lived extensional regime, following block rotation of the metamorphic envelope above a diapirically emplaced cusp of the Lands End pluton. Radiogenic isotope studies show that more than one pulse of Rb-bearing fluids was involved. The exact timing of the fluid incursions is unclear, they have been putatively assigned to the interval between deformation phases D3 and D4.

M. K. Durkin. Department of Earth Sciences, University of Oxford, Parks Road, Oxford OX1 3PR.

INTRODUCTION

In the British Geological Survey Penzance Memoir, Sheets 351 Viand 358, Goode and Taylor (1988) observe that the history of faulting in the Penzance District is complex and that difficulty may be experienced in ascribing faults to specific phases of deformation. In the present contribution isotope and geochemical techniques are employed to establish a chronology for several minor episodes of crustal compensation between Mousehole and Newlyn. Evidence for sequential reorientation of the local stress field is discussed.

Several phases of fluid generation accompanied emplacement of the Cornubian Batholith. Fluid movement under these circumstances is often described as channelised advective flow. Orientation of the fluid pathways, largely a function of the prevailing structural template, may change with time. Such changes may be more easily recognised as discrete events if the various generations of fluid impose distinctive geochemical signatures. Geochemical expressions reflecting these events may be assessed in relation to post-magmatic adjustment of the metamorphic aureole.

GEOLOGICAL SETTING OF THE MOUNTS BAY AREA

The Mounts Bay coastline, (Mousehole-Newlyn-Penzance-Prussia Cove) displays a silt-shale olistostrome, conventionally assigned to the Mylor Slates of Famennian (Upper Devonian) age. Intercalated within the metasediments are highly fragmented remnants of dark green basic igneous bodies collectively referred to as greenstones. Granite contacts are exposed at two localities, between the Merlyn Rock [SW 469 258] and Mousehole Harbour [SW 470 264] and on St Michaels Mount [SW 515 300]. Late stage porphyritic intrusions are not uncommon.

Structural studies by Smith (1965), Stone (1966), Turner (1969), Rattey (1980), and Hobson and Sanderson (1983), identify six phases of deformation as occurring generally within the Devonian succession in south-west Cornwall. The deformation history may be subdivided into two broad categories, pre/syn- orogenic events (D1 to D3), and post- orogenic adjustments following emplacement of the Lands End pluton (D4 to D6). Regional Dl structures are widespread and characterised by recumbent isoclinal Fl folds, and a gently dipping south-south-easst S1 penetrative cleavage which accompanied greenschist facies metamorphism. Deformations due to D2 are well-developed between Porthleven [SW 628 255] and Gunwalloe [SW 54 224] but their presence between Mousehole and Newlyn is less than certain. No S2 cleavage has been identified as occurring in the terrain between these two localities. From Mousehole to Newlyn complex polyphase D3 structures associated with diapiric emplacement of the granite impose the dominant imprint. An intense penetrative S3 cleavage transposes earlier fabrics including bedding. Towards the Merlyn Rock, veins of fine-grained granite have utilised this structural framework to penetrate strongly hornfelsed metasediment; the granites themselves show no evidence of D3 deformation. Around Mounts Bay south-south-east-plunging folds (F4), and a sub-vertical axial planar cleavage (S4) are locally developed. Inter-tidal reefs below the Tavis Vor access steps [SW 474 267] show crushed folds constituting a north-west — south-east-trending zone a few metres in width, generated by a late compressive event (D4?) that post-dates emplacement of the granite. Strain gradients, localised within the zone, have greatly enhanced diffusion processes producing an array of pressure-solution stripes.

It would appear that relaxation of the D4 stress field had important implications for the Lands End pluton, it facilitated development of the main phase of sulphide ore mineralisation, i.e. in a direction sub-parallel to the north-north-west — southsouth-east-trending S4 cleavage. The significance of this orientation in regard to the development of mineralised veins was anticipated from other considerations by Moore (1975). Deformation phases D5 and D6 appear to be unrepresented in the Newlyn area.

On the western side of Mounts Bay the Upper Devonian succession is pervasively sheared, characterised by deformed, dark blue-grey, silt grade phacoids up to several metres in length, embedded in a slatey matrix. Many phacoids have undergone dextral rotation, a late distortion readily demonstrated in proximity to D3 structures. Such modification in orientation may be related to accomodation acquired in response to uplift during D3, the phase of deformation accompanying diapiric emplacement of the Lands End pluton. Within the olistostrome there is a marked macroscopic foliation defined by a north-north-west — south-south-east olistolith oriention. High angle S1 and/or S3 mesoscopic penetrative foliation is usually visible in hand specimen or minor outcrop. Small greenstone bodies between Mousehole and Tavis Vor display a conspicuous S3 foliation which in this locality dips gently in a direction varying between east and east-north-east.

METHODS

Samples were collected from a traverse around Mounts Bay for a geochemical reconnaissance study.* The samples included a suite of metasediments, metabasic igneous rocks, and contacts between them. Trace element analyses were carried out using standard XRF techniques. Samples for mass spectrometric analysis were prepared using conventional cation exchange column procedures and analysed on a

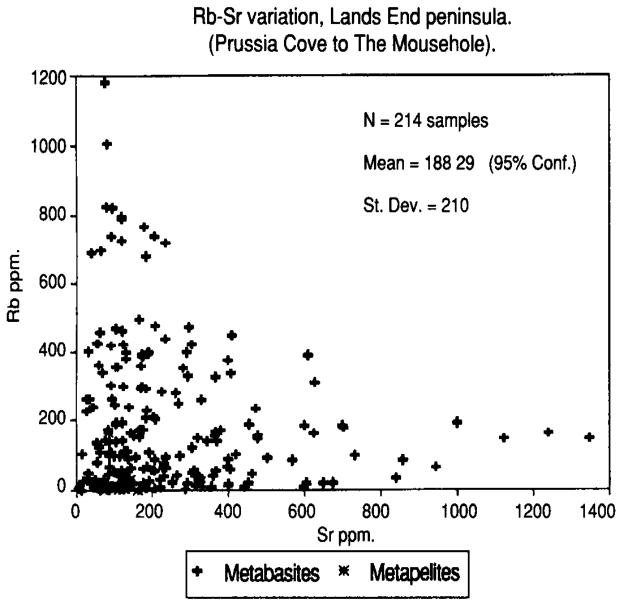


Figure 1: Rb-Sr variation for the Lands End peninsula from Prussia Cove to The Mousehole (Concentrations in ppm).

VG Isomass 54E fully automated mass spectrometer, using a single Faraday cup collector. Calibration of the instrument was achieved by the determination of 87Sr/86Sr for NBS987 over the period of the study. All results are corrected to a value of 0.71025. The Rb decay constant used in age calculation is the value recommended by the IUGS Subcommision for Geochronology (1.42 x 10^{-11} a^{-1}). Linear regression analyses for isochron plots were carried out using the Isoplot techique developed by Ludwig (1990 revision). Errors in the isochron ages and 87Sr/86Sr are given at the 95% confidence level.

SAMPLE SITE DESCRIPTION

Figure 1 shows a bivariate plot of Rb/Sr for 214 samples of a mixed suite of metabasites and metapelites collected during the survey. Two populations separated by a break in Rb concentration are apparent. Lithologies bearing elevated concentrations of Rb, i.e. above 600 ppm, appear confined to fracture zones or narrow channels conspicuous by an imprint of secondary water-rock interactions. Figure 2 illustrates in cartoon form the areal distribution of known conduits with elevated Rb/Sr ratios on the western side of Mounts Bay. Intense Rb enrichment is most easily demonstrated within Penlee Quarry but a total of four other localities have been identified as displaying, to a much reduced degree, this secondary phenomenon. The localities are:

1. South of Mousehole Harbour [SW 469 262], granite veins, a few centimetres in width, injected into metapelites parallel to the S3 cleavage. Metapelite just below the granite-metapelite interface is occasionally fringed by a pale cream alteration zone up to a centimetre in width, consisting of a fine-grained mosaic of interlocking quartz and plagioclase grains with subsidary hornblende, ilmenite and rare biotite. Zones show pervasive alteration characterised by high modal quartz. Millimetre-scale veins or channels with a quartz-sericite-illite mineralogy crosscut the S3 cleavage and overprint the early contact assemblage. The secondary alteration furnishes lithologies low in quartz and Ba, high in Rb, V, and Cr. The replacement process varies in intensity and rarely proceeds to completion, a better developed example occurs in the Penlee Quarry (see below).

2. A shore section below the Tavis Vor Hotel [SW 474 267] displays numerous metabasite-metapelite junctions. Minor granite veins of the type previously described from the southern side of Mousehole harbour are absent. Rb-bearing channels at Tavis Vor occur in similar mode to those at Mousehole, but are juxtaposed instead to metabasite-metapelite junctions. Poorly developed at this locality they are most easily located using geochemical techniques.

3. Penlee Quarry [SW 468 278] exposes a decametre scale metapelite-metabasite boundary active as a conduit for several episodes of Rb-bearing fluid penetration. This locality will be used as the type example in discussion of this phenomenon.

4. Newlyn. [SW 461 292] and therabouts. Several small (3 to 10 cm) Rb-bearing channels in metapelites adjacent to metapelite-metabasite contacts are to be found among terraces heavily overgrown with trees and foliage. A single example of a fractured metapelite-metapelite junction (3 cm in width) acting as a Rb-bearing conduit has been recorded from this locality.

5. Tredavoe [SW 455 291]. Temporary section north of village adjacent to disused metabasite quarry used as local authority storage area. Small (cm-scale) Rb-bearing conduits at metabasite-metapelite boundaries. Bulk chemical trends across the boundary are similar to those within the Penlee Quarry.

DISCUSSION OF THE RESULTS

The metabasite-metapelite boundary, Penlee Quarry

Large-scale channelised advective fluid-flow brought significant increases in Rb concentration at a metabasite-metapelite boundary on the upper levels of Penlee (Gwavas) Quarry near Newlyn. Here a zone at the contact between metabasite and metapelite, ca. 20 m in width, acted as a conduit for the passage of Rb-bearing fluids. The Penlee conduit system is unique both in respect of its overall dimensions and in the evidence it affords for more than one phase of fluid penetration. Fluid passage was fracture-assisted in the early stages and confined to the first few metres of metapelite.

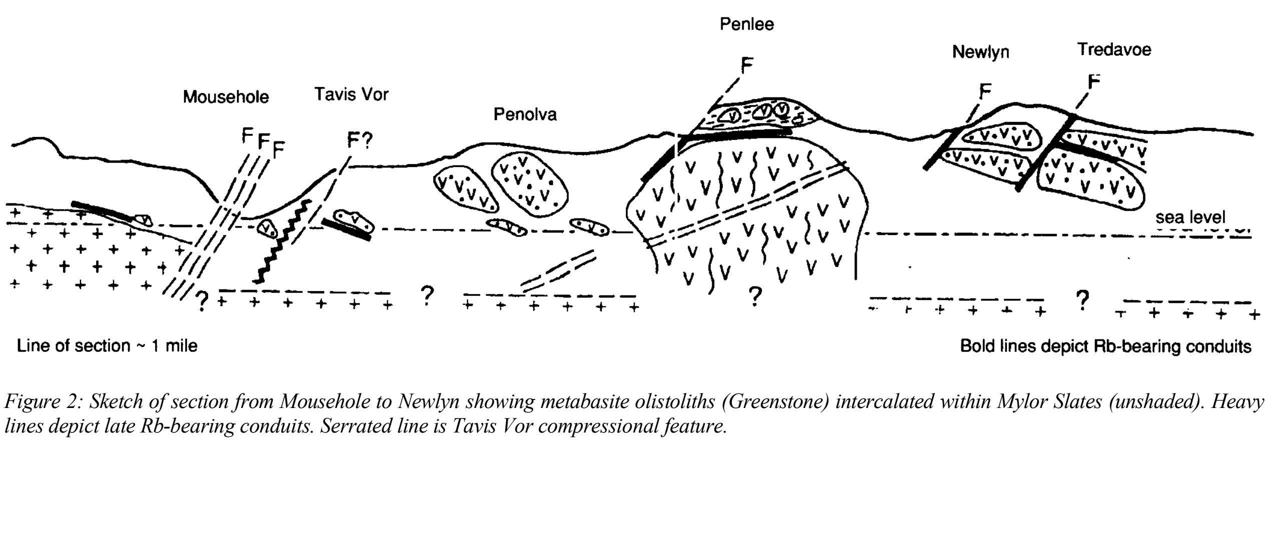


Figure 2: Sketch of section from Mousehole to Newlyn showing metabasite olistoliths (Greenstone) intercalated within Mylor Slates (unshaded). Heavy dark lines depict late Rb-bearing conduits. Serrated line is Tavis Vor compressional feature.

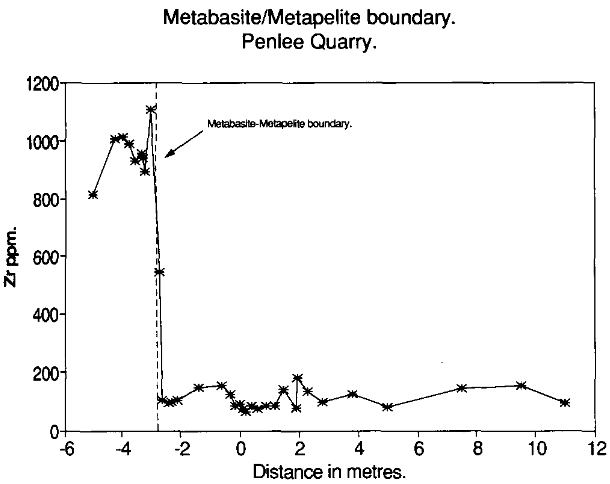


Figure 3: Rb profile across the metabasite-metapelite boundary in Penlee Quarry. See text for discussion.

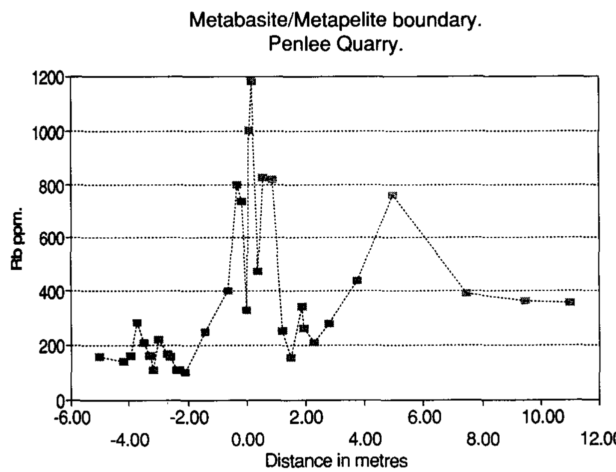
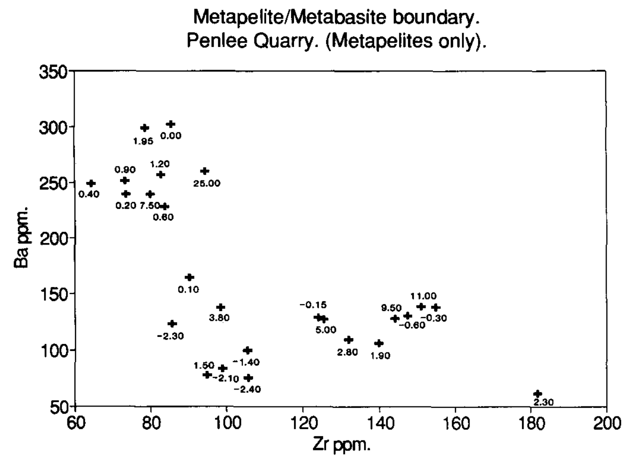


Figure 4: Zr profile across the metabasite-metapelite boundary in Penlee Quarry.

Quartz pods mark a distinctive but intermittent lithological horizon close to the undulatory contact between metabasite and metapelite. Deposition of the quartz is attributed by the author to fluid impounding at the boundary. Quartz at this horizon contains two-phase aqueous inclusions. Primary inclusions are generally small (10 to 30μ), situated in clusters, and of low to moderate salinity (2 to 10 eq. wt. % NaCl). Secondary inclusions tend to occur in trails. Fluid inclusion homogenisation temperatures (TH) derived from the primary inclusions in the quartz afford (minimum) trapping temperatures (uncorrected for pressure) showing two maxima , 260°C (±22) and 320°C (±27). Geochemical evidence demonstrates a lack of affinity between fluids initiating quartz deposition and those involved in the Rbbearing events.

The timing of the first infiltation by Rb-bearing fluids is unclear but since the infiltration process overprints a strong S3 cleavage the initial influx is unlikely to have occurred prior to the cessation of D3 movements.

Figure 3 depicts a Rb profile across the Penlee metabasite-metapelite conduit system, the zero point signifying the quartz-bearing lithology used as a marker horizon in the field. The exact point of contact between metabasite (high Zr) and metapelite (low Zr) is obscure upon field observation, yet can be determined clearly by inspection of the Zr concentration across the profile (Figure 4). Figure 3 demonstrates that Rb concentrations peak at two positions, coincident with the sites of early fracture development in the body of



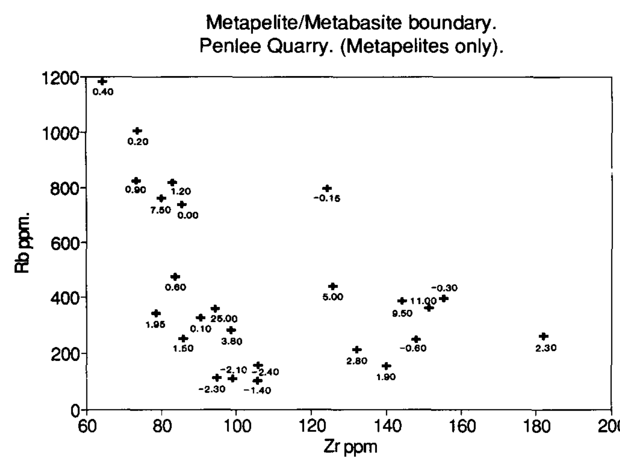


Figure 5a and 5b: Bivariate plots of Ba vs Zr and Rb vs Zr for metapelites within the Rb-bearing conduits. Numerals adjacent to each sample are reference points within the boundary sequence. See figures 3 and 4 to aid location.

the metapelite. A halo of Rb-enriched metapelite, about a metre in width, surrounds each fracture plane, emphasising the relatively impervious nature of the medium. The two former fluid channels each with elevated levels of Rb, coincide with a change in mineralogy from quartz-hydrothermal biotite-(magnetite+sericite) to an assemblage containing mixed K-bearing dioctahedral micas.

Rapid changes in bulk chemistry are a consistent feature of the boundary zones, which reveal a complex trace element disposition. A bivariate plot of Rb (mobile) against Zr (immobile) and Ba (mobile) against Zr (immobile) illustrate the differing response of two elements to mobilisation. (Figure 5)

Rb enrichment within the conduit may arise from one or any combination of two or more of the following mechanisms:

(1) Apparent enrichment arising from volume change.

(2) Dehydration and decarbonation of the metapelite.

(3) Hydrothermal processes arising from emplacement of the granite.

From studies of the bulk chemistry it seems untenable that in-situ volume change of the metapelite would be sufficient to account for the observed enrichment in Rb. The lack of significant change in Zr concentration (Zr is considered to be immobile) across the boundary zone implies volume preservation. Dewatering of the metapelite during contact metamorphism is also thought unlikely as the source for Rbbearing fluids. Other studies, e.g. Walther and Orville (1982), have shown that progressive metamorphism, through dehydration and decarbonation, produces about 2 mol of fluid per kilogram of

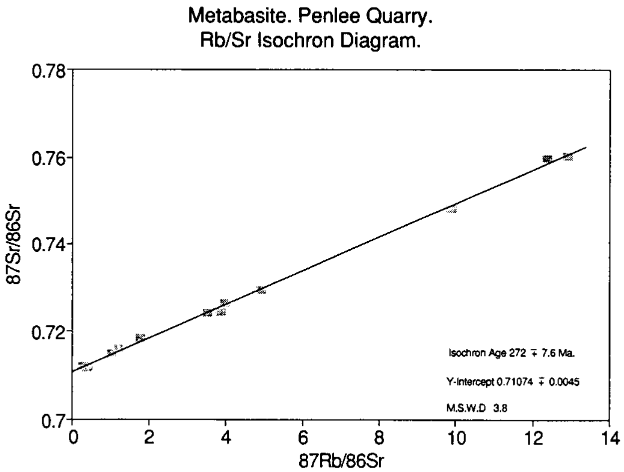


Figure 6: Isochron diagram for the Penlee Quarry metabasite.

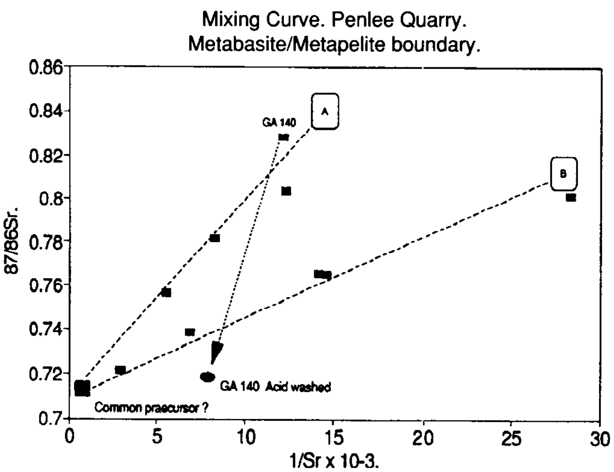


Figure 7: Mixing array diagram showing the presence of two phases of incursion by Rb-bearing fluids.

pelite. It is likely that the greater part of such a volume of fluid were it to have been produced, was lost during an earlier deformation phase, certainly before the metapelite came into close proximity with the Cornubian granite.

Protracted evolution of a granitic magma, fractionating quartz, K-feldspar, plagioclase and biotite has been cited elsewhere in other circumstances as a likely source of Rbbearing fluids, e.g. Gerstenberger (1989). The Cornubian magma is postulated by the present author to have supplied late-stage Rb-bearing fluids envisaged as invading secondary fractures developed within the metabasite-metapelite boundary zone in Penlee Quarry.

Radiogenic isotopes afford, in theory, an opportunity to date fluid incursions and they can also be sensitive indicators of fluid source. Results of Rb/Sr and 87Sr/86Sr signatures from metabasite in the quarry and from a traverse across the metabasite-metapelite boundary are given in Table 1. Metabasites in the quarry, away from the altered boundary, yield a re-set age of 272 7 Ma. (Figure 6). This date is in reasonable agreement with the (re-set) date of 268 ± 2 recorded by Darbyshire and Shepherd (1985) for the Lands End megacryst granite. Although the MSWD for the Penlee quarry samples marginally exceed that acceptable for an isochron (Moorbath *et al.,* 1986 employ MSWD < 2.5 to distinguish isochrons from errorchrons) it is considered here that the data is meaningful. The scatter is probably attributable to a lack of homogenisation within the metabasite rather than later alteration.

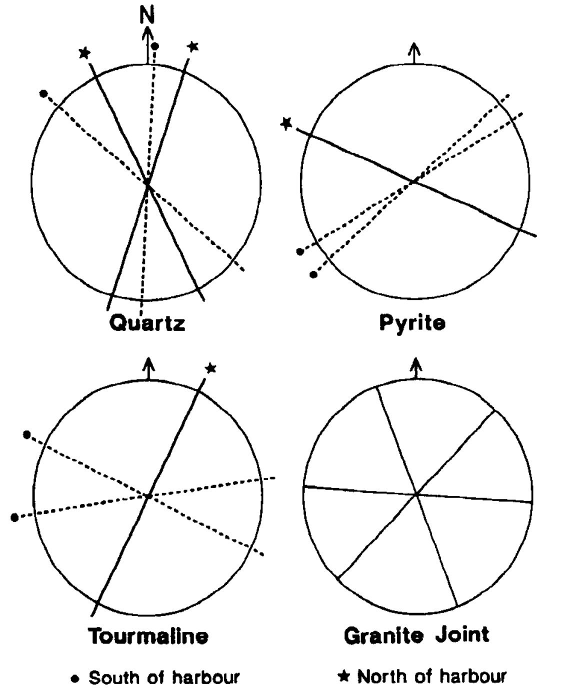


Figure 8: Principal orientation directions for minor fractures containing quartz, sulphides (mainly pyrite), and quartz-chlorite tourmaline assemblage on the foreshore around Mousehole harbour.

See Verschure *et al.,* (1990) for an introduction to the concept of isotopic equilibrium distance in metamorphic rocks.

By contrast the boundary metasediments define an errorchron of 226 ± 38 Ma. where the Rb-Sr data points display considerable scatter. Interpretation of the isotopic data is aided by consideration of a simple mixing array, Figure 7, which confirms that fluid flow at the boundary was not confined to a single event. Two arrays (A and B) intersect at a point approximating to the composition of a common praecursor, and the errorchron date therefore derives from open system behaviour during several perturbations of the Rb-bearing system. Leaching experiments to purge Rb and Sr isotopes from the boundary metasediment with 0.1M HCL furnished a residue of composition 87Sr/86Sr = 0.72212. The result confirms that cations of Rb and Sr are in a readily exchangeable form after passage of the Rb-bearing fluids , and that the residue might not be overly different in Sr isotope composition from an inferred praecursor. Loosely bound elements may therefore be symptomatic of unequilibrated alteration by fluidised processes.

In summary, exact dating of the various phases of fluid incursion is beyond reach. The radiogenic isotope data merely permit one to state that an open system prevailed. Late-stage Rb-bearing fluids utilised the fractured boundary zone as a conduit during separate events, probably after the metabasite itself had been isotopically re-set. An indication of a difference in age between overprinted metabasite in the mass of the quarry and fluid pathways within the boundary zone is helpful, possibly the best that can be achieved at present.

MINOR FRACTURE SETS IN THE VICINITY OF MOUSEHOLE HARBOUR

The extent to which fluid rock exchange affects a Rb-Sr isotope system will be determined by fluid migration pathways and by the scale over which migration occurs. It has been demonstrated that effective Rb-bearing fluid migration in the metapelites was limited to fracture-assisted routes and, less importantly, to preferred cleavage directions. Both fracture and cleavage are constrained by orientation of the major components of a prevailing stress system. Localised variation, in time and space, of the

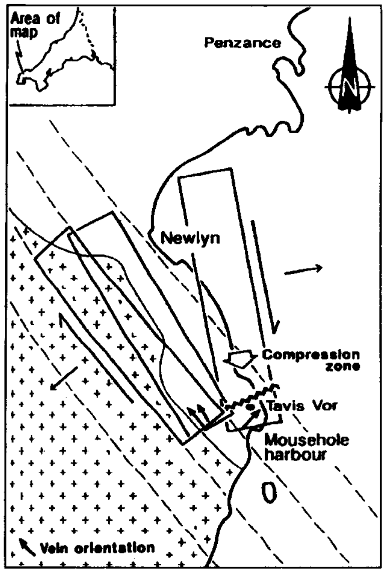


Figure 9: Cartoon showing postulated movement of a block of metasediment between Mousehole and Newlyn, probably in a time interval between deformation phases D3 and D4. (See text for discussion.

orientation of an applied stress should therefore find ready expression in the field.

The small, millimetre-scale, sub-vertical, mineralised veins, up to several metres in length, that occur throughout the metapelite succession from Mousehole to Newlyn show four dominant mineral assemblages; quartz, sulphides (usually pyrite), a tourmaline-chlorite association, and a muscovite-filled vein with a quartz selvedge.

Figure 8 depicts the orientation of three vein sets from localities on either side of Mousehole harbour. Fracture orientations differ north and south of the harbour for all three vein types *. The mica-filled vein type is limited in its distribution north of the harbour and cannot be used for comparison. Also shown are granite joint orientations which reflect a valid expression of the regional stress system. The dominant set of quartz veins south of the harbour (n=134) are parallel or sub-parallel to the intense, flat-lying, S3 cleavage which here is axial planar to north-west-plunging F3 folds. A subsidiary, minor set of veins (n=27), align with what may be the nearly coaxial regional S1 foliation, now largely obscured by D3 events. Both early quartz-filled fractures are likely associated with movement initiated soon after emplacement of the granite. When quartz vein-pair orientations from the south are transposed to the north side of the harbour and the orientations from the two areas compared, then it is seen, that along with the cleavage orientation, the northern pair (n=87 and n=31) have undergone a 15 to 20 degree rotation. Neither set of quartz-filled veins, either side of the harbour, appear geometrically related to the regional stress field, i.e. to align with orientations of the principal granite joints.

Vein re-orientation is inferred to have taken place in a clockwise sense. Interpretation of the evidence of phacoid orientation shows that many have undergone dextral rotation. Rotation may have been induced during emplacement of the granite, alternatively it may have developed during cooling of the pluton and its metamorphic carapace. The founding mechanism for rotation is not a matter for contention, the direction of block motion arising as the result of either updoming or contraction might be similar irrespective of the mechanism of activation.

Pyrite-filled, sub-vertical, mm-scale ribbon veins post-date the quartz veins and traverse carbonaceous metapelites on both sides of Mousehole harbour. Trace element and petrographic analysis suggests that the sulphide minerals have been remobilised. They commonly occur as vestigial or skeletal remnants. Fabric analysis reveals that sulphides ramify away from the sub-vertical extensional structures, their main habitat, into adjacent matrix cleavage domains.

TABLE 1

Sample No.	Rb ppm.	Sr ppm.	87Rb/86Sr	87Sr/86Sr
Penlee Quarry Metabasite.				
GA 1	95.7	155	1.7836	0.71863 + 5
GA 2	446	104	12.3801	0.75994 + 5
GA 2R	467	105	12.9112	0.76036 + 1
GA 6	13	95.1	0.3957	0.71205 + 5
GA 7	31.1	74.8	1.2039	0.71603 + 5
GA 8	141	105	3.8998	0.72443 + 5
GA 11	420	305	3.9929	0.72654 + 5
GA 26	107	88.4	3.5388	0.72425 + 5
GA 28	19.7	151	0.3778	0.71166 + 5
GA 34	356 .0	104	9.8821	0.74827 + 2
GA 102	17.3	176	0.2839	0.71218 + 5
GA 103	19.8	55.9	1.0255	0.71485 + 5
GA 114	298	175	4.9411	0.72963 + 2
Metabasite-Metapelite Boundary. Penlee Quarry				
GA 232	760	179	12.2854	0.75615 + 4
GA 236	260	332	2.2656	0.72134 + 5
GA 237	338	68.6	14.3523	0.76513 + 3
GA 241	826	81.2	29.7079	0.80382 + 6
GA 140	1005	82.2	35.804	0.82801 + 5
GA 246	799	120	19.3226	0.78146 + 5
GA 249	166	144	3.335	0.73892 + 5
RH 195	258	341	2.1958	0.72154 + 3
RH 190	338	70.4	13.9939	0.76533 + 3
GA 213	261	35.3	21.6465	0.80171 + 4

On the south side of the harbour small pyrite veins (n=141 and N=34) may reach 4 or 5 m in length. Clearly structures derived from an extensional regime, they lie approximately west-south-west — east-north-east near to the orientation of a major granite joint. Comparison of the pyrite veins on either side of Mousehole harbour, shows that the vein pair to the south, have coalesced into a single fracture set to the north. A rotational transposition of about 60° on passing across the harbour has also been observed. Using arguments similar to those employed for the quartz vein sets, rotation of the stress field during this period is interpreted as being of a clockwise sense. Pyrite veins to the north of the harbour crudely bisect a granite joint orientation and are not aligned with the modern regional stress field.

Tourmaline-chlorite veins with minor quartz (width 2 to 4 mm, length 2 to 3 m) are moderately common on both sides of the harbour, they are less obviously structures arising from simple extension. To the south a pair of closely aligned tourmaline-bearing veins (n=59 and n=24) cross-cut cleavage and earlier vein sets alike.

North of the harbour a single tourmaline vein set (north-north-west — south-south-east) (n=41) has undergone rotational transposition, by as much as 90°, when compared with counterparts on the south side. The magnitude of rotation of this vein set may have been enhanced by distortions arising from proximity to the compression zone, (Figure 9). The orientations of both tourmaline vein sets, north and south, are not aligned with major granite joint plane directions. Tourmaline veins that invade metapelite at high levels in Penlee Quarry, lie in an orientation sub-parallel to those on the north side of Mousehole harbour. Tourmalinisation within the Penlee metasediments is more extensive and more pronounced than that observed on foreshore exposures. In the quarry, tourmalinisation often adopts invasive modes, it utilises minor extensional structures where it overprints existing wall-rock minerals such as biotite or feldspar, and less frequently penetrates the S3 where it replaces matrix biotite. Significantly tourmalinisation cross-cuts the Rb-bearing conduits at metabasite-metapelite boundaries both in the quarry and on foreshore exposures.

CONCLUSIONS

Examination of the three minor vein arrays suggests that early quartz mineralisation accompanied or closely followed diapiric emplacement of the granite. Quartz emplacement was promoted by fluid incursion along fractures sub-parallel to the S3 cleavage orientation. At some later stage, questionably associated with, D4 following relaxation of the regional hydraulic overpressure, stress-relief fracturing constrained fluid emission to facilitate formation of the main sulphide ore vein arrays which, in southwest Cornwall, follow a structural template generally aligned with the granite joint directions.

In an interval of time between emplacement of the Lands End pluton (D3) and development of the main ore veins (D4) a localised perturbation of the regional stress-field activated the Rb-bearing conduits and produced an evolving array of minor extensional structures between Mousehole and Newlyn.

The Rb-bearing conduits above Penlee Quarry were initiated, post D3, by fracture: an east-west oriented extensional regime clearly persisted across a block of aureole rocks from Mousehole to Newlyn. Extension followed emplacement of the granite, but preceded formation of the cross-cutting tourmaline veins.

In the vicinity of Mousehole harbour, minor quartz and pyrite vein structures also reflect this history of extension, and progressive stress-field re-orientation, during a period of post-orogenic relaxation. These minor forms of stress-relief fracturing can be demonstrated to have undergone sequential rotation of orientation across Mousehole harbour. They, together with the tourmaline veins, accommodated movements following diapiric uplift of the metasedimentary envelope on the shoulders of the rising granite pluton.

The evidence suggests that a block of the metasedimentary envelope, from Mousehole to Newlyn, underwent progressive, constrained, dextral rotation. Extensional fracture systems developed within the enclosed block of the metamorphic envelope, as the result perhaps of incoherent movement. Rotation probably commenced soon after diapiric emplacement of the granite, continued as the pluton cooled, and was concluded before regional sub-vertical joints developed in the granite and its hornfelsed envelope of metamorphic rocks. Intrusion by cross-cutting tourmaline veins post-dates activation of the Rb-bearing conduits and precedes establishment of the regional joint systems. Whilst it is possible to interpret a zone of modified F3 folds on the foreshore below the Tavis Vor Hotel as a crush zone of D4 age, its structural complexities are at variance with simple east-west compression. Alternatively the crush zone could be interpreted more as an expression of impediment to free movement of the toe of a rotating Mousehole-Newlyn block. Figure 9 depicts a cartoon suggesting a simplistic reconstruction of events.

An extensional regime that promoted activation of the Rb-bearing conduits and development of the minor quartz and pyrite-filled structures north of Mousehole harbour was short-lived. The co-axial nature of later cross-cutting invasive tourmaline veins at Penlee and north of Mousehole harbour shows that both sets are founded upon a similar structural template. In contrast to the earlier quartz and pyrite structures, tourmalinisation conveys the impression of having been injected into lithologies under compression. A unified compressional regime probably existed within the Mousehole-Newlyn block at that time but it is not necessary to conclude that rotation of the stress field or the block had ceased.

Rotation of the (Mousehole-Newlyn) block terminated to the south, apparently abutting against a structure concealed beneath Mousehole harbour. In this vicinity a dramatic change in attitude of the granite boundary is thought probable. South of Mousehole harbour granite sheets dip gently seaward at about 5°. North of Mousehole harbour the granite boundary runs inland, striking north-east, it probably dips south-eastwards at a high angle. A splayed fault, downthrow to the east, runs north-north-east inland at Mousehole.

It is interesting to speculate that a block of the metamorphic envelope, emplaced above a granite cusp, underwent rotation, a rotation initiated by relaxation of the stress field following diapiric emplacement of the Lands End pluton. Dextral movement along a concealed fault may have assisted in initiating movement. The compression zone, a series of crush folds, just north of Mousehole harbour, is a conspicuous feature. A reconstruction involving block movement might realistically interpret these crush folds below the Tavis Vor Hotel locality as a ruck in the metasedimentary carpet, its southward toe abutting against gently dipping granite below sea level south of Mousehole.

Further reconnaissance is needed to locate other Rb-bearing channels in the Mounts Bay area beyond Newlyn. Their existence is to be anticipated if, as seems likely, the blanket of metasediments and intercalated metabasic rocks underwent brittle fracture and fragmented after emplacement of the Lands End pluton.

ACKNOWLEDGEMENTS

The author would like to express his thanks to Dr. R.T.Taylor and Dr.R Clayton for helpful discussions on the geology of the area around Penzance. The manuscript has been greatly improved by the attentions of a careful reviewer, Dr. D.P.F. Darbyshire.

* The full data sets, too detailed for inclusion here, are available on application to the author.

REFERENCES

DARBYSHIRE, D.P.F. and SHEPHERD, T.J. 1985. Chronology of granite magmatism and associated mineralisation, SW England. *Journal of the Geological Society of London,* **142**, 1159-1177

GOODE, A.J.J. and Taylor, R.T. 1988. Geology of the country around Penzance. *Memoirs of the British Geological Survey*. Sheets 351 and 358.

GERSTENBERGER, H. 1989. Autometasomatic Rb enrichments in highly evolved granites causing lowered Rb-Sr isochron intercepts. *Earth and Planetary Science Letters,* **93**, 65-75

HOBSON, D.M. and SANDERSON, D.J. 1983. Variscan deformation in south west England. In: *The Variscan Fold Belt in the British Isles.* 108-129 Ed: P.L.Hancock. Adam Hilger Ltd.

LUDWIG, K.R. 1990. Isoplot. A plotting and regression program for radiogenicisotope data, for IBM-PC compatible computers. *Open-File Report 88-557. United States Geological Survey*.

MOORBATH, S., TAYLOR P.N. and JONES, N.W. 1986. Dating the oldest terrestrial rocks-Fact and Fiction. *Chemical Geology,* **57**, 63-86

MOORE, J.McM. 1975. A mechanical interpretation of the vein and dyke system of the SW England orefield. *Mineralium Deposita,* **10**, 374-388

RATTEY, P.R. 1980. Deformation in south west Cornwall. *Proceedings of the Ussher Society,* **5**, 39-43

SMITH, M.A.P. 1965. Repeated folding between Hayle and Portreath, Cornwall. *Proceedings of the Ussher Society,* **1**, 170-171

STONE, M. 1966. Fold structures in the Mylor Beds near Porthleven Cornwall. *Geological Magazine,* **103**, 440-459

TURNER, R.G. 1969. *The influence of granite emplacement on structure in SW England.* Unpublished PhD Thesis, University of Newcastle-upon-Tyne.

VERSCHURE, R.H., MAIJER, C. and ANDRIESSEN, P.A.M. 1990. Isotope age determinations in South Norway: II. The problem of errorchron ages from Telemark rhyolites. *Norges Geologiske Undersokelse. Bulletin 418.*

WALTHER, J.V. and ORVILLE, P.M. 1982. Volatile production and transport in regional metamorphism. *Contributions to Mineralogy and Petrology,* **79**, 252-257.