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The Rb-Sr isochron age of the Kennack Gneiss and its bearing on the age of the Lizard Complex, Cornwall

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SUMMARY: An acid vein from a borehole in the Kennack Gneiss has given a whole-rock Rb-Sr isochron age of 369 ± 12 Ma. This is interpreted as a metamorphic age recording the time of emplacement of the Lizard Complex. This emplacement in late Devonian times was part of an early phase of the Hercynian Orogeny which also affected the Gramscatho 'Series' of S Cornwall.

The Kennack Gneiss is the most varied and enigmatic rock group of the Lizard Complex. It consists of a series of interbanded acid and basic gneisses that occur within and perhaps largely beneath the peridotite on the E coast of the Lizard between Kennack and Landewednack Church Cove, inland and rarely on the W coast (Flett 1946). The lithology varies from migmatitic basic gneiss with acid folia a few cm thick to acid and basic rocks interlayered on a scale of several metres. They are high-grade metamorphic rocks with foliation, where seen, parallel to the contact with peridotite. Many hypotheses have been advanced regarding the nature of the Kennack Gneiss. Bonney (1877) thought it was composed of Archean migmatites, pre-dating peridotite intrusion, while Flett (1946) believed it to consist of composite acid and basic intrusions post-dating the peridotite, and Sanders (1955) suggested it was an anatectite associated with overthrusting of hot peridotite.

The Lizard Complex is now considered to be an ophiolite (see discussion in Styles & Kirby 1980 and many authors, this Part) but there is no general agreement regarding the origin of the Kennack Gneiss. Bromley (1979) favoured composite acid and basic intrusions followed by intense later deformation, while Styles & Kirby (1980) preferred migmatization and anatexis of Old Lizard Head metasediments and Landewednack hornblende schists. However, a feature common to both models and most pertinent to the discussion in this paper is that all recent workers have considered the Kennack Gneiss to be formed late in the evolution of the Lizard Complex.

When an ophiolite model is considered, two main events need to be identified, the crystallization of the mafic and untramafic rocks in the oceanic setting and the emplacement of the ophiolite on to the continental margin. The final emplacement of the Lizard Complex over the Meneage Mélange occurred at low temperatures (Barnes & Andrews 1984), but within the Lizard a widespread phase of high temperature thrusting has been recognized during which the sub-units of the ophiolite were assembled, prior to final emplacement (Styles & Kirby 1980). It is probable, however, that these apparently distinct phases were part of one progressive evolutionary sequence of emplacement, as described by Jamieson (1981) for the St Anthony Complex, Newfoundland. The high grade metamorphism and possibly the generation of the Kennack Gneiss took place during the high temperature thrusting period.

In spite of careful mapping and the efforts of several workers, the age of the Lizard Complex has remained somewhat uncertain. Previous radiometric dating of rocks of the Lizard Complex has been carried out by Dodson (1961) and Miller & Green (1961*a,b*), who obtained mineral ages, mostly by the K-Ar method, ranging from 355–499 Ma (early Carboniferous–early Ordovician). The exact significance of some of these ages is rather uncertain, but it is possible that some younger ones are the result of partial argon loss during tectonic and/or thermal events.

The Rb-Sr whole-rock method used in this study is less likely than methods used previously to have been re-set by later Hercynian folding and low grade metamorphism, and should give a more reliable age.

Sample location

The samples selected for Rb-Sr dating consist of core from a depth of *c.* 113 m in the I.G.S. borehole at Kennack Sands (I.G.S. boreholes 1980). The borehole cores show peridotite with thin basic gneiss layers to a depth of 45 m, variable acid and basic gneisses to a depth of 135 m and, below this, interbanded peridotite and gneisses to the base of the hole at 155 m. Around the depth where the specimens were taken are interlayered acid and basic gneisses with thin serpentinized peridotites (bastite serpentine), 1–2 m thick that are possibly tectonically detached blocks, as seen in coastal outcrops. The particular layer sampled was a fairly homogeneous vein of acid gneiss 4.5 m thick with a few basic schlieren up to 5 cm thick. The lower part of the vein was fractured and somewhat altered and hence only the upper 1.5 m was sampled. Ten samples of core approximately 50 mm in diameter and 40 mm long were taken from this zone for the study.

Petrography

The samples are all broadly similar when examined in thin section, consisting largely of quartz, feldspar

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and biotite with minor epidote, apatite, zircon, and chlorite after biotite. Biotite makes up *c.* 5% of the rock but in strongly banded varieties may vary from 2–10%. The biotite is usually fresh except in specimens E 52514 and E 52521 where there is extensive alteration to chlorite. [E numbers refer to specimens in the English sliced rock collection of the Institute of Geological Sciences.] The proportion of K-feldspar ranges from *c.* 10–30%, and always appears to have formed at a late stage, surrounding the other minerals and particularly sodic plagioclase which it has clearly partly replaced. In many of the K-feldspar rich layers it occurs as porphyroblastic perthites up to 3 mm diameter, some with marginal myrmekitic patches. Quartz and sodic plagioclase occur in roughly equal proportions, each 30–35%. All the specimens contain some large crystals of sodic plagioclase up to 2.5 mm, while those in the groundmass are usually less than 0.5 mm. The larger crystals have well developed compound twinning, are clearly zoned, commonly have their centres saussuritized, and are thought to be relic phenocrysts.

All the specimens have a well developed foliation, shown particularly by parallelism of biotite flakes and an elongation of quartz and feldspar grains along the foliation. The relic phenocrysts have a fairly random distribution, and are only vaguely aligned parallel to the foliation. Zones of granulation along the foliation indicate late shearing. Samples E 52513 and E 52515 are cut by thin calcite veins.

Six samples were analysed for major elements by electron excitation X-ray fluorescence spectrometry (beta-probe), described by Roberts & Davis (1977). Only a small variation was observed from sample to sample and the mean and range of the analyses is given in Table 1. They are of granitic composition, with $Na_2O \simeq K_2O$.

TABLE 1: *Chemical composition of acid Kennack Gneiss vein*

	Mean	*Range*
SiO_2	72.48	71.74–73.65
TiO_2	0.23	0.20–0.29
Al_2O_3	14.41	13.50–14.81
$Fe_2O_3^*$	1.68	1.49–2.05
MgO	0.99	0.91–1.07
CaO	1.60	1.20–1.78
Na_2O	4.03	3.36–4.34
K_2O	3.79	3.41–4.41
P_2O_5	0.07	0.06–0.08
H_2O^-	0.57	0.45–0.72
LOI	0.57	0.45–0.72
Total	99.94	

* Total iron as Fe_2O_3.
LOI = Loss on ignition.

TABLE 2: *Rb-Sr results for the Kennack Gneiss*

Sample no.	ppm Rb*	ppm Sr	$^{87}Rb/^{86}Sr$ (± 0.5%)	$^{87}Sr/^{86}Sr$ (± 0.01%)
E 52512	91	360	0.733	0.70817
E 52513	95	373	0.735	0.70826
E 52514	94	369	0.734	0.70829
E 52515	98	345	0.824	0.70852
E 52516	94	360	0.749	0.70819
E 52517	87	321	0.778	0.70834
E 52518	93	308	0.879	0.70878
E 52519	102	234	1.260	0.71075
E 52520	121	201	1.745	0.71349
E 52521	85	196	1.256	0.71137

* Approximate values only.

Rb-Sr analyses

Rb/Sr ratios were determined by XRF analysis using a Phillips PW 1450 automatic spectrometer. Strontium was separated by standard ion exchange techniques and the isotopic composition was measured using a VG Micromass 30 mass spectrometer. Replicate analyses of the Eimer and Amend strontium isotope standard made during the period that the samples were analysed gave a mean of 0.70805 ± 4 (1 sigma); no normalization of sample ratios was considered necessary. The results of the analyses are shown in Table 2 where the analytical errors, quoted as 1 sigma, are based on the overall reproducibility of replicate samples in the I.G.S. laboratory.

Discussion of results

When the data for all ten samples of the acid material are regressed using a least squares calculation based on that of York (1969) the calculated parameter MSWD has a value of 6.3. This indicates that the scatter of data points about the best fit line is greater than can be attributed to the quoted analytical errors alone (Brooks *et al.* 1972) and the excess may be attributed to geological factors. If samples E 52514 and 21, in which the biotite is chloritized and E 52513 and 52515 which contain calcite veins are rejected, the remaining six points define a straight line within analytical errors (MSWD = 1.3, Fig. 1) and indicate an age of 369 ± 12 Ma (2 sigma error, $\lambda^{87}Rb = 1.42 \times 10^{-11}\ a^{-1}$) and an initial ratio of 0.7042 ± 2.

These results are not significantly different from those derived from all ten points, (376 ± 28 Ma, 0.7042 ± 4) but are far more precise and it is clear that, whichever regression is preferred, these samples are recording an age of around 370 Ma.

It is possible that the granite vein originated as an anatectite during the high grade metamorphism. However, the petrographic examination suggested that it has undergone extensive recrystallization and possibly potassic metasomatism (as indicated by the alteration of sodic plagioclase to potassium feldspar)

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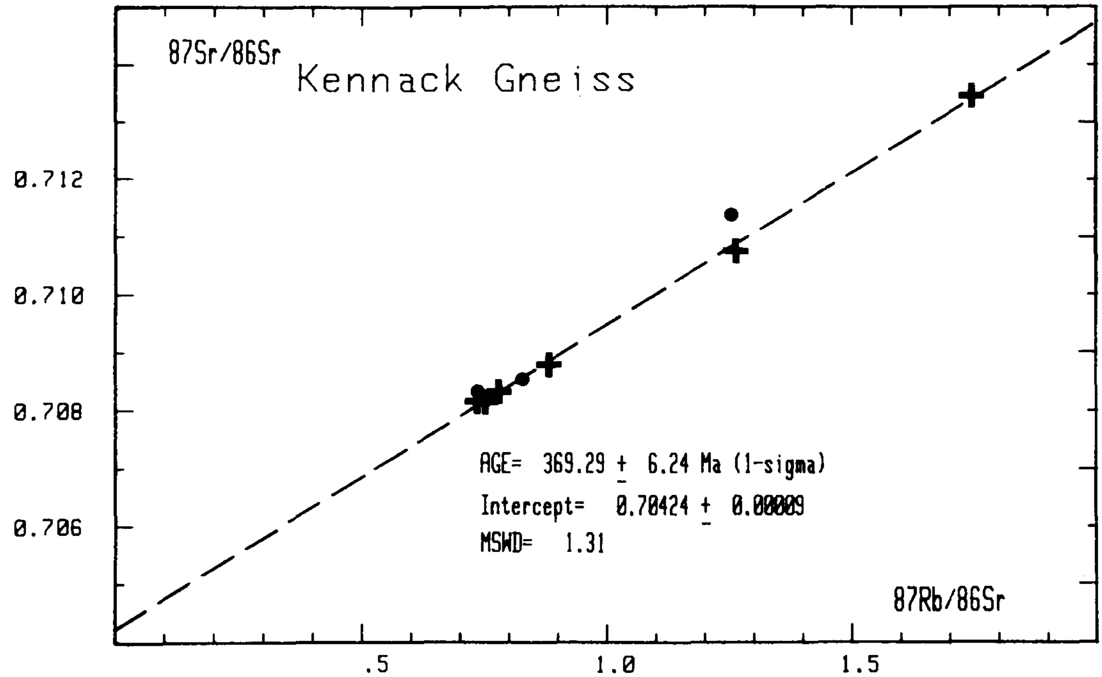

FIG. 1. Rb-Sr isochron diagram for samples of Kennack Gneiss. Solid circles indicate data points which have been omitted from the regression.

since magmatic crystallization. Moreover, since the minerals that are likely to contain Rb and radiogenic Sr (biotite, orthoclase and plagioclase) have been extensively recrystallized and in view of the small sample size and good fit of points on the isochron diagram, it is thought probable that isotopic homogenization took place during high grade metamorphism and this is therefore the event recorded by the isochron age.

The low initial $^{87}Sr/^{86}Sr$ ratio suggests derivation from a source with a large component of mantle or juvenile crustal material and also implies that any crustal precursor cannot have had a long history before metamorphism. For example, it is unlikely that the initial ratio for any granite magma would have been less than about 0.7035 and therefore with an average $^{87}Rb/^{86}Sr$ of about 1 the maximum possible crustal prehistory before metamorphism would not exceed 50 Ma.

It is likely, however, that although the magmatic crystallization and subsequent metamorphism were distinct events, recognizable by petrographic studies, they could be phases of an essentially continuous geological process, indistinguishable by radiometric dating methods.

It is also likely that later retrogressive metamorphism, common throughout the Lizard, is responsible for the chloritization and resulting deviation of some sample points from the best fit line.

Previous dating of the Lizard Complex

Early dating studies on Lizard rocks by Dodson (1961) and Miller & Green (1961*a,b*) were summarized by Green (1964). When these ages are recalculated using the decay and other constants recommended by Steiger & Jager (1977), the Kennack Gneiss gives mineral ages by both Rb-Sr and K-Ar methods of about 370 Ma (Fig. 2). Muscovite ages from the

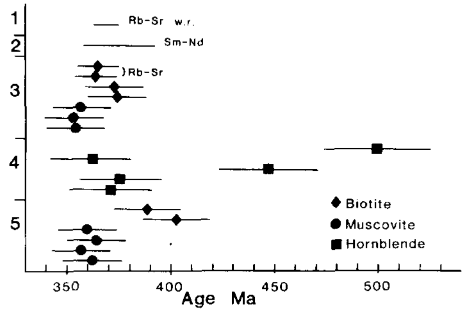

FIG. 2. Radiometric ages from the Lizard Complex, K-Ar unless stated. Errors shown are 1-sigma or as given by authors where confidence limit not specified. Sources: 1. Styles & Rundle 1984; 2, Davies 1984; 3, Dobson 1961; 4, Miller & Green 1961*b*; 5, Miller & Green 1961*a*.

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metasediments cluster around 360 Ma. The close grouping of these ages suggests that isotopic homogenization took place on a scale from a mineral up to a hand specimen at around 370 Ma and that there has been no major disturbance subsequently.

These ages are from high grade metamorphic rocks and presumably record the age of metamorphism. The best guide to the age of crystallization of the magmatic rocks is the plagioclase–clinopyroxene–whole-rock Sm-Nd isochron on a gabbro from the Coverack area, which gave 375 ± 17 (1 sigma) Ma (Davis 1984). This suggests that crystallization of the igneous rocks, metamorphism and emplacement all took place within a period of a few million years at about 370 Ma.

There are, however, two dates that are not compatible with such a hypothesis. Miller & Green (1961*b*) measured hornblende from a Landewednack hornblende schist from Pen Olver and obtained an age of 449 Ma, although a mica from schist interbedded with the amphibolite, also from Pen Olver, indicated 362 Ma, while another hornblende from the hornblende schist at Pencra Head give a similar age, 367 Ma. Another hornblende from a hornblende granulite at Pol Cornick indicated an age of 499 Ma, while hornblende from an amphibolite, nearby on Predannack Head gave 363 Ma. The authors suggested that the rock with the older age (which was interbanded with peridotite near the peridotite margin), had been protected from later events. However, field and petrographic studies of rocks from the Pol Cornick area (M.T.S.) show that this area has been affected by high temperature thrusting and metamorphism during the early stages of emplacement, similar to that at Kennack. This is recorded by the age of 363 Ma. Either the hornblende granulite suffered metamorphism in the upper amphibolite facies without being reset, or the older dates are due to the presence of a small amount of excess or inherited ^{40}Ar. In view of the incompatibility of these two older ages with all the other ages discussed above, the latter interpretation is preferred, and it is not thought that they 'point back' to an older original age.

A regional survey of K-Ar ages from slates and phyllites of SW England was carried out by Dodson & Rex (1971). They showed that there was a belt of Gramscatho 'series' rocks along the coast of S Cornwall including the Lizard, Roseland and Dodman areas that gave ages in the range of 350–370 Ma. They interpreted this as dating the period of regional metamorphism and folding, and the data presented in this paper suggest that the emplacement of the Lizard was also part of this regional tectonic event.

Discussion

The results presented in this paper show that the high-grade metamorphism associated with thrusting during the early stages of emplacement of the Lizard Complex took place around 370 Ma, during the late Devonian (Odin 1982). It is important that this emplacement is recognized to be as young as late Devonian since many previous models of evolution of the Lizard Complex, e.g. Bromley (1979) consider the Lizard to be an eroded upland area in the early Devonian, based on the Emsian age of fossils in the Meneage Mélange (Stubblefield 1939). It cannot, however, be assumed that the fossils come from the matrix of the mélange as this is not stated either by Stubblefield (1939) or in the Lizard Memoir (Flett 1946). It is much more likely, in the light of this dating study, that the fossils are from one of the many blocks within the mélange (Barnes *et al.* 1979). On a wider scale, Brazier *et al.* (1979) discussed the tectonics and thermal history of SW England, suggested that the Lizard Complex was pre-Ordovician, and implied that most of the radiometric ages had been re-set. The results presented here show that the majority of previously reported mineral ages have not been substantially re-set and confirms that they do reflect the cooling from high temperatures upon emplacement.

The balance of evidence points to the Lizard Complex as having a relatively short but eventful history with crystallization of the magmatic rocks in early to middle Devonian times (Davies 1984) and high-grade metamorphism and emplacement during late Devonian times. The final stages of emplacement were at low temperatures and probably associated with deformation in the underlying Gramscatho 'Series'.

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