Read at the Annual Conference of the Ussher Society, January 1981

A tectonic 'watershed' of fundamental consequence in the post-Westphalian evolution of Cornubia

J.R. HAWKES

J.R. Hawkes 1981. A tectonic 'watershed' of fundamental consequence in the post-Westphalian evolution of Cornubia. *Proc. Ussher Soc., 5,* 128-131.

An examination of isotopic age, stratigraphical and tectonic evidence suggests that the exposed Cornubian granites are between 310 and 300 Ma old, and that they were generated, probably with other Armorican Carboniferous plutons, in tectonic systems related to the Variscan Orogeny. However, it seems the orogenic regime was replaced before the end of Carboniferous times by major tensional forces which exercised critical control during early Red-bed sedimentation and which led, in conjunction with mantle activity, to the eruption of Stephanian lamprophyric rocks, and later to the Lower Permian elvan volcanism and attendant mineralization phenomena.

J.R. Hawkes, Institute of Geological Sciences, Exhibition Road London SW7 2DE

According to Styles and Rundle (1981) there are new reasons for believing that the ophiolite complex of the Lizard (Styles and Kirby 1980) was joined to the Devonian foreland of Cornubia approximately 370 Ma ago. Following this Upper Devonian episode of compression, the region witnessed a period of relatively shallow water, lagoonal, shelf and deltaic sedimentation which continued almost uninterruptedly into Westphalian times (Edmonds and others 1979). Some tectonic activity occurred during the Lower Carboniferous, being represented, for example, by products of the mainly basic volcanism seen around Marytavy, Meldon and Tintagel. Post lower Namurian-pre Lower Westphalian uplift and erosion has also been proposed by Selwood (1966) to account for the nature of ?southerly-derived, conglomeratic material present in Upper Culm rocks near Launceston. Slump structures in Crackington and Bude strata provide further general evidence of instability. But it is obvious that none of these features compares in intensity with the folding produced during an episode of compression which terminated this lengthy period of Carboniferous sedimentation. The youngest beds involved in the folding correlate with the base of Westphalian C (Freshney and others 1979). However, comparison with the Radstock area provides stratigraphical evidence for a possible late Westphalian-early Stephanian timing (Simpson 1962, p.72).

The significance of the two major episodes of compression was emphasized by Dearman in a structural interpretation of Cornubia presented to the Ussher Society in 1971. By drawing on the metamorphic K/Ar age data which Dodson and Rex (1971) obtained from various argillaceous rocks, he was able in part to r econcile complex structural Patterns resulting from the strong, province-wide, largely E-W, late Carboniferous (310-270 Ma) overprinting of primary, late Devonian (365-345 Ma), NE-SW folding. The primary folding is seen clearly only in South Cornwall, to the north of the Lizard block. Its general extent in the province remains obscure, partly because Devonian shales in North Cornwall and South Devon tend also to reflect effects of the less intense Lower Carboniferous-early Namurian (340-320 Ma) tectonic events referred to above. And as Dearman remarked, tectono-thermal events related to the intrusion of the granite batholith provide additional complications in trying to deduce correct structural correlations from available metamorphic age data.

Attempts to date the exposed granite plutons have further Confused structural issues: K/Ar data at present offer a spread of ages between 303 and 246 Ma (see Dodson and Rex 1971, pp. 493-495). However, a majority of determinations lie between about 300 and 265 Ma which places them in roughly the same time span (310-270 Ma) Dodson and Rex derived for argillaceous rocks displaying pronounced effects of the late Carboniferous folding. One obvious question arises from this information: why should the Variscan tectonic activity apparently show so long a Permian tail when stratigraphical evidence in the Radstock area and in adjacent red-bed strata seems to deny such a possibility?.

Before pursuing the question, it should be noted that recent changes in the constants used for calculating K/Ar ages (Steiger and Jager 1977) mean that all the figures quoted above should be amended by the addition of approximately 5 Ma. Table I shows these adjustments. In addition, there is dispute about the numerical figure for the Devonian-Carboniferous boundary, although a compromise age of 360 Ma is currently proposed. The figure for the Carboniferous-Permian boundary has been amended to 285 Ma.

Table of Contents

Table 1. Amended K/Ar ages

	Published K/Ar ages	Amended K/Ar ages	
			PERMIAN
Data from Metamorphic rocks	310-270	c. 315-275	-285-
	340-320	c. 345-325	CARBONIFEROUS
	365-345	c. 370-350	-?360-
			DEVONIAN
Granite Data	303-246	c. 308-251	

From knowledge of more deeply eroded batholiths, it follows that the Cornubian mass is probably composite. Stone (1971) made this particular point in considering that plutons younger than those exposed at the surface might exist at depth. If true, his proposition could well account for the Permian tail seen in the K/Ar data. The province-wide elvan volcanism of approximately 270 Ma ago (Hawkes and others 1975) can certainly be held as circumstantial evidence for continued plutonic activity. It is within this general context that the genesis of greisens, quartz-tourmaline veins and the primary lode-mineralization is usually explained. But there is an alternative view.

The potassium-rich granite cupolas with their localized lithium-rich phases represent the highest and therefore possibly the youngest plutons of the batholith. Interior regions may comprise granodioritic and perhaps dioritic bodies evolved and intruded following successive phases of Variscan compression. Although no evidence for initial growth as early as Upper Devonian times has been recognized, Matthews (1977) considered that the rising mass may have been responsible for the abrupt change from E-W axial sedimentation in the Crackington Basin to northerly-derived, top-set Bude sedimentation at the beginning of Westphalian. A post- Lower Namurian - pre- Lower Westphalian uplift and erosion cited by Selwood (1966) could mark an even earlier stage in the batholith's development. Slump structures in Crackington and, more especially, in Bude strata certainly suggest periodic instability throughout much of the Upper Carboniferous.

Unfortunately, all we know for certain is that the exposed plutons post-date the major Carboniferous folding. Prior to their relatively tranquil emplacement at observed levels, the Bodmin and Dartmoor granites caused some doming of folded rocks and were also responsible for shuffling numerous segments of adjacent Devonian and Carboniferous strata between a series of northerly-dipping, low-angle faults (Freshney 1965; Freshney and Taylor 1971; McKeown and others 1973). Mica from crenulation cleavage zones in certain associated minor folds might conceivably yield a constraining K/Ar age for the arrival of the easternmost plutons.

After the folding, uplift and erosion led to a style of deposition markedly different from that seen during the Upper Palaeozoic. Continental red-bed material began to accumulate in south-west England and throughout the British Isles in a series of subsiding, fault-bounded basins. In discussing the development of the English Channel, Smith and Curry (1975) stressed that tensional forces had become a potent factor in western parts by early Permian times. Moreover, Whittaker (1975) has suggested that crustal tension continued to exercise critical control during the subsequent Mesozoic marine sedimentation which followed in the wake of the Rhaetic Transgression. On this evidence, the tensional forces evident at the start of the red-bed deposition were more than just a local relaxational response to Variscan crustal compression. It can be argued that we are observing in these rocks the very earliest symptoms of the breakup of Pangea.

Basal breccias in Cornubia survive on land only to the north and east of Dartmoor. Coarse-grained sediments such as the St Cyres Beds and the Kennford and Teignmouth Breccias contain abundant fragments of xenoliths, finer granite types and white feldspar megacrysts derived from the nearby pluton. Thus, at the outset of the Red-bed era, the easternmost end of the batholith was exposed to the atmosphere. This fact carries alternative implications with regard to internal temperatures. If the entire mass was generated quite rapidly in late Carboniferous times, temperatures might have remained high despite the erosion. But supposing the visible plutons to be the youngest in a succession of intrusions dating back to the Upper Devonian, then most of the batholith could have been as cold and physiochemically inert as the Dartmoor Granite

Table of Contents

apparently was at this juncture. Lack of evidence prevents a balanced choice between these extremes. Nevertheless, another implication arises from the exposure of the Dartmoor Granite. Provided there were no subsequent vertical movements in excess of a few thousand feet between the various crustal blocks constituting Cornubia, each of the plutons must have been subject to groundwater circulation during the Red-bed era.

By analogy with Midlands stratigraphy; several observers have suggested that the basal breccias might be Stephanian in age. They are more usually regarded as being Lower Permian on account of K/Ar data from two interbedded basalt and lamprophyre lavas which have yielded a mean figure of about 280 (285) Ma (Miller and Mohr 1964). However, new K/Ar isotopic information from 11 contemporary dyke and lava rocks (chiefly lamprophyres) indicates instead a Stephanian mean age of 295.2±_2.6 Ma (Rundle, personal communication), a figure comparable with data from similar lamprophyres in the Channel Islands and in Brittany (see Lees 1974).

Two particular consequences follow from the revised age for this volcanic activity and from the presence of granite detritus in the breccias. Clearly the Dartmoor Granite must be more than 295 Ma old and, by analogy, so too the Cornish plutons. Intrusion probably occurred between 310 and 300 Ma ago, a time span suggested by the oldest of the available K/Ar dates (see Dodson and Rex 1971 pp. 493-495). If this proposition is true, the Cornubian granites may correlate age-wise with the French plutons at Flammaville and Ploumanac'h'Trégastel (Adams 1967), and it seems possible that they were generated, along with other late-Carboniferous Armorican granites, in similar Variscan orogenic systems. The second implication relates to the apparent abruptness with which the Variscan compressional forces faded out in Stephanian times. There is no longer a need to interpret Cornubian Permian events within an orogenic context, nor indeed the Stephanian volcanism.

All volcanic materials erupted during the latter episode are enriched in "incompatible" elements and in potassium. Cosgrove (1972) has suggested genesis from subducted Variscan crust, but because of the actual amounts of these elements in the contemporary Channel Islands (Jersey) lamprophyres, Lees (1974) considered that the magma may have been derived by partial melting of mantle material under a stable continental area. He alluded to the chemical similarities between these mica lamprophyres (chiefly minettes) and the potash-basalt and kimberlite-carbonatite suites which, incidentally, tend rather to characterise major rift environments (see also Bachinski and Scott 1979; Rock 1980; Bachinski and Scott 1980).

Production of acid magma during the subsequent Lower Permian volcanism about 270 Ma ago cannot be explained in these terms. According to Henley (1972), the highly fluidised dyke systems (Stone 1968) contained remobilized granite material derived from the interior of the batholith. There is no obvious chemical evidence in the resultant elvans for a direct mantle connexion. Nevertheless, the associated intrusive and pneumatolytic breccias (Goode and Taylor 1980), and the sheer intensity of the sub-aerial hydrothermal systems responsible for broadly coincident greisenization, tourmalinization, primary tin, tungsten and copper mineralization and also for the extensive destruction (kaolinization) seen in various granite plutons (Dangerfield and Hawkes 1969; Hawkes 1974), point to a quite unusual degree of crustal heating. In these circumstances, loss of argon to thermalised groundwaters offers a possible explanation for the range of K/Ar ages from about 300 to 270 Ma shown by many of the granite and country rock micas.

Some observers still relate the lode mineralisation phenomena to granite intrusion and the Variscan Orogeny (Mitchell 1974; Jackson 1979). However, while an appeal to plate collision and subduction may be appropriate in the cases of the Thai, Malayan and Bolivian tin provinces, the thesis of this essay remains that Cornubian tectonic and stratigraphical evidence firmly rules out any such connexion.

Isotopic ages from a variety of vein minerals suggest the intermittent occurrence of smaller-scale hydrothermal activity in Upper Permian, Triassic, Jurassic, Cretaceous and Tertiary (Eocene) times. With the accumulation of more data, it may be possible to correlate these events with igneous activity in surrounding continental and continental shelf areas, and to show how these events reflect the tortuous tectonic steps by which Cornubia was translated from a late-Carboniferous position a few degrees north of the equator to its present location at about 50°N. The reality of this translation, which happened in conjunction with the erratic post-Rhaetian development of the North Atlantic ocean basin, is not seriously doubted, However, none of the 'mantle processes involved appears to have had quite the same effect on the province as the one responsible for the elvan volcanism and primary mineralization. In the light of present knowledge, the author agrees with Bromley (1975) that a mantle plume may prove to have been influential. This is not to suggest that the Sn, W and Cu were necessarily derived from a sub-crustal source, although some vein minerals could well contain critical evidence of fugitive H, He, Li, Be, B, C, N, O, F, Ne, P, S, CI, Ar, Kr and Xe.

Acknowledgements are due to R.K. Harrison, J. Dangerfield, C. Rundle and M.T. Styles for many helpful discussions.

Table of Contents

References

Adams, C.J.D. 1967. A geochronological and related isotopic study of rocks from north-western France and the Channel Islands (United Kingdom). *D. Phil. Thesis. University of Oxford.*

Bachinski, S.W. and Scott, R.B. 1979. Rare-earth and other trace element contents and the origin of minettes (mica-lamprophyres). *Geochim et Cosmochim. Acta, 43,* 93-100.

Bachinski, S.W. and Scott, R.B. 1980. Author's reply (to N.M.S. Rock). *Geochim. et Cosmochim. Acta, 44,* 1389-1392.

Bromley, A.V. 1975. Tin mineralization in Western Europe: is it related to crustal subduction? *Trans. Instn. Min. Metall., 84,* B28-B30.

Cosgrove, M.E. 1972. The geochemistry of the potassium-rich Permian volcanic rocks of Devonshire, England. *Contr. Miner. Petrol., 36,* 155-170.

Dangerfield, J. and Hawkes, J.R. 1969. Unroofing of the Dartmoor Granite and possible consequences with regard to mineralisation. *Proc. Ussher Soc.,* 2, 122-131.

Dearman, W.R. 1971. A general view of the structure of Cornubia. *Proc. Ussher Soc.,* 2, 220-236.

Dodson, M.H. and Rex, D.C. 1971. Potassium-argon ages of slates and phyllites from south-west England. *Q. Jl. geol. Soc. London, 126,* 465-499.

Edmonds, E.A., Williams, B.J. and Taylor, R.T. 1979. Geology of Bideford and Lundy Island. *Mem. Geol. Surv. Gt. Britain,* x + 143pp.

Freshney, E.C. 1965. Low angle faulting in the Boscastle area. *Proc. Ussher Soc., 1,* 175-180.

Freshney, E.C. and Taylor, R.T. 1971. The structure of Mid Devon and North Cornwall. *Proc. Ussher Soc.,* 2, 241-248.

Freshney, E.C., Edmonds, E.A., Taylor, R.T. and Williams, B.J. 1979. Geology of country around Bude and Bradworthy. *Mem. Geol. Surv. Gt. Britain,* 62pp.

Goode, A.J.J. and Taylor, R.T. 1980. Intrusive and pneumatolytic breccias in south-west England. *Rep. Inst. Geol. Sci., No 80/2,* 23pp.

Hawkes, J.R. 1974. Volcanism and metallogenesis: the tin province of south-west England. *Bull. Volcanologique, 38,* 1125-1146.

Hawkes, J.R., Harding, R.R. and Darbyshire, D.P.F. 1975. Petrology and Rb:Sr age of the Brannel, South Crofty and Wherry elvan dykes, Cornwall. *Bull. Geol. Surv. Gt. Britain, 52,* 2%42.

Henley, S. 1972. Petrogenesis of quartz porphyry dykes in southwest England. *Nature Phys. Sci., 235,* 95-97.

Jackson, N.L. 1979. Geology of the Cornubian tin field, 'a review'. *Geol. Soc. Malaysia, Bulletin 11,* 209-237.

Lees, G.J. 1974. Petrochemistry of the mica-lamprophyres (minettes) of Jersey (C.I.) *Proc. Ussher Soc., 3,* 149-155.

Matthews, S.C. 1977. Carboniferous successions in Germany and in southwest England. *Proc. Ussher Soc., 4,* 67-74.

McKeown, M.C., Edmonds, E.A., Williams, M., Freshney, E.C. and Masson Smith, D.J. 1973. Geology of the country around Boscastle and Holsworthy. *Mem. Geol. Surv. Gt. Britain,* ix + 148pp.

Miller, J.A. and Mohr, P.A. 1964. Potassium-argon measurements on the granites and some associated rocks from southwest England. *Geol. J., 4,* 105-126.

Mitchell, A.H.G. 1974. Southwest England granites: magmatism and tin mineralization in a post-collision tectonic setting. *Trans. Inst. Min. Metall., 83,* B95-D97.

Rock, N.M.S. 1980. Rare-earth and other trace element contents and the origin of minettes. A critical comment on a paper by Bachinski and Scott (1979). *Geochim. et Cosmochim. Acta, 44,* 1385-1386.

Selwood, E.B. 1966. Derived fossils from Upper Culm Measures south of Launceston, Cornwall. *Proc. Ussher Soc., L* 234.

Simpson, S. 1962. Variscan orogenic phases. In, Some aspects of the Variscan fold belt. Ed. Coe, K., *Manchester University Press,* 65-73.

Smith, A.J. and Curry, D. 1975. The structure and geological evolution of the English Channel. *Phil. Trans. R. Soc. London, A., 279,* 3-20.

Steiger, R.H. and Jager, E. 1977. Subcommission on Geochronology: convention in the use of decay constants in geo- and cosmochronology. *Earth Planet. Sci. Lett., 36,* 359-362.

Stone, M. 1968. A study of the Praa Sands elvan and its bearing on the origin of elvans. *Proc. Ussher Soc.,* 2, 37-42.

Stone, M. 1971. Form and structure of the granites of S.W. England. *Proc. Ussher Soc.,* 2, 253-263.

Styles, M.T. and Kirby, G.A. 1980. New investigations of the Lizard complex, Cornwall, England and a discussion of an ophiolite model. Extracts from Ophiolites, Proceedings International Ophiolite Symposium, Cyprus 1979, *Cyprus Geol. Surv. Dept.,* 517-526.

Styles, M.T. and Rundle, C.C. 1981. A whole rock Rb/Sr isochron for the Kennack Gneiss (Abstract). *Proc. Ussher Soc., 5,* 246.

Whittaker, A. 1975. A postulated post-Hercynian rift valley system in southern Britain. *Geol. Mag., 112,* 137-149.

This paper is published with the approval of the Director, Institute of Geological Sciences (N.E.R.C.).

Discussion

Dr D.J.C. Laming enquired where the radiometric dates of basal New Red lavas had been obtained. He pointed out that several thousand feet of breccias separated the lava horizon from the occurrence of "granitoid' rocks in the Crediton-Teignmouth Breccias, and that these were the result of canyon erosion reaching the granitic dykes or the granite itself. A subsequent layer in which abundant feldspar fragments occurred -- interpreted as the result of a volcanic episode -- is regarded as being late Lower Permian.

Author's reply: The mean Stephanian age of 295 ± 2.6 Ma (Rundle, personal communication) has been derived from rhyolitic lava specimens centimetres from the base of the New Red strata at Kingsand and from a variety of lamprophyre samples from dykes outcropping between Bridford and Chyweeda (near Leedstown). Lamprophyre lava from Killerton Park is also being analysed, but results are not yet available. Thus, the data provide only a general indication that the breccias (many of which contain abundant acidic and lamprophyric volcanic detritus) are of Stephanian age. Dr Laming is correct to point out that granite fragments occur well above the base of the breccias. An important task now is to redefine the base of the Permian which may be much higher in the New Red succession than presently believed. As for feldspar fragments, the author is satisfied that the abundant large, white, crystals in the St Cyres Beds and at least some of those in the Teignmouth Breccias are from the Dartmoor Granite rather than from volcanic material.

Table of Contents