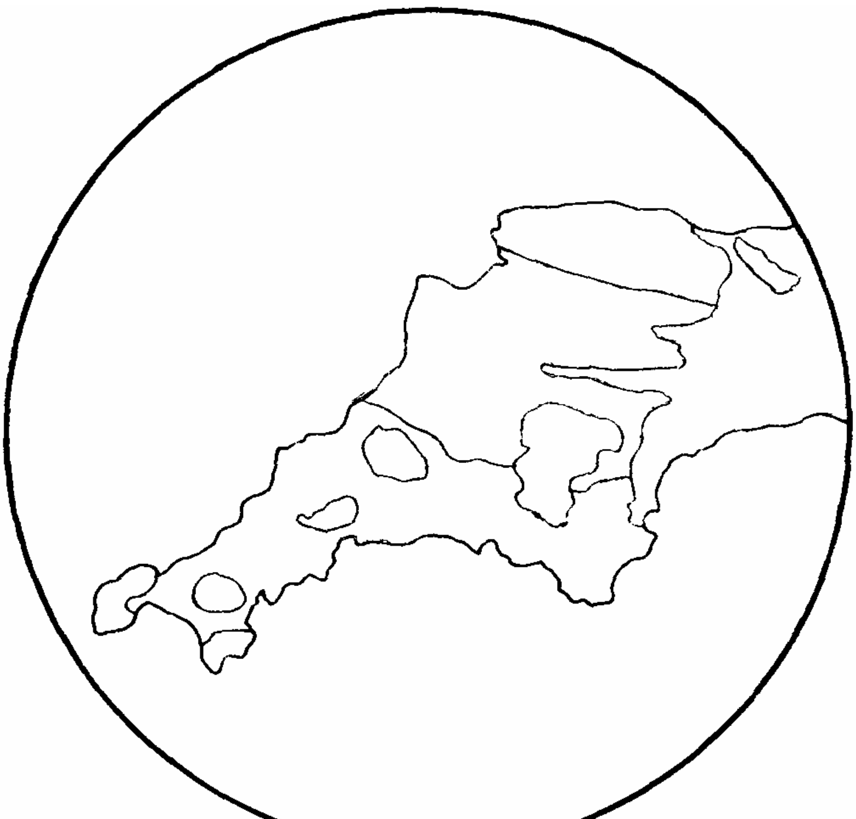
PROCEEDINGS
OF THE
USSHER SOCIETY

VOLUME THREE
PART ONE



1974

THE USSHER SOCIETY

Membership of the Ussher Society is open to all on written application to the Secretary and payment of the annual subscription (£ 1.50 ordinary members, £1.00 students and retired members) due on January lst each year. Cheques should be made payable to the Ussher Society.

Back numbers may be purchased, post free, from the Secretary at the following rates:

Volume 1(Parts 1-6)	£1.50 each part (75p members)
Volume 2 (Parts 1-6)	£1.50 each part (75p members)
Bristol Abstracts (1960)	£1.00 (50p members)

Correspondence and requests for membership and publications should be addressed to:

Dr. S.C. Matthews,
Department of Geology,
Queen's Building,
University Walk,
Bristol. BS8 1TR

PROCEEDINGS

OF THE

USSHER SOCIETY

VOLUME THREE

PART ONE

Edited by
A. WHITTAKER

LEEDS, 1974

W. A. E. USSHER

CONTENTS

CONFERENCE: OF THE USSHER SOCIETY HELD AT NEWQUAY, JANUARY 1974

CHAIRMAN'S REPORT

The auspices for the 1974 meeting at Newquay were mixed. The programme held promise of much that was new and intriguing with a wide range of interests represented. The guest speaker, already known to many members of the Society had chosen a topic relevant to the wider implications of Cornubian geology. But the restrictions on travel, the energy crisis and the inclement weather seemed likely to assure a small attendance. In the event, as I should have known, members were not deterred from attending for the whole, or part of, a highly successful conference. An instructive excursion led by Drs. Henley and Sanderson on January 2nd was well attended and acclaimed a success despite the downpour.

The conference opened with the invited address from Dr. J. T. Renouf, of Jersey, about the geology of Brittany. Some interesting comparisons with the geology of South west England were made, and an outline of some of the problems that now engage the attention of geologists (British and French) in that region provided the basis for much question-and-answer after the lecture. Dr. Renout has given impetus to the Society's expressed wish to visit Brittany and we thank him for his excellent paper.

The remainder of the day's programme was occupied by papers concerned principally will) stratigraphy and structural topics which provoked plenty of active discussion. Papers on the following day were primarily to do with mineralogical and petrological aspects and similarly engendered enough discussion to fill all the time remaining for the conference. Indeed, members departing through the continuing downpour and dusk at the end of the meeting were still audibly engrossed in the topics raised at this year's session.

The Annual General Meeting provided the executive officers with the opportunity of reminding the Society not only of its robust state of health but also of some of the economic problems of the day.

Table of Contents

Each issue of the *Proceedings* seems to exceed its predecessors in size: the contents continue to include significant contributions on virtually every aspect of the earth sciences in the Southwest. Despite the general rise in the cost of producing the *Proceedings,* the Society's financial condition remains satisfactory.

Looking forward to events in 1975 and beyond, the Society welcomed Dr. Renouf's kind invitation to lead an excursion in Jersey should the Society ever wish to hold a meeting there. The 1975 A.G.M. will be held in Plymouth and indications are that it will rise to the high standard of its forerunners.

All the portents suggest that despite the financial restrictions that are now placed upon academic - and industrial - investment in geological research, the work that our members have in hand in Southwest England will continue vigorously. It is clear to me that in the time since the Ussher Society was founded our knowledge of the geology of the region has grown very much. Not only has local detail been accumulated but new concepts have formed, and the relevance of the geology of this part of England to a much wider region, including a large part of the adjacent continental shelf, is becoming apparent. I am especially impressed by the continuing refinement of the Palaeozoic stratigraphy and palaeontology and by structural studies and by the vast wealth of geochemical data now to hand. Not only have we an overall geochemical survey completed but also several detailed studies of granites, elvans, greenstones and the like.

The use of geophysics to advance matters of detail concerning ore bodies and sub-drift topography illustrates another aspect of our science that in its quiet way is enlarging our knowledge and serves to stress the importance of taking new looks at old problems and of making an adventurous re-interpretation of familiar phenomena.

Our region is one of great complexity - appearing to be the more so as work continues. No major paper on the geology of Southwest England can nowadays omit reference to the work by members of the Society. Many important new ideas have appeared at the Society's conferences or on the pages of its *Proceedings*. The extent to which Cornubian Palaeozoic geology is one of thrust tectonics involving thin slices and nappes was perhaps far from obvious even ten years ago.

Table of Contents

It is almost a prime necessity today to try to fit a geosynclinal geology into the concept of plate tectonics. Yet the Variscan geosyncline is proving difficult to mould to the established pattern, and this is certainly the case in Cornwall and Devon. Nevertheless, attempts to do so are welcome and stimulating. Questions about the nature and origin of our distinctive metallogenic province arc stubborn and as yet incompletely answered.

At the same time, several of our members are concerned with the most recent geological history of our province. There is an advance to be applauded in studies of the various superficial deposits and of the possible evidence of real glacial activity here.

This Address marks the end -of my term of office as Chairman and it gives me pleasure to acknowledge the help I have had from the Officers and Committee in conducting the Society's business.

I was fortunate to follow Dr. F. W. Sherrell as Chairman and would like to record the thanks that I and the Society owe him for his good offices. My own duties have been made smooth and enjoyable by the help of the Committee. I would especially mention the unfailing cheerful services of our Secretary, and the patience and competence of our Editors.

The Ussher Society has from its very beginning been most fortunate in the close links it has had with the Institute of Geological Sciences, especially in the persons of its officers at Exeter. It must be a source of satisfaction to us all that so many contributions to the *Proceedings* are by our friends at I.G.S. Thus it is with pleasure that I greet our incoming Chairman, Keith Beer of the Institute of Geological Sciences at Exeter. He is known to our membership as a distinguished geologist and an enthusiastic and long-standing member of our Society. I know he will find his duties pleasant arid the Society's support as firm as ever.

The retiring Editor is grateful to C. J. Burton, B. B. Clarke, R. J. D. Maloney, J. W. Perkins, T. R. Wilson and in particular to R. C. Scrivener for assistance in compiling the index for Volume 2 of the *Proceedings.*

D. L. Dineley
26 February 1974

Table of Contents

THE PROTEROZOIC AND PALAEOZOIC DEVELOPMENT OF THE ARMORICAN AND CORNUBIAN PROVINCES

by J. T. Renouf

Abstract. A critical and interpretative review is made of present evidence bearing on the relationships between Armorica and Cornubia from Proterozoic through to Upper Carboniferous times. The Armorican Upper Proterozoic cycle, comprising the development of a Brioverian geocline and its deformation in the Cadomian orogeny, is described and spatial associations with Britain examined. A series of compound palaeogeographical maps is used to demonstrate the possible links between Armorica and Columbia during the Palaeozoic. Special attention is paid to the pattern of tectonic events affecting the two provinces during the Devonian and Lower Carboniferous, and the nature and origins of the early and paroxysmal Variscan orogenic phases are discussed. It is concluded that deep water developed over the south-west England southern margin of the Old Red Sandstone continent across a series of strike-fault controlled basins and swells under the influence of possible basement extension (? thinning) with mobility developed at depth. Apart from the still equivocal basic complex of the Lizard, there is little evidence to show that oceanic crust formed in the extensional area the mechanism responsible for the main Variscan deformation in the Upper Carboniferous is considered to be that of a plate tectonic model of uncertain configuration on present knowledge

1. The pre-Upper Proterozoic basement

Three significant papers appeared in 1957 providing irrefutable evidence of a major unconformity beneath the Palaeozoic sediments of the Armorican Massif. Cogné (1957) described the successions found in southern Armorica concentrating his attention on the structural and metamorphic history of file area; Philippot & Chauvel (1957) gave clear examples of the sub-Palaeozoic unconformity in the Rennes area while Graindor (1957) devoted his thesis to a detailed description and sub-division of the successions beneath the Cambrian unconformity in Normandy. The subPalaeozoic successions of dominantly greywacke type occurring throughout Armorica, and mostly within greenschist facies, had long been referred to the Brioverian, a term created by Barrois, but the nature of their relationship with the Palaeozoic had for equally long been the subject of much debate (Cogné 1963, p.420 *et seq*).

Within two years another major step was taken when Cogné (1959a) recognised a pre-Brioverian basement on the coast at Jospinet northeast of St. Brieuc (fig. 1) to which he gave the name

Table of Contents

Pentevrian. Though unsupported by radiometric age determinations at this stage, other areas to the north and northeast in the Channel Islands and adjacent Cotentin were assigned to the Pentevrian (Cogné. 1959b. Graindor. 1910). Cogné (1963) published a review of the Precambrian in Armorica in which he delineated two broad arcs of' Pentevrian outcrop. The more northerly, embracing the northern Cotenti,. Alderney and Guernsey and swinging southwestward into the Tregorrois, had already been given the name Sarnian: the more southerly band included the original Pentevrian of tie St. Brieuc region.

Radiometric dating from 1965 onward proved the correctness of Cogné's original work on the Pentevrian with ages between 900 and 1100 m.y. (Leutwein & Sonet, 1965). Further results were soon forthcoming for the Sarnian zone to the north where Adams (1967a & b) demonstrated die existence of yet older basement in the Channel Islands. Leutwein *et al.* (1973) confirmed Pentevirian outcrops in the Cherbourg area though the Pentevrian age of the Coutances diorite remains radiometrically unproven.

Roach *et al.* (1972' tab. 1) summarised the pre-Palaeozoic episodes: the Icartian with an age range of 2550-2700 m.y. and the Lihouan 2000-1900 m.y. The rocks of Pentevrian age mapped west of the Tregorrois (Verdier, 1968) have not yet been proven by radiometric dating but conform to the situation at Jospinet. The rather isolated area of Les Abers (Cogné &. Shelley, 1960) ideally awaits further proof of the Pentevrian age of its oldest rock-groups. Likewise the suspected zones of possible pre-Brioverian basement in southern Armorica (e.g. Cogné, 1959a) require more confirmation before their acceptance.

The close involvement of the sub-Brioverian basement in the succeeding Upper Proterozoic cycle of sedimentation and deformation is indicated by widespread K/Ar mineral dates of 500-600 m.y. from hornblendes and biotites in Lower Proterozoic and Archaean rocks in northern Armorica (Adams, 1967 a & b). Structural trends reported from the pre-Upper Proterozoic basement are more or less affected by the major Cadomian orogeny which deformed the Upper Proterozoic Brioverian successions. Cadomian trends vary somewhat from ENE/WSW to E/W. Trends from NE/SW to N/S in the Pentevrian basements (Graindor, 1960, Roach, 1957, 1966, Verdier 1968, Bradshaw *et al.,* 1967) are pre-

Table of Contents

Upper Proterozoic in age. Where large enough areas of pre-Upper Proterozoic basement crop out, as in the region north-east of St. Brieuc, or on Guernsey, the NE/SW direction appears its a mappable feature, though the main foliation trend on Guernsey is somewhat variable due to refolding during the Lihouan deformational event.

The limits of the pre-Upper Proterozoic basement in northern Armorica, as distinct from a boundary line defining the present outcrops, are doubtful. The Alderney/Ushant line marks the known northeastern extent of proven outcrops while an arc from Cherbourg through Coutances to Dinan thence swinging NW through the Trégorrois before passing north of Morlaix into the Pays de Léon is the corresponding southern margin. This latter margin is characterised by being the northern known limit of early Brioverian marine volcanics and associated siliceous shales (see below).

North of the Alderney/Ushant line, rocks of possible Lower Proterozoic age crop out in an arc from Rosslare through Pembrokeshire and the Midlands to Kings Lynn (Wright, 1969, Baker, 1971 fig. l.). Between the two zones only the Lizard Complex offers a possibility of Precambrian rocks at surface outcrop. However, it seems more likely that the oldest rocks present there (Adams, 1967a & b) are Upper Proterozoic and/or Palaeozoic.

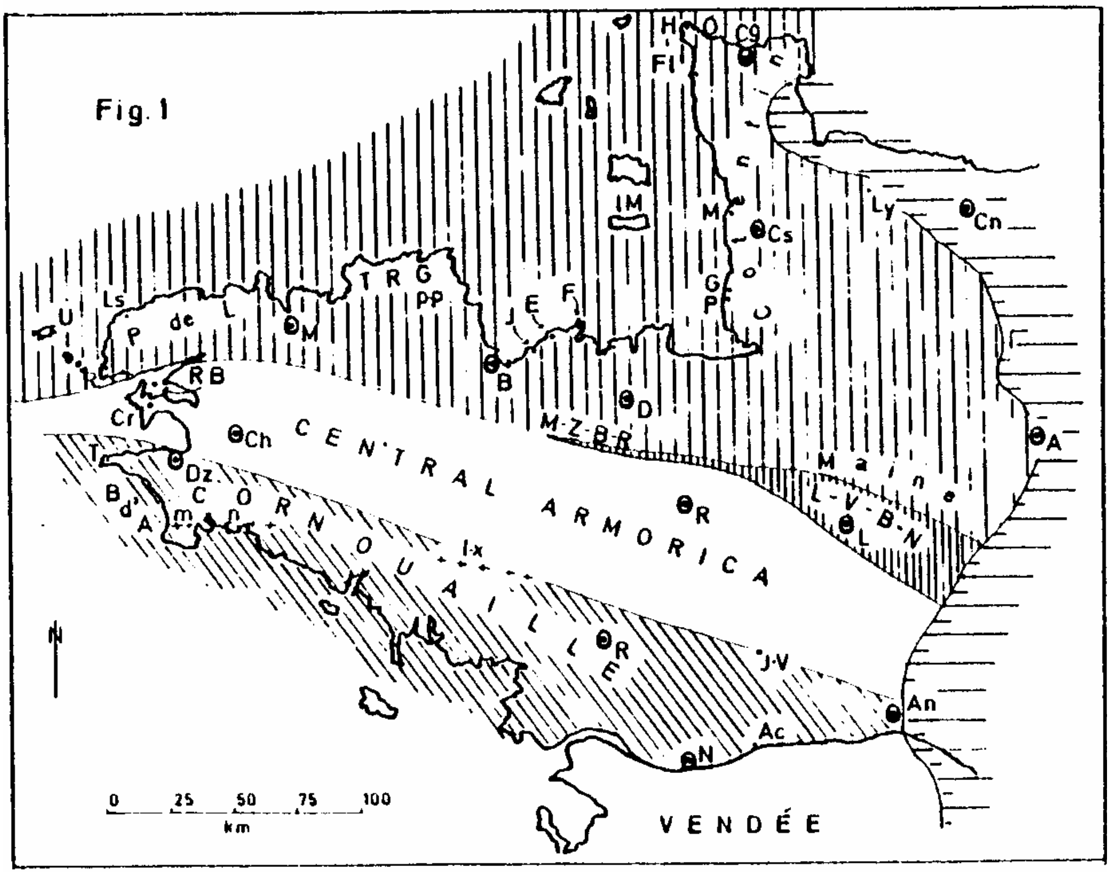


Table of Contents

FIGURE 1. Location Map.

H. Cap de la Hague. O. Omonville-la-Rogue. Cg. Cherbourg. Fl. Flamanville. IM. les Minquiers. M. Montmartin. Cs. Contances Ly. Littry. Cn. Caen. G. Granville. P. St. Pair. D. Dinan. M-Z-B-R. Bassin de Ménez Bélair. F. Fréhel. E. Erquy. J. Jospinet. B. St Brieue. pp. Plouézec/Plourivo. T-R-G. Trégorrois. M. Morlaix. Ls. Les Abers. P de L. Pays de Léon. U. Ushant. R.B. Rade de Brest. Cr. Crozon. Ch. Châteaulin. Dz. Douarnenez. T. Baie des Tréspassés. D d' A. Baie d'Audierne. m-n +=+ = 1-x. Moëlan/Lanvaux. R. Redon. J-V. St. Julien de Vouvantes. N. Nantes. An. Angers. Ac. Ancenis. R. Rennes. L-V-B-N. Laval Basin. I. Laval. A. Alençon

2. The Upper Proterozoic or Brioverian of Armorica

The stratigraphy of the Brioverian is not well known anywhere in Armorica and there are still large gaps to be filled in the late Cadomian, mainly Cambrian, history. Radiometric dating has provided both a broad outline of, and much local detail on, the sequence of orogenic events from 700-500 m.y., a time interval which effectively defines the Cadomian orogeny (Roach *et. al.* 1972 Bishop *et. al.* 1974).

The earliest Brioverian rocks overlie the Pentevrian basement around the Baie de St. Brieuc (Cogné, 1959a, Ryan, 1973), the Cotentin (Graindor, 1960) and western Trégorrois (Verdier, 1968). Ages of c. 900 m.y. are the youngest so far recorded from the Pentevrian basement and occur northeast of St. Brieuc (Leutwein & Sonet, 1965). The last cooling dates for the Cadomian fall at about 520 m.y. (Adams, 1967a & b). These two dates provide the maximum and minimum age brackets for the Upper Proterozoic cycle.

Deposition of the Brioverian is further confined between the opening of the cycle at c. 900 m.y. and the onset of the main Cadomian metamorphism at c. 650 m.y. which has affected all known Brioverian sediments. These limits are broad; only exceptionally has greater precision proved possible locally. The thick sequence of shales and greywackes that form the Brioverian in northern West Finistère were intruded by the Gneiss de Brest at c. 690 m.y. (Adams, 1967b), and Bradshaw *et al.* (1967) have shown that the sediments were already folded at this (late. A similar situation obtains in Guernsey if the Brioverian age of the Pleinmont metasediments is accepted (Roach 1966, Squire, 1974), because the

Table of Contents

L'Erée adamellite which affects the metasediments is also dated to c. 660±25 m.y. (Adams, 1967b).

Graindor (1957) proposed a threefold division of the Brioverian in northeastern Armorica. In general terms his Lower, Middle and Upper divisions correspond to an upward Briuverian succession from shales, often interbedded with spilitic lavas and siliceous shales, to thick shale/greywacke formations which are overlain more or less unconformably by thick and variable flysch deposits. Cogné (1963), in his full and perceptive review of the Brioverian of Armorica, extended Graindor's divisions to the whole of the province titling them closely to the developmental pattern of the classical geosyncline culminating in orogeny (cf. Aubouin 1965). The influence of Jung & Roques (1936) is evident in the separation of the orogeny into a first phase of updoming or intumescence resulting from or causing an upward penetrating, granitising and metamorphosing front (cf. Cogné *et. al.* 1966 fig. 15 and Jung & Roques, 1936 fig. 15), and a second event producing the lateral compression that caused the Folding. The scheme of correlation proposed by Cogné (1963, tab. 3) depends largely on the *a priori* assumption of the synchronous development of the whole geosyncline. This assumption is no longer tenable either in the light of plate tectonics or the advances made in dating by palaeontological means the progression of flysch prisms in time and space (e.g. the Welsh Palaeozoic geosyncline or the onset of flysch formation in SW England during the Westphalian).

Spilites and associated siliceous shales occur in a broad band from northern West Finistère along the southern margins of Pentevrian outcrop into the northern Cotentin. These marine deposits and associated extrusives overlie thin conglomerates and arkosic sandstones which rest upon weathered Pentevrian basement (Cogné, 1959a, Ryan, 1973 in press, Verdier, 1968, Graindor, 1960). The association is not typical of the true 9phiolitic suite since it is developed on a continental basement and shows little evidence of being related to upthrust or rafted slices of the continental crust. There is a conspicuous absence of ultrabasic and gabbroic sheets. By contrast, zones of basic rocks found in southern Armorica contain all the elements of the ophiolite suite (Cogné, 1966, Peucat, 1973). It is difficult to accept the implications of the correlation of the two groups as proposed by Cogné for, even if they are time equivalents,

Table of Contents

and this seems unlikely, their origins appear to be different (fig. 3a).

No internal stratigraphical subdivisions have yet been substantiated for the widespread and thick shale/greywacke associations that make up the hulk of the early Brioverian deposits throughout the areas on and beyond the southern margins of the Pentevrian basement.

Insofar as these sediments fit within the age bracket 9(x)-7(x) m.y., then it is valid to correlate them, but this tends to obscure the very real age differences that must lie concealed within this typically monotonous Precambrian greywacke succession. Deposits broadly coeval with these greywacke are the Pleinmont metasediments. It is possible that the original sediments of this formation may have been of different facies from the typical geosynclinal sequences to the south and southeast of the areas of basement outcrop.

The evidence from these pre-flysch Brioverian deposits is suggestive of a miogeoclinal (Dickinson, 1971) wedge of sediment built out from the Pentevrian continental basement southward and southeastward. As the Brioverian deposits of central Armorica conceal what underlies them it is not possible to be definite about the southward extent of the Pentevrian basement but there is no evidence at the present time to preclude the basement extending as far south at least as the northern Cornouaille. Two facts lend support to this possibility. The early Brioverian greywackes would be most likely to form over the continental rise and adjacent oceanic bottom. The ophiolites of the Cornouaille suggest that this oceanic bottom was not farther away than 100km. (not taking shortening into account) which seems a minimum distance to allow for the considerable thicknesses of early Brioverian deposits. The ophiolites themselves belong to a zone of intense Cadomian disturbance and may, in addition to their almost certain oceanic crust origin (Peucat, 1973), be indicative of the nearby presence of a subduction zone. The southern margin of a Pentevrian continental rise could thus have extended as far south as the northern Cornouaille.

The characteristics of the younger Brioverian deposits, i.e. those classified by Graindor (1957), Dangeard and Dore (1961), and Cogné (1963) as Upper Brioverian, are those of a flysch facies. Graindor (1957) interpreted coarse polygenetic breccias and conglomerates in

Table of Contents

the Granville area of the Cotentin as of glacial origin. Cogné (1963) extended recognition of glacial effects in the Upper Brioverian to the rest of Armorica. Winterer (1964) offered cogent arguments against the glacial origin of the Granville deposits and subsequent examination by the author and others (Squire 1974 in press, Dupret, 1974 in press) has also led to the favouring of a non-glacial origin. With such doubts cast upon the glacial theory, the accuracy of the correlations proposed by Cogné (1963) becomes suspect in detail and the time equivalence of the orogenic movements that initiated the flysch phase can no longer be substantiated.

Spore-like microfossils (Roblot, 1963, 1964) and trace fossils. (Squire. 1973) have been found in the Upper Brioverian successions of Normandy and the Channel Islands and the age of the trace fossils is thought to be consistent with a (late between 700 and 650 m.y. This would indicate that the Upper Brioverian in these areas was deposited after a phase of folding and intrusion ending at about 690 m.y. and the onset of the main metamorphism at about 650 m.y. No such evidence is yet available for areas of Armorica to the south.

Northward from Armorica. the possibly pre-Upper Proterozoic rocks which occur as isolated outcrops in the broad band from Kings Lynn to Pembrokeshire are the basement from which a thick wedge of Longmyndian sediments was built out northeastwards during the upper Proterozoic (Baker, 1971).

Radiometric dates of c. 600 m.y. from accepted pre-Upper Proterozoic Malvernian rocks are necessarily interpreted as reflecting the effect of Upper Proterozoic events in a way similar to the Cadomian mineral ages obtained from proven Pentevrian basement rocks in the Channel Islands (Adams, 1967a & b). Trends from the Malvernian Complex and other pre-Upper Proterozoic rocks in the South Midlands belt are significantly N/S, offering a further example of the similarity of the pre-Upper Proterozoic history of Armorica and the Midlands. The problem remains to determine whether the similarities are coincidental or real evidence of the existence of a common cratonic basement as suggested by Baker (1971)

Such a conclusion was foreshadowed in the various reconstructions assumed for the area south of the Caledonian

Table of Contents

regions by several authors who have concentrated on this orogeny (e.g. Dewey, 1969, Rast & Crimes, 1969). South of the Caledonian front a large tract of country extending into northern Europe was linked into a single broad zone having a more or less common structural history. However, the separation between southern Wales and the northern Cotentin is considerable and the possibilities of plate movement suggest caution.

The evidence From the Lizard Complex is important if equivocal. The significance of published radiometric dates from the Lizard are reviewed by Adams (1967b) who assesses their implications along with his own results. A spread of K/Ar hornblende figures from the Landewednack schists back to nearly 500 m.y. is possibly indicative of rejuvenated Cadomian metamorphic ages consequent upon Variscan thermal events such as the intrusion of the Kennack Gneiss (Miller & Green, 1961a & b). Certainly there is no evidence of Caledonian influences strong enough to expel argon as far south as the West Country. A Cadomian metamorphism of the older Lizard rocks would make likely the correlations suggested on lithological grounds with the Sark schists and gneisses (Wooldridge, 1925, Sutton & Watson, 1957) proven in part to be of Proterozoic age (Adams, 1967a & b) though not enough is known of the Sark complex to rule out a Pentevrian age for some parts of it at least. Such a conclusion advances the known northern limits of Upper Proterozoic Armorica to the Lizard but still does not prove that the south Midland basement to the Upper Proterozoic was one with that of Armorica. Nonetheless it narrows the possible location of any break that may have existed to virtually the northern boundary of the Lizard since it can be shown that structurally the later Old Red Sandstone continent extended at least as far as the area in which the Dartmouth Slates were deposited (see section 6).

3. The Cadomian Orogeny

The Cadomian orogeny affected different parts of Armorica in different ways (fig. 3B). In Normandy, Graindor (1957, 1962, etc.) first hesitantly, and then firmly, recognised two main phases of movement. The Constantian phase was considered the cause of a widespread uplift essentially without tangential compression which initiated the flysch facies of the Upper Brioverian. The evidence for

Table of Contents

the phase relied primarily on differences in fold style apparent between the Upper Brioverian and the older Brioverian. The structural evidence presented by Graindor in his papers cannot be taken as proving the unequivocal existence of two major structural events in the older Brioverian and only one in the Upper Brioverian. Dupret (1974 in press) and Squire (1974 in press) have been unable to substantiate two fold phases in the older Brioverian of the Granville and St. Pair sections and conclude along with Roach *et. al.* (1972) that there is no significant difference structurally between younger and older Brioverian. This is a vital matter because it was from the presence of a phase of deformation between the older and younger Brioverian that Cogné (1963) defined his Normannian updoming and correlated it with another updoming in southern Armorica.

If the onset of flysch sedimentation is considered essentially synchronous over the whole Brioverian geosyncline, as is implicit in Cogné's reconstruction (1963), then a period of orogenic activity must precede the event. However, it has already been shown that contemporaneity of flysch sedimentation is extremely unlikely and certainly unproven in Armorica. Additionally, if the flysch facies indicates updoming there should be a similar updoming preceding the flysch of central Brittany (grès et poudingues de Gourin). The counter evidence of the last decade argues convincingly for a time-space development of orogeny that is at fundamental variance with the synchroneity and uniformity implied in the classical geosynclinals concept (Aubouin, 1965).

In northeastern Armorica the principal phases of deformation led to tight folding on upright axes running c. E/W and regional metamorphism. In Normandy the metamorphism is of greenschist facies but on Sark higher facies occur (but see reservations as to possible occurrence of Pentevrian within the complex). Evidence from radiometric work on K/Ar in biotite and hornblende from St. Brieuc to the northern Cotentin (Adams, 1967a) has shown that both Penlevrian and Brioverian rocks were heated sufficiently in the Cadomian metamorphism to reset the K/Ar ratios between 650 and 620 m.y. Two phases of tight, near isoclinal, folding are recorded (Kyan. 1973).

The intrusive history of the area was full and varied (Adams, 1967a & b, Roach *et al.* 1972, Bishop *et al.* 1974) with an early

Table of Contents

synkinematic intrusion represented by the L.'Erée adamellite, at c. 690 m.y., a middle phase of gabbros and diorites in the Channel Islands of post metamorphic date (c. 600-550 m.y.) and late post-orogenic granites in Normandy and the Channel Islands. The huge Mancellian batholith Union, 1973) belongs to this stage.

A second area of considerable interest and somewhat different structural evolution is that of northern West Finistère (Bradshaw *et al* 1967). All early phase of probably recumbent folding on axes of possibly more northerly trend than the typical Cadomian direction was succeeded by the principal folding to give tight folds cm ENE/WSW axes together with the intrusion of the synkinematic granodiorite of the Gneiss de Brest (c. 690 m.y., Adams 19671)).

The main phase of regional metamorphism followed the folding, though several other minor folds, often of local extent only, are also found. The main metamorphism produced a band of metamorphic rocks reaching upper almandine amphibolite facies in the southern Pays de Leon. The late Pointe des Renards Granodiorite, dated to 565 m.y. occurs in the north of the area (Taylor 1970).

The southern part of Armorica is a difficult area in which to study the Cadomian for there is a very strong Variscan overprint throughout the whole region. A main phase of southward facing recumbent folds associated with regional metamorphism appears to be the dominant deformation (Cogné 1966). The trend is E/W and is discernible in the Cadomian axes of Lanvaux and Moëlan which are cut through by the WNW/ESE-trending Variscan structures.

Throughout Armorica, the principal Cadomian structural trend, whether it be metamorphic foliation or axial plane cleavage, falls within the narrow sector ENE/WSW to E/W (fig. 3B). The Pentevrian basement received this same impress in some areas, but commonly more northerly trending pre-Upper Proterozoic structures are still discernible. North of southern Armorica, the Cadomian grain dominated the Phanerozoic development of the whole area affecting the nature and course of Palaeozoic sedimentary and tectonic history, guiding deformation during the Variscan orogeny and continuing to offer lines of weakness during post-Palaeozoic times right up to the present (Bishop *et al.*, 1969).

Table of Contents

The period after the main Cadomian metamorphism ended at c. 620 m.y. until the final cooling at the end of the Cambrian, beginning of the Ordovician at c. 520 m.y. (Adams, 1967a). embraced a number of increasingly acidic intrusions particularly in northeastern Armorica, uplift of the orogen and deep erosion. Areas of some extent still remained above sea level during the Lower Ordovician but the transgressions represented by the Gras Armoricain and the succeeding *Schistes à Calymènes* are comparable to the post-orogenic Lower Carboniferous and Liassic marine transgressions across Britain.

4. Cambrian

The complete and final acceptance of the profound nature of the post-Cadomian unconformity throughout Armorica (Cogné, 1963) provided the basis for a new look at a number of preOrdovician successions such as the *Série de Montfort* (Rennes area), the *Arkoses de Bain* (northern Cornouaille), red beds in the Vendée and the important and extensive Cambrian deposits of Normandy and Maine (Doré, 1972, etc).

In spite of the advances in the last 15 years one outstanding problem remains and provokes diverse views. Five deposits of coarse red beds occur more or less on an arc marking out the deep gulf between the Cotentin and the Tregorrois. These, together with the Lessay series from the Montmartin syncline, are shown on fig. 3C and an excellent summary is given by Cogné (1965a). The Lessay series has been conclusively dated to the end-Devonian regressive phase (Doubinger & Poncet, 1964) but this series differs markedly from the other five outcrops (Doubinger & Poncet, 1964) for, though it commences with a polygenetic conglomerate and passes up into alternating red shales and sandstones, the main member, the *Grès du Robillard* is of Culm facies. By contrast, the other outcrops are entirely isolated from any marine successions and their general coarseness and red colour are indicative of a major phase of post orogenic erosion.

The deposits of Plouézec/Plourivo and Erquy/Fréhel are the subject of controversy in the wake of the radiometric data published by Bonhomme *et al.* (1966). The authors of this article consider that the results, in spite of their own reservations as to the significance of

Table of Contents

a spread of ages, favour a Lower to Middle Devonian age for the deposition of the two series. The results published by Adams (1967a & b) indicate that the majority of mineral ages from northern Brittany, in contrast with those from the Channel Islands, yield Variscan or partial overprint dates whether the rocks from which they are derived are of Lower or Upper Proterozoic or more recent age. Thermal events in the Variscan were able to cause rehomogenisation of the isotopes of all earlier formations and, in view of this and the nature of the reservations indicated by the authors themselves, it is assumed that the evidence for a Lower to Middle Devonian age is still inconclusive.

British authors working on the Rozel Conglomerate (Squire and Renouf) and the Alderney Sandstone (Sutton & Watson, 1970 Renouf & Squire, 1972) and on the Channel Islands in general consider that these red beds and the comparable deposits at Omonville-la-Rogue near Cap de la Hague (Sutton & Watson, 1970) are of late Cadomian age directly consequent upon late Cadomian uplift. The Rozel Conglomerate is cut by a hornblende lamprophyre dyke with a minimum age of 427 m.y. (Adams. 1967b) but the Alderney sandstone is not so well delimited.

With the exception of the Lessay series, these conclusions are in accord with the late Cadornian age favoured by Cogné (1965a) before the radiometric data from Erquy raised doubts. It is not easy to envisage in event in early Devonian times sufficient to cause the mountainous terrain required for the deposition of the Plouézec/Plourivo and Erquy/Fréhel coarse continental clastics when the evidence from immediately adjacent areas to the south (Châteaulin/Ménez-Bélair/Laval) and east (Lessay to Flamanville) is for deepening of the water not shallowing. It is of significance to note that the series of red beds under discussion all overlie rocks of the Brioverian or Pentevrian cycles (Cogné, 1965a) and never of the Lower Palaeozoic.

Deposits of late Cadomian-pre-Ordovician age are better dated in Normandy and Maine, central and southern Brittany and the Vendée. The principal successions are well summarised by Babin *et al.* (1968). In the Vendée, the earliest Palaeozoic rocks are Middle Cambrian (Cavet *et al.,* 1966) but northwest of this region it is still not possible to be precise about the age of the various basal Palaeozoic conglomerates such as that of Montfort or of the rather

Table of Contents

variable series of red beds that overlie them (fig. 3C). However, all are overlain by the Grès Armoricain. In Maine and Normandy the Cambrian successions are now well documented and the palaeogeography established in sonic detail as a result of the work of Doré (see Doré 1972, for synthesis and bibliography). The Alderney and Omonville sandstones are brought into the framework of a Cambrian land area draining more or less eastward (Sutton & Watson, 1970) towards the deeper water lying in that direction (Dore, 1972). In spite of the intrusion of granites in Jersey in the very youngest Cambrian, the Rozel Conglomerate tits better into an earlier Cambrian palaeogeography such as is suggested by Dore (1972) for his oldest or middle Cambrian regressive stages.

A particular feature brought out by Doré's work is the emergence of ENE/WSW to E/W trending shorelines and facies changes during the Cambrian. Rapid changes of thickness occur across a series of embayments penetrating into the land area of Domnonaea lying to the west and these embayments and the intervening promontories are aligned ENE/WSW (fig. 3C). A series of transgressions and regressions record the phases in the uplift and denudation of the Cadomian mountain chain. Sonic igneous activity occurred late in the Cambrian, even into the Ordovician (fig. 3B). On Jersey, the youngest granites are dated to 490 m.y. (Adams, 1967b) and this lends support to the palaeogeographical reconstruction of Lower Ordovician times offered by Doré (1972, fig. 6) which shows Jersey and areas to both south and west as part of a still emergent land area. On the southeastern margin of the Mancellian batholith keratophyric activity was widespread and important along another ENE/WSW trending line.

Northwards Cambrian rocks are found in Pembrokeshire and the Welsh Borders where they are everywhere unconformable on the Precambrian. The lack of Cambrian sediments suitable for palaeomagnetic work is hindering progress which might have aided an assessment of the relative positions of Armorica and South Wales/southern Midlands in early Palaeozoic times.

5. Ordovician and Silurian

The distribution of the distinctive *Grès Armoricain* facies of largely Arenig age has been singled out for particular attention in a

Table of Contents

number of reconstructions of early Ordovician palaeogeography (Spjeldnaes, 1961, 1967). The temporal and environmental equivalence of the deposit southward from the English Channel into Morocco and possible pre-drift Florida suggests continuity of basement below it at this time. The minimum northern extent of the facies on present day geography is shown in figure 3D which is based upon the work of Doré (1972) and the author's work in western Brittany (Renouf 1965). If there has been no separation of the southern British area south of the Lizard Complex, then the *Grés Armoricain* reached very close to England north of the Cotentin.

In its ideal expression the *Grés Armoricain* is a mature orthoquartzile very variable in thickness as befits its expression of a major transgression onto a well peneplained recently stabilised continental platform. In Normandy (Doré, 1972) and in Pinistère (Bishop *et al.,* 1969), detailed information is available on the position and trend of shorelines and the direction of transgression (Fig. 3D). The trend of the shorelines in Normandy shows the continuing influence of the ENE/WSW structures already in evidence during the Cambrian though the details become increasingly blurred as the Ordovician progresses and more of the land area to (lie west becomes submerged. In Finistère the most striking change of' thickness occurs across all important ENE/WSW line which crosses the Crozon peninsula. The earliest phase of the *Grés Armoricain* transgression reached northward only as far as this point while the second phase carried the sea well into the Pays de Leon. This Crozon disturbance continued to influence sedimentation at least until Silurian times and was the site of considerable Caradocian basic volcanic activity.

The faunal evidence from the succeeding deeper water Llanvirnian *Schistes à Calynènes* is suggestive of a common province existing between the Welsh basin and Armorican (Spjeldnaes, 1967, Whittington & Hughes, 1972) though detailed comparisons are lacking. On the simple, if unproven, assumption that the deeper water of the Llanvirn indicated a further northward extension of the Ordovician seas from Armorica the shoreline could have reached southern England (on present geography).

The succeeding Llandeilian stage is of particular significance for positive evidence is forthcoming from Southwest England for the first time. The Gorran Quartzites of the Roseland area of south

Table of Contents

Cornwall belong to the long disputed Lizard/Dodman/Start zone. Their existence has been known for a very long time as has their similarity to deposits of equivalent age in Armorica but many conflicting views have been expressed on how they came to be in their present position, a piece of Armorica on the northern side of the Channel. Sadler (1973b) has confirmed the Llandeilian age of the fauna and made precise correlation with the *Petit Grès de May* (Normandy) and the *Grès de Kerarvail* (Finièstre) and emphasizes its distinct faunal affinities with these formations. From his detailed mapping Sadler (1973a, 1973b) asserts that the regularity of attitude of the Gorran Quartzites and their consistent relationship to the beds above them precludes a wildflysch origin and limits the thrusting to the minimum needed to move Ordovician rocks locally onto Devonian. The balance of evidence strongly favours the extension of the Armorican Ordovician facies northward from Armorica at least to the south coast of Devon and Cornwall in Llandeilian times and probably in the Llanvirn. The place of the other rocks of Armorican aspect and somewhat less certain age from the Meneage and other localities between the Lizard and Dodman remain somewhat uncertain but the conclusion just drawn does not contradict Lambert's (1965) contention that the Meneage breccias are primary structures of probable Devonian age.

In the Lower Palaeozoic palaeogeographical reconstructions offered by many authors (Spjeldnaes, 1961, 1967, Whittington & Hughes, 1972, Smith, Briden & Drewry. 1973, etc.), the evidence for the position of the area between South Wales and Armorica must be questioned. Because of the general absence of information on the Lower Palaeozoic in the area, the faunal and sedimentary boundaries indicated on the majority of Spjeldnaes' maps (1961, 1967) between Armorica and Wales are usually placed north of the last known occurrence of the evidence under review and south of the next to the north which means somewhere between Cap de la Hague and South Wales.

The end of the Ordovician in Armorica was characterised by a regressive phase which led to much restricted Silurian deposition often with a tendency lo develop a euxenic phase. Recently Deunff *et al.* (1971) have described a submarine Silurian outcrop on the southern margin of the Minquiers between St. Malo and Jersey.

Finistère is the site of the only significant volcanic activity in

Table of Contents

Armorica during the Ordovician and Silurian. Recently Dangeard and Doré (1971) have claimed glacial involvement in the deposition of some uppermost. probably Ashgillian. deposits in Normandy.

6. Devoniau

At the close of the Silurian and the opening of the Devonian, a distinctive lithology is developed in many parts of Armorica known as the *Schistes et Quartzites.* The onset of this rather flysch-like facies cannot be dated precisely but the formation is certainly of post-Ludlow to pre-Siegenian age almost everywhere. The distribution of the facies is not as widespread as that off the succeeding *Grès à Orthis Monnieri* which is one of the most important marker horizons in Armorica (Renouf, 1972). The chief feature of the *Schistes et Quartzites* (Bradshaw, 1963, and Renouf 1965) is the indication it gives of a sudden period of instability throughout the area. In Finistère the sediment was derived from a rising source to the north and deposited in an unstable southward-facing slope occupying al least central west Finistère. How far away to the north was the rising source area is uncertain but it could not have been less than tens of kilometres and may have been considerably more. In terms of present geography this would mean probable derivation from the southern part of the Western Approaches (fig. 3E). Unfortunately similar information on source areas for *Schistes et Quartzites* elsewhere in Armorica is not available. An area of particular interest would be the Cotentin where Robardet (1964) has indicated the problems of poor outcrop. If is difficult to avoid the conclusion that the movements involved and particularly those affecting the source areas of the thickest *Schistes et Quartzites* in Finistère were different in kind from those affecting sedimentation in the Lower Palaeozoic.

The return to the more typical platform/shelf conditions of the Silurian and Ordovician is heralded by file onset of *Grès à Orthis Monnieri* ssedimentation which represents a marine transgression across Armorica (fig. 3D). The most northerly outcrops occur in the Cotentin and in Finistère. The author (1972) has described the formation in some detail and indicated its palaeogeographical significance concluding that file transgression is not discernible in the Ardennes area to the east nor in southwest England though southward there are Spanish outcrops, notably the Carazo

Table of Contents

Formation, which can be correlated with the *Grès à Orthis Monnieri* thus recalling the *Grès Armoricain* situation.

In Southwest England north of the Lizard/ Dodman/Start line the youngest Devonian strata are represented by the "purple and greenish fish-bearing" Dartmouth Slates (House & Selwood, 1966). The fauna (White, 1956) is a typically Old Red Sandstone continent fish assemblage with the Pteraspids providing evidence of Lower and Middle Siegenian age. Stress must be laid on the significance of this fauna. The environment of deposition indicates that the conditions were marginal to the Old Red Sandstone continent and that the fauna was washed into the area. In other words the Dartmouth Slates provide incontrovertible evidence that the Old Red Sandstone continent extended almost as far south as the Lizard/ Start/ Dodman zone. The subsequent Devonian history of Southwest England must be interpreted against this background which has as a vital consequence the impossibility of having a pre-Lower Devonian oceanic crust anywhere between the Lizard/ Dodman/Start zone and the Old Red Sandstone continent in the north. The choice is further limited by the presence of the Gorran Quartzites of Llandeilian age and the Gedinnian shales and volcanics resting on them (see below).

A notable advance in Lower Devonian stratigraphy is provided by evidence from the Roseland area of South Cornwall (Sadler, 1973a, 1973b). Sadler has described spilites within a condensed Gedinninan and Siegenian sequence of shales with associated bioclastic limestone lenses and conglomerates. Both the sedimentary and volcanic deposits are less than 100 metres thick giving a Lower Devonian succession of not more than 200 metres in total. According to Sadler the lowermost Devonian rests on the Llandeilian Gorran Quartzites with a non-angular unconformity. Such a relationship would not be out of place in Armorica, as Sadler points out, though no environmental equivalence exists between the two areas during the Lower Devonian.

The Llandeilian and Lower Devonian environments in the Roseland area were very different, and subsidence of this probable northern edge of the Armorican platform/shelf area to relatively deep water must have been rapid, particularly in view of the Upper Ordovician and Silurian regressive phase in northern Armorica.

The nature of these late Lower Palaeozoic disturbances is most easily related to an extensive period of relative uplift and

Table of Contents

subsidence across strike trending zones or lines of weakness and by further extension to fault movements. It will be argued that Four distinctive zones existed between the southern margin of the Old Red Sandstone continent and the northern margin of Armorica throughout the Devonian and Lower Carboniferous. These are from north to South:

(i) a sub-continental environment (Dartmouth Slates. Hangman Grits, etc).
(ii) a central zone of basins and swells which were probably fault bounded and which moved northward in time from Gedinnian in the Roseland area to Visean in southern Exmoor and resulted in the general depression of an extensive tract marginal to the Old Red Sandstone Continent.
(iii) a zone always forming the southern boundary of zone (ii) at any one time in which greywackes were deposited.
(iv) these greywackes derived from a yet more southerly area of uplift which also advanced northward with time and finally overtook the area of subsidence in Namurian times after a lull in the late Devonian and early Carboniferous.

Sequences above the Gedinnian and Siegenian continue to show similar differences between the four zones outlined (figs. 3D to 3I). The Dartmouth Slates are succeeded by the marine sandstones, shales and coarser beds of the Meadfoot Beds, Staddon Grits, Newquay slates, etc. The faunal affinities of these deposits lie with the Ardennes rather than with Armorica (Renouf, 1972). In general terms, the fluvio-deltaic environment of the Dartmouth Slates has been replaced by a transgressive marine facies still of strongly clastic nature. The possibility exists of correlating the deepening water conditions from late Gedinnian times in Armorica with the marine invasion of the area of Dartmouth/Meadfoot/Staddon coarse clastic sedimentation of Old Red Sandstone links and the deeper water Roseland succession.

In Armorica, the re-establishment of a moderately stable platform environment during Siegenian, Emsian and early Eifelian times with the deposition of shales and limestones in many areas (Babin *et al.* 1972) proved to be only a temporary reversion. The Middle and Upper Devonian throughout Armorica was a period of

Table of Contents

shrinking seas and emerging areas.

In Southwest England the situation is strikingly different. Between South Devon and North Devon an area of diverse underwater topography was established (Erben, 1964) with Facies representative of many environments. The deltaic/fluviatile zone fringing the Old Red Sandstone continent was pushed northward to the classical areas of North Devon. A consequence of the earlier proof for the southward extension of the Old Red Sandstone continent in the early Lower Devonian is the establishment of this deeper water complex on an underlying Old Red Sandstone basement. There is no evidence to suggest that oceanic crust could have developed north of the Lizard/Dodman/Start zone during this time which lasted at least until the early Frasnian (House & Selwood, 1966).

South of the outcrop of the Meadfoot Beds lies the large area of the Gramscatho and Mylor formations. Once again Sadler's work in the Roseland area (1973a, 1973b) is directly relevant. The onset of the first phase of the Gramscatho greywackes in the Roseland area is considered to be probably Eifelian though Sadler was not entirely sure of its certain commencement in the Eifelian. The volcanic sequence certainly extended into the Eifelian. Other evidence, little of it published, is more than suggestive of a predominantly Middle Devonian age for these thick greywackes (Flendriks *et al.* 1971) though Upper Devonian is also present locally. Derivation of the clastics for this succession is considered to be from the south. The interest of the complete Lower-into-Middle Devonian succession from the Roseland area is that it extends the significance of the sequence there to the northern edge of the Gramscatho deposits. In terms of palaeogeography, the Roseland Lower and Middle Devonian successions indicate the existence of an area of relatively deep water free from terrigenuus clastics throughout the Lower Devonian but invaded from the south by copious greywacke sediments in the Eifelian.

In North Cornwall the late Middle and Upper Devonian deposits (Gauss & House 1972), though thoroughly clastic are of deeper water origin than the preceding Staddon Grits lying to the south. In South Devon, Middle Devonian limestone deposition was possible on the swells in certain favoured areas but general

Table of Contents

deposition in this area and westward into north Cornwall was related to the unstable area of basins and swells undergoing overall, if differential, subsidence (fig. 3F). The subsidence culminated in the Upper Devonian with the establishment of a larger area of deeper water in which a spilitic/shale facies akin to the earlier Roseland episode was dominant (fig. 3G). Only in North Devon was there a continuation of the terrestrially derived clastic facies marginal to the Old Red Sandstone landmass. The generally thin Upper Devonian successions to the south are continued, apparently conformably, into the Lower Carboniferous with increasing evidence of volcanism and associated radiolarian cherts - the bathyal lull of Goldring (1962).

The Devonian of Armorica is admirably summarised by Babin *et al.* (1972). Following the deposition of the *Grès à Orthis Monnieri* the seas over Armorica generally deepened during the later Siegenian and Emsian though nowhere did they become very deep. In general the outcrops are rather scattered and this restricts the accuracy of palaeogeographical reconstructions. The author considers that the Siegenian seas shown by Rabin *et al*. (1972, fig. 3a) are too restricted, particularly in the north where evidence is largely lacking. Certainly the indication of comparatively large numbers of the *Grès à Orthis Monnieri* fossils found in the Budleigh Salterton Pebble Beds of Lower Triassic age is for a much greater extension of this sea to the north. Even in the Eifelian (ibid., fig. 3b), the evidence and extent of a land area over northern Armorica must remain open to considerable modification as no Eifelian strata have survived north of the Laval Basin (fig. 3F).

The same problem of absence of strata assumes even greater significance in the Givetian and Upper Devonian when an attempt is made to reconstruct the tectonic history underlying the events of that time interval. It is just not possible to be sure in many cases whether absence of beds is because no deposition occurred or because erosion subsequently removed them. Nonetheless the overall pattern of increasingly restricted areas of marine sedimentation throughout Armorica is firmly established (Fig. 3G).

No Givetian is known in Armorica north of the Vendee. This is interpreted by most geologists as indicating non-deposition and consequently also general uplift and regression of the sea. Babin *et al*. (1972) note that this stage produced "mouvements épirogéniques annoncant la phase bretonne de l'orogéncèse hercynienne".

Table of Contents

The Upper Devonian outcrops (fig. 2) are patchy and scattered but there are indications of marine influences in all areas of previous Devonian sedimentation except for the eastern Laval Basin and Normandy where the Upper Devonian is not recognised (but see next section). Nowhere is the Upper Devonian present in an uninterrupted sequence and the deposits are either those of sea areas of restricted circulation and access to the main Devonian oceans (Finistère is a good example, Babin and Plusquellec 1965) or even the first coarse clastics of terrestrial or sub- terrestrial environment (*Serie rouge de Hyenville*, Doubinger & Poncet, 1964, and the precocious Culm of the Ancenis synclinorium, Cavet *et al.* 1966).

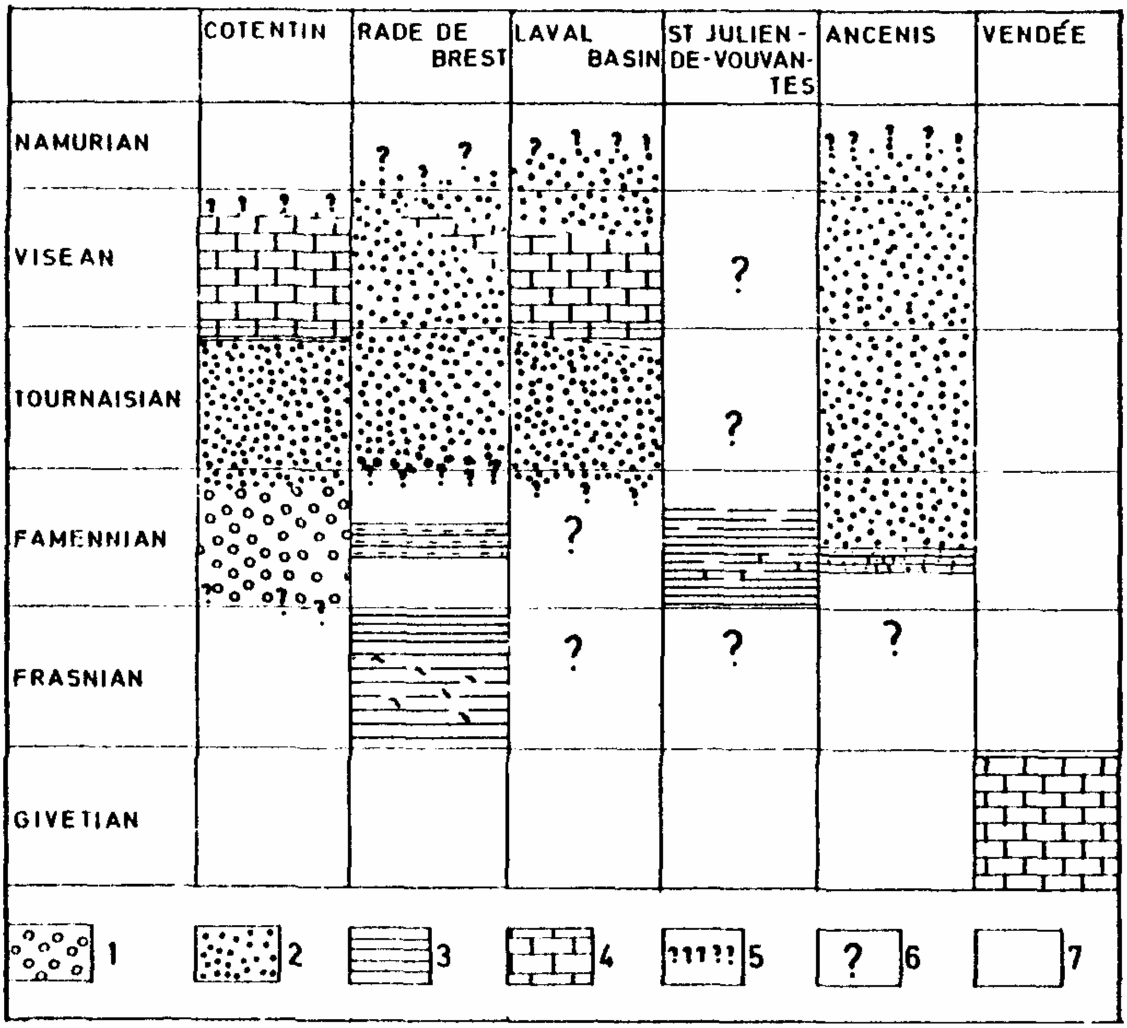


FIGURE 2. Givetian to Namurian facies changes in Armorica.
1. Série rouge de Hyenville. 2, Undifferentiated Culm. 3, Upper Devonian regressive facies. 4. Visean limeslones. 5, commencement or cessation of sedimentation uncertain. 6, emergence of land area uncertain. 7, emergence of land area likely.

Table of Contents

N.B. Since the preparation of the figure. Monsieur H. Lardeux has kindly suggested slight modifications. Ancenis column: limestones and cherts (lydiennes) are represented in the Frasnian, and the shales above pass without apparent break into the Fanennian Culm Facies. The Culm facies should be ended at about the Visean / Namurian boundary. St. Julien de Vonvantes: the Famennian succession is proved to Zone VI at the Devono-Carboniferous boundary. Rade de Brest: the title should read *Rade de Brest/Châteaulin.*

7. Lower Carboniferous and Namurian

The earliest Culm measures of Armorica - for which Pelhate, (1967) makes an excellent case for accepting as a molasse rather than a flysch in that it is deposited from a land area above sea level into basins at or near sea level - are dated to the Upper Devonian. Unfortunately there is no direct fossil evidence from within the Culm to give precise dating. The *Serie rouge de Hyenville,* in spite of the evidence presented (Doubinger & Poncet, 1964 and Pelhate & Poncet, 1970) cannot be precisely dated within its broad Upper Devonian context.

In the Laval Basin there are thick Culm deposits with associated volcanics underlying Middle Tournaisian marine intercalations (Pelhate, 1967). In the Ancenis synclinorium marine Frasnian shales, underlain by a basal lydite conglomerate, pass up without any apparent break into the Culm which in this area is known to reach as high as the Namurian in this facies (Cavet *et al.* 1966). A Famennian age for the onset of the Culm here seems likely, with a Famennian (or perhaps slightly younger) age for the St. Julien de Vouvantes synclinorium to the north where marine Famennian is known. An early Famennian age is also likely for the Laval Basin.

A useful pointer to the nature of the movements during this critical Middle and Upper Devonian interval results from a study of the shift of loci of sedimentation. In Finistere the Devonian locus is the Rade de Brest but after the Famennian the sedimentation had shifted to the Chateaulin basin in the south. The first Culm conglomerates, undated, but of post Famennian V age in this basin are disconformable on various members of the Devonian (Pelhate, 1970). In the Laval Basin the area of Carboniferous sedimentation was much reduced from that of the early Devonian. In the Cotentin the *Serie rouge de Hyenville* rests on Brioverian in places and is quite separate from the Devonian outcrops to the north (Poncet, 1972).

Table of Contents

Culm deposition in Armorica resulted from a general rise of the land throughout the region and the expulsion of the sea from most of it. Where marine influences persisted there is equal evidence to demonstrate that finally these were overwhelmed by coarse, terrestrially derived material.

The Carboniferous of the Laval Basin provides much of the present evidence on which interpretations can be based thanks to the excellent work by Pelhate (1967). A picture emerges of an unstable basin flat lying southward of elevated uplands to the north. These uplands seem to bear a direct relationship to the Mancellian batholith (fig. 3H - & Doré, 1972). The palaeogeographical trends influencing sedimentation run WNW/ESE in a direction paralleling the axes of the structural basins of St. Julien de Vouvantes and of Ancenis to the south. Pelhate considers that the boundary basin/upland was fault-controlled and produced a steep slope in the late Devonian down which the first molasse conglomerates tumbled and with which keratophyric volcanic activity was associated. Following this period of initial fault instability on a considerable scale, the interval from the end of the Tournaisian to at least Visean 2b was one of limestone deposition on a shallow water area deepening a little to the SW across a line of flexure, that of Changé/Laval. Many varieties of limestone were deposited in environments that fluctuated in the wake of slight tectonic movements. Fresh uplift to the north at the end of the Visean heralded a further period of Culm deposition represented by the *Schistes de Laval.* The new flood of deposition was slightly earlier in the north than the south but rapidly extended to cover the whole basin. The *Schistes de Laval* are thick and mainly Namurian but no detailed information is available on true thickness or upper age limit. Coal lenses are locally developed.

Apart from a disconformity of "quelques degrés" (Pelhate. 1967) beneath the early Culm, which rests upon various levels of the Devonian, there is no evidence of any compress ional movements until after the deposition of the *Schistes de Laval* which Pelhate (ibid.) reports as strongly folded with steel) southern limbs to anticlines (cf. Bradshaw *el al.* 1967).

To the north, in the Montmartin syncline the succession is not as well known though it corresponds in broad terms to that of Laval (Doubinger & Poncet 1964, Pelhate & Poncet 1970). The Culm of the

Table of Contents

Châteaulin Basin is not yet properly dated (Pelhate, 1970) but is thick and has some Visean calcareous elements in the succession. In terms of facies it is comparable to Laval. The St. Julien de Vouvantes and Ancenis synclinuria show less marine influence than the other Culm areas.

Cavet *et al* (1966) report small outcrops of Lower Westphalian from the Ancenis synclinorium which rest "en discordance sur le Namurien". However, no information is given to indicate whether there is a significant structural discordance between Namurian and Lower Westphalian. No Westphalian is known elsewhere in Armorica through Stephanian in intramontane basins occurs if Normandy (Littry), near Laval and in the *Baie des Trépassés,* east of Douarnenez (fig. 1).

FIGURE.3. Explanation.
1. marine transgressions. 2. Sediment movement. 3. pre-Upper Proterozoic basement. 4. spilite/siliceous shale association. 5. undifferentiated Upper Proterozoic. 6. ophiolite suite. 7. recumbent fold phase recognised. 8. synorogenetic granite intrusions. 9. areas of regional metamorphism higher than greenschist facies. 10. intermediate and acid vulcanism of Jersey and St. Germain-le-Gaillard. 11. late Cadomian cross-cutting granites. 12. generalised Cadumian trend. 13. Douarenez Ordovician granitic intrusion. 14. red beds. 15. marine sediments. 16. keratophyric vulcanism. 17. western boundary known Cambrian. I8. Alderney/Omonville-la-Rogue. 19. Erquy/Fréhel. 20. Plouézec-Plourivo. 21. Rozel Conglomerate. 22. Mancellia. 23. initial Grès Armoricain transgression (1) with northern shoreline and site of Caradocian vulcanism.24. minimum northern limits of main Grès Armoricain transgression (2-2). 25. minimum northern limit of Llavirn transgression (3-3). 26. possible northern limit of Llandeilian transgression (4-4). 27. sediment movement for Schistes et Quartzites. 28 boundary of northern-most outcrops of the Grès à Orthis Monneiri (not of the transgression itself). 29. known areas of Siegenian/Emsian limestone/shale deposition. 30. rising source area of lower Devonian times. 31. spilite/shale association based upon the Lower Devonian Roseland succession. 12. Dartmouth Slate zone. 33. sediment movement from the Old Red Sandstone Continent in the Siegenian. 34. areas of limestone shale deposition. 35. source area as for 30 but further north. 36. area of Gramscatho sedimentation. 37. basin and swell province with varied facies. 38. uncertain due to lack of outcrop. 39. deposition marginal to the Old Red Sandstone continent. 40. restricted facies. 41. continental deposition of the Série rouge de Hyenville. 42. Gramscatho type deposition. 43. as for 37. 44. as for 39. 45. Culm facies with restricted marine limestones. 40. known shoreline. 47, as for 42. 48. as for 37. 49, as for 39. 50. Culm facies. 51, known line of facies change.

Table of Contents

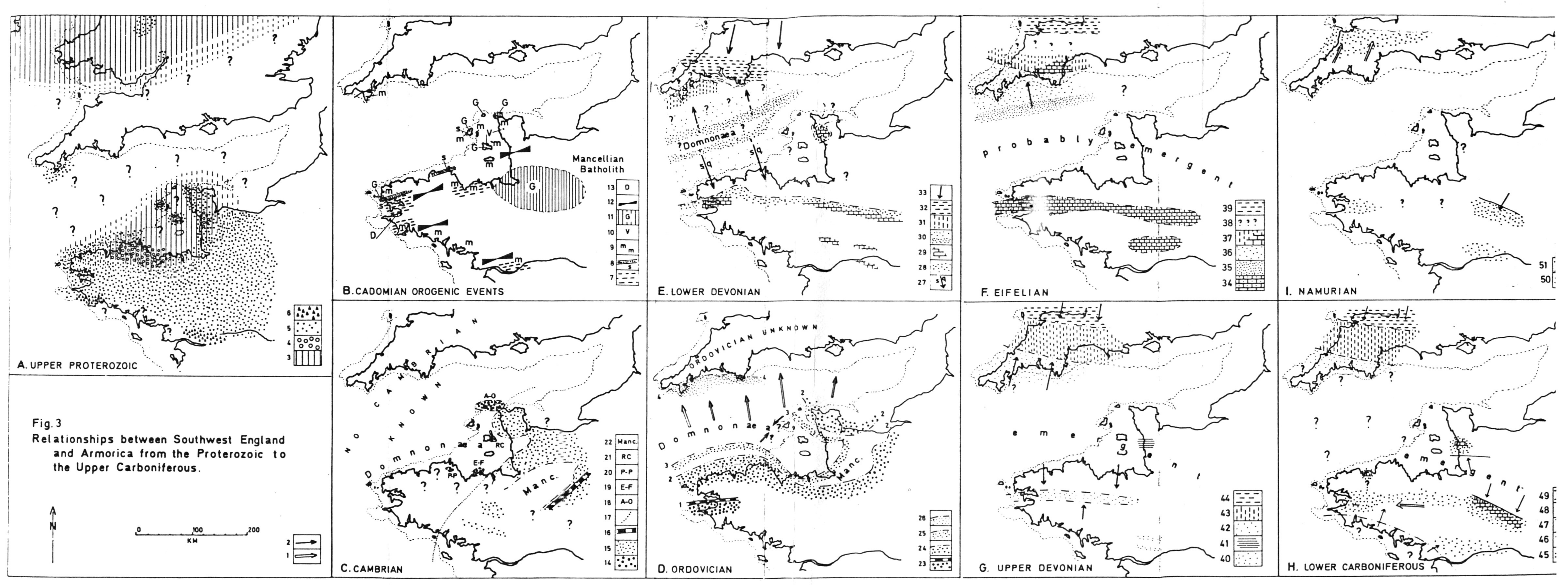


Fig. 3
Relationships between Southwest England and Armorica from the Proterozoic to the Upper Carboniferous.

8. The Variscan Orogeny - the main elements

(i) The Bretonic Phase in Armorica

In order to isolate a single Bretonic event of Stillerian type at the Devono-Carboniferous boundary, it is necessary to demonstrate evidence of dating. If it is further required to decide whether such an event represents the first phase of the Variscan orogeny, it must be shown that the event differs in kind from those preceding it. The evidence for accurate dating is not present and it is not easy to be certain that the event itself, whether expanded or not to embrace the Upper Devonian as well as the Dinantian, is fundamentally different front earlier movements affecting the Palaeozoic superstructure.

The sequence of events commenced with uplift during the Givetian which culminated in the maximum emergence during Tournaisian and Namurian times. The natural sedimentary progression during this period was increasing restriction of marine influences, passing eventually to continental controls, with a phase of renewed but minor marine influence in the Visean separating a lower Tournaisian Culm from an upper Nainurian one. The regressive Upper Devonian marine facies appears to have partially overlapped the onset of Culm deposition in the Famennian, a not unexpected feature of such a pattern of events. Unconformity was slight, indicating the general dominance of vertical movements over compressional stresses. In post-Namurian times the main compression of the Variscan orogeny developed more or less synchronously from southern Armorica to South Wales.

Comparison of the Devono-Carboniferous sequence can be made with the rather similar history of the Siluro-Ordovician and Lower Devonian. During the Upper Ordovician widespread uplift restricted Silurian marine deposition to a number of small basins, a trend which culminated in wide emergence during Ludlow times. The succeeding *Schistes et Quartzites* are comparable to some extent with the later Culm facies, the major difference relating more perhaps to relative degree of uplift and depression with respect to sea level than to any fundamental difference in type of uplift. The succeeding marine transgression of the Siegenian, Emsian and Eifelian was more widespread than, but not dissimilar from, that of the Visean. The comparison should not necessarily be taken too far but it emphasises the difficulty of defining not only the timing but

Table of Contents

the nature of the movements occurring from the Givetian onwards. If there is a real difference between the movements of Siluro-Ordovician and Devono-Carboniferous times it eludes recognition in the standard stratigraphical history of the Palaeozoic superstructure of Armorica as at present known.

In Southern Armorica, Cogné; (1957, 1963, 1965, 1966, etc.) and Cogné *et al.* (1966) have explained the onset of Culm conditions as deposition from the surface expression of an uprising, fundamental granitising dome located beneath the Cornouaille and active during the Dinantian (see in particular Cogné, 1965b, pp 237-245; Cogné *et al.*. 1966 pp 75-86 & fig. 15). Further consideration of the nature of the early Variscan deformation at depth is deferred until after a discussion of events in Southwest England.

(ii) Devono-Carboniferous Tectonic Events in Cornubia

The progressive depression of the continental margin of the Old Red Sandstone continent from the Dodman to southern Exmoor during the Devonian and Lower Carboniferous is an established fact. In general terms this effect developed with the appearance of a basin and swell topography which became steadily more depressed overall (luring the period up to the Lower Carboniferous.

It is possible that the northern edge of the Armorican shelf/platform in Llandeilian times at about the latitude of the Dodman was the first continental area to be depressed. This occurred before the Gedinnian spilite/shale sequence was deposited at Roseland. It is thought likely that these spilites, as those of the north (Floyd, 1972), developed from a continental basement.

The radiometric data from the Gramscatho belt (Dodson & Rex, 1971) point to a metamorphic event between 365 and 345 m.y. ago a period spanning the Upper Devonian. These authors correlate this event with that causing the Bretonic unconformity in Armorica although Sanderson & Dearman (1973) suggest that the dates represent uplift and cooling rather than the folding and metamorphism itself. The implication that the folding and metamorphism were earlier than Upper Devonian does not agree with the earlier structural interpretation advanced by Dearman (1971) for a period of folding and thrusting towards the end of the Devonian. Matthews (1966a & b) in his notes' on the St. Mellion

Table of Contents

outliers of Lower Carboniferous age considers that the structural evidence does not warrant the supposition of a late Devonian/early Carboniferous age for the recumbent folding that he recognises.

The facies that Matthews describes for the higher parts of the Lower Carboniferous outliers resembles the Culm of Armorica more than it does the contemporaneous ‘bathyal lull’ facies to the north. In north Cornwall (Gauss & House, 1972) and south Devon (House & Selwood, 1966), the late Middle Devonian to Lower Carboniferous strata are deposits of relatively deep water with fine argillites, turbiditic limestones and associated spilitic lavas. Derivation of the clastics appears to be from the south and in the Middle Devonian at least, the Pymouth ridge with its well-known limestones was the site of relatively shallow water and a possible source area.

This and other evidence suggests that the basin and swell area in south Devon and Cornwall during the Lower Devonian was overwhelmed from the south by sediments laid down in advance of an area of uplift, which either moved from one strike zone to another in a jerky fashion or more smoothly, though in both cases with a cumulative northward effect. It has yet to be shown conclusively that folding and thrusting accompanied this uplift. The structural history proposed by Sanderson & Dearman (1973) is heavily reliant on a relative chronology of deformations which is not at present related to the known stratigraphy. It is still possible that gravity tectonics were involved in the uplifts causing northward slides; hut this also has yet to be demonstrated conclusively.

(iii) Post-Namurian compressional folding

In neither Armorica nor Cornubia are strong compressional movements shown to affect the Palaeozoic superstructure before Westphalian times. It is equally important to note that whatever the history of the two provinces was before the Westphalian, during and after it there is a common development. The principal folding in Western Armorica has been described by Bishop *et al*. (1969) and is a line example of Stockwerktektonik. The youngest stratigraphical levels of the Culm in the Châleaulin Basin have a flat-lying cleavage which may relate to superfical deformations while the Devonian and Lower Palaeozoic formations have responded very much according to their lithology. The thick and competent *Grès Armoricain* has defined a simple series of asymmetrical folds facing SSE in western

Table of Contents

Brittany while the younger, less competent. formations show varying degrees of smaller scale yet consistent deformation. The Brioverian infrasfructure shows none of this folding style but has deformed by tightening and vertical extension. This vertical extension is thought to be the mechanism by which the Palaeozoic superstructure was deformed far, had the stresses been transferred through this superstructure, it would not have been thick enough to cause the observed deformation of the basement and an almost certain major décollement at the base of the Palaeozoics would have resulted.

In Cornubia equally important Stockwerktektonik is to be observed, though the complexity of the situation is much greater. The superstructure was both thicker and the infrastructure had been much disturbed by the development of a basin and swell topography and major overall depressions and elevations before the main folding phases. In spite of all that is now known of the structures from north Devon to south Cornwall, the full significance and explanations of the various styles of deformation and the different confrontations still await a convincing synthesis. An invaluable advance has been the recognition and isolation of the deformations associated with the intrusion of the late granite batholiths.

In southern Armorica the Brioverian infrastructure is largely overprinted by the Variscan structures which give to this area its distinctive WNW to ESE trend. Recent papers (e.g. Cogné. 1967, Bard *et al.* 1971. etc.) have proposed the continuation of the structures of western Armorica through a southward swinging arc across a pre-Biscay-sphenochasm into northwestern Iberia. It is worth emphasising that the ENE/WSW trends of Finistere north of Douarnenez are those of the Brioverian infrrastructure and are not of Variscan origin.

Both in the Cornouaille and elsewhere in northern Armorica, the so-called Armorican direction - WNW/ESE - is found cross cutting the WSW/ENE Cadomian structural trends. In the south the Variscan overprint is dominant and relates not only to lines of comparatively late shear zones (Cogné, 1963. 1965b, 1966, etc.) but also to more fundamental metamorphic lineations and foliations. In the north where the Variscan metamorphism is less intense, the Armorican trend is expressed by zones of dislocation e.g. Basin de Ménez Bélair and Les Abers (Cogné and Shelley 1966). The existence of such strong expressions of WNW/ESE trends throughout the

Table of Contents

province offers the possibility that the direction of principal post-Namurian compression had a more northerly component than is immediately apparent from the controlling effect of the WSW/EWE trending basement structures. This interpretation could perhaps be extended to SW England where the generally E/W trends north of the Gramscatho Belt would reflect decreasing basement control where Upper Palaeozoic sedimentation was thickest.

Features of common geochemistry between the two provinces (Floyd, 1972) are significant. Variscan granites occur from the Cornouaille, where they are a little earlier and more elongated than those farther north, throughout northern Armorica and in Southwest England.

9. The Variscan orogeny - synthesis

Any synthesis of the Variscan progeny across the provinces of Cornubia and Armorica must account for a number of features:

1. The Armorican shelf/platform of Upper Proterozoic and earlier infrastructure extended across the present Channel to the Gramscatho belt in the Llandeilian.
2. Between the Llandeilian and the Gedinnian, depression of the Armorican shelf/platform over the Gramscatho Belt occurred to moderate depths.
3. The Old Red Sandstone Continent extended south to at least the northern edge of the Gramscatho Belt in the Siegenian.
4. The Gramscatho Belt and the area to the north of it as far as southern Exmoor underwent a northward-younging overall depression from at least Gedinnian times.
5. Mobility at depth is witnessed by the extrusion of spilitic lavas of continental affinities through all the area of (4) and by the metamorphic event in or about the Middle Devonian affecting the Gramscatho Belt.
6. There is a general absence of significant compressional movements in both Armorica and Cornubia until after the Namurian.
7. The Lizard Complex.

Table of Contents

8. The existence of deep seated centres of late Devonian/early Carboniferous granitic diapirism in southern Armorica and perhaps northern Armorica *(Pays de Léon).*
9. The more or less simultaneous onset of the phase of intense compressional deformation throughout the area in post Namurian times.

The author finds no evidence to support the hypothesis of a mid-European ocean located as far north as that proposed by Johnson (1973). Three alternatives are considered here:

a. The Floyd model (1972) with a single subduction zone dipping northward from a surface expression somewhere south of southern Armorica.
b. The Reading model (1973) with an extensional phase within Cornubia to account for the basin and ridges developed there and the inherent possibility of developing out of this concept an ocean of the types proposed by Burrett (1972) and Burne (1973).
c. A solution involving no plate tectonic model but a mechanism on the lines of granite diapirism (Cogné, 1957 c(c, or Krebs and Wachendorf 1973).

In the first place much hinges on whether the Proterozoic infrastructure was continuous across both provinces in post-Cadomian times. No final proof has been offered but an overlap of evidence in the Middle Devonian Gramscatho Belt seems a realistic proposition on the data available.

It is known that a basin and ridge province was established from the Dodman to southern Exmoor between the Llandeilian and the end-Visean which caused major crustal-depression of the Proterozoic infrastructure with widespread extrusion of spilitic lavas. Similar lavas of continental affinities arc also known from Armorica and particularly relevant is the direct association between Caradocian volcanism and the infrastructural zone of weakness known as the Crozon hinge line (fig. 3D).

The depression of the Proterozoic infrastructure north of Armorica agrees well with an extensional phase of continental rifting. However, there is little evidence of either subduction zone or volcanic island arc. The mid- to late-Devonian metamorphic event

Table of Contents

identified in the Gramscatho Belt cannot be related at the present time to a suhduction zone in the immediate area because the extensional effects both preceded and succeeded it. This event also affected Armorica in the form of major uplift which extended lit least to the Alderney/Ushant line. A mobility at depth is required with effects extending from southern Armorica to the Gramscatho Belt. Such mobility at depth could relate to a deep lying subduction zone of the sort proposed by Floyd (but the extensional movements before and after are against this) or could be explained by independent granitic diapirism at depth (Krebs & Wachendorf. 1973).

Radioisotope data from the Eryuy spilites and Erquy/ Fréhel/ Plouézec/ Plourivo red beds have been interpreted as indicative of Upper Cambrian/Lower Ordovician and Devonian ages respectively. This and other recent work suggests caution in the interpretation of some series around the Baie de St Brieue though the main relationships described remain valid.

ACKNOWLEDGEMENTS. The author wishes to thank the committee of the Ussher Society for its invitation to give the annual address (January 1974) from which this article has grown, Drs. A. J. Barber (Chelsea College. London) and R. A. Roach (Keele University) for much stimulating discussion, Dr. R. T. Taylor and R. A. Roach for reading the manuscript and all friends and colleauges in Armorira who are always most generous in their discussion and supply of information.

ADAMS, C. J. D. 1967a. K/Ar ages from the basement complex of the Channel Islands (United Kingdom) and the adjacent French mainland. *Earth Planet. Sci. Letters*. 2, 52-56.

______ 1967b. A geochronological and related isotopic study of rocks from north-western France and the Channel Islands (United Kingdom). *Unpublished D. Phil. thesis, Unin. Oxford.*

AUBOUIN, J. 1965. Geosynclines: Developments in geotectonics, 1: 305 pp., Elsevier, Amsterdam.

BABIN, C. and PLUSQULLLEC, Y. 1965. Sur la profondeur des mers dévoniennes dans l'ouest du Finislère. *Bull. Soc. geol. miner. Bretagne.* (N.S.), I962/3: 1-8

Table of Contents

______ **CHAUVEI., J., CHAUVEL, J. J., HENRY, J. L., LE CORRE, C., MORZADEC, P., NION, J., PHILIPPOT, A., PLUSQUELLEC, Y. and RENAUD, A.** 1968. Le Palaeozoique antécarbonifère de Bretagne (France). *Casposis Mineral. Geol. Prague, 13. 3 261-278.*

______ **CAVET, P., LARDEUX, H., MORZADEC, P., PARIS, F., PONCET, J. and RACHEBOEUF, P.** 1972. Le Dévonien du Massif Armoricain, *Bull. Soc. geol. Fr.* (7). *14.* 94-109.

BAKER. J. W.. 1971. The Prolerozoic history of southern Britain. *Proc. Geol. Ass.,* 82, 249-266.

______ 1973. A marginal late Prolerozoic ocean basin in the Welsh region. *Geol. Mag.,* 110 447-4 55.

BARD, J. P., CAPDEVILA, R. and MATTE Ph. 1971. La structure de la chaine hercynienne de la Mescla ibérique: comparaison avec les segments voisins· *Collect. Collog. Semin. Inst. fr. Petrole. Histoire structurale du Golfe de Gasgogne 1, 1-68*

BISHOP, A. C., BRADSHAW, J. D., RENOUF, J. T. and TAYLOR, R. T. 1969. The stratigraphy and structure of part of West Finistère. France. *Quart. Jl. geol. Soc. Lond.,* 124,309-348.

______ **ROACH, R. A. and ADAMS, C. J. D.** 1974. *(in press) Precambrian rocks Within the Variscides.* Spec. *Rep. geol. Soc. Lond.*

BONHOMME, M., COGNE, J., LEUTWEIN, F. and SONET, J. 1966 Données nouvelles sur l'âge des séries rouges du golfe normanno-breton. *C. r. hebd. Seane. Acad. Sci. Paris.* 262, 606-619.

BRADSHAW, J. D. 1963. The Lower Palaeozoic and lowest Devonian rocks of the Crozon Peninsula (Finistère). *Unpublished Ph. D. thesis. Univ. London.*

______ **RENOUF, J. T. and TAYLOR, R. T.**, **1967.** The development of Brioverian structures and Brioverian/ Palaeozoic relationships in west Finistère (France). *Geol. Rdsch..* 56, 567-596.

BURNE:, R. V. 1973. Palaegeography of South West England and Hercynian continental collision. Nature. *physic. Sci.* **241,** 129-1,11.

BURRETT, C. F. 1972 Plate Tectonics and the Hercynian orugeny. *Nature,* 239, 155157.

CAVET, P., LARDEIJX, H, and PILLET, J. 1966. Notice stratigraphique sur les formations paléozoiques des synclinoria de Saint Julien de Vouvantes et de Redon Ancenis. *Bull. Soc. Et. Sri. Anjou.* (N.S.). 5, 23-44.

CHAURIS, L., HALLEGOUET, B., BABIN, C., PLUSQUELLEC, Y. and MORZADEC, P. 1972. Notice explic. Carte géol. dét. Fr., 1:80 000 Brest (57), 3rd Edit.: 1-29.

Table of Contents

COGNE, J. 1957. Schistes cristallins et granites en Bretagne méridionale. Le domaine de l'anticlinal de Cornouaille. *First published as thesis in 1957. available as:* Mém. Serv. Carte géol. dét. Fr., 1960: 1-382, 25 pls, 78 tfs.

______ 1959a. Données nouvelles sur l'Antécambrien dans l'Ouest de la France. Pentévrien et Briovérien en baie de St. Brieuc (Côtes-du-Nord). *Bull. Soc. geol. Fr..* (7), 1: 112-118.

______ 1959b. Comparaison et relations entre le Precambrien de Normandie et de Bretagne. *C.r. somm. Séanc. Soc. géol. Fr.,* 1959- 2b9-270.

______ 1963. Le Briovérien. *Bull. Soc. geol. Fr..* (7), 4 (1962): 141-156.

______ 1965a. Reflexious sur l'âge des séries détritiques rouges du nord de l'Armorique (Golfe normanno-breton). *Bull Soc. géol. minér. Bretagne.* (N.S.). 1962-63: 17-30.

______ 1965b. Observations sur l'âge et la signification de la phase bretonne. *Bull. Soc. belge Géol. Paléont., 73* (1964), 18: 239-243.

______ 1966. Une nappe cadomienne de style pennique: la série crystallophyllienne de Champtoceaux en bordure méridionale du synclinal d'Ancenis (BretagneAnjou). *Bull. Serv. Carte geol. Alsace Lorraine.* 19, 1-2: 107-136.

______ 1967. Zones stables et zones mobiles au cours de l'orogénèse hercynienne dans le Massif armoricain en relation avec le champ de la pesanteur. *In*: Contrib. Carte gravimétrique. Géol. Massif Armoricain. *Mem. B.R.G.M..* No. 52. 15-23.

______ **and SHELLEY, D.** 1966. Structure géologique de secteur des Abers (Nord Finistère). *Bull, Serv. Carte géol. Alsace-Lorraine 19, 1: 1-40*

______ **JEANETTE, D., and RUHLAND, M.** 1966. L'île de Groix. Etude structural d'une séries métamorphique â glaucophane en Bretagne méridionale. *Bull. Ser. Carte géol. Alsace-Lorraine.* 19, 1-2: **41-96.**

CURRY, D., HAMILTON, D., and SMITH, A. J. 1971. Geological evolution of the western English Channel and its relations to the nearby continental margin. **In:** Delany(ed.) *ICSU/SCOR Working Party 31. Symposium. Cambridge* 1970: 130-142.

DANGEARD, L. and **DORE, F.** 1961. Le Briovérien supérieur de Basse Normandie (Etage de la Laize), série à turbidites, à tous les caractères d'un flysch. *Rev. Géog. phys. GéoL dyn.,* (2). 4. 4. 251-259.

______ 1971. Faciès glaciaires de l'Ordovicien supérieur en Normandie. In: Colloque sur Ordovicien- Silurien. *Mem. B.R.G.M.* No. *73.* 119-25.

DEARMAN, W. R. 1971. A general view of the structure of Cornubia. *Proc. Ussher Soc.* 2, 220-36.

Table of Contents

DEUNFF, J., LEFORT, J. P. and PARIS, F. 1971. Le microplanction ludlowien des formations immergées des Minquiers (Manche) et sa place dans la distribution du paléoplancton silurien. *Bull. Soc. géol. minér. Bretagne,* 1971: 9-28.

DEWEY, J. 1969. Evolution of the Appalachian/Caledonian orogen. *Nature. 222,* 124-129.

DICKINSON, W. R. 1971. Plate tectonic models of geosynclines. *Earth Planer .Sci. Let.,* 10, 165-74.

DODSON, M. H. and REX, D. C. 1971. Potassium-argon ages of slates and phylliles from south-west England. *Quart. Jl. geol. Soc. Lond.,* 126. 465-499.

DORE, F. 1972. La transgression majeure du Paléozoïque dans le NE du Massif armoricain. *Bull. Soc. géol. Fr.,* (7),14: 79-93.

DOUBINGER, J. and PONCET, J. 1964. Découverte de microorganismes dans la série rouge de Montmartin (Manche). Attribution de cette série au Dévonien moyen ou supérieur. *C.r hebd. séancm Acad. Sci. Paris,* 258, 10O<t-1006.

DUPRET, L. Thèse, 3e cycle, Univ. Caen: *(in press).*

ERBEN, H. K. 1964. Facies developments in the marine Devonian of the Old World. *Proc. Ussher.Soc.,* 1, 92-118.

FLOYD, P. A. 1972. Geochemistry, origin and tectonic environment of the basic and acidic rocks of Cornubia, England. *Proc. Geol. Ass.,* 83, 385-404.

GAUSS, G. A. and HOUSE, M. R. 1972. The Devonian successions in the Padstow area, north Cornwall. *Jl. geol. Soc. Lond..* 128, 151-172.

GOLDRING, R. 1962. The bathyal lull: Upper Devonian and Lower Carboniferous sedimentation in the Variscan geosyncline. In. Coe, (ed.), *Aspects of the Variscan Fold Belt:* 75-91. Manchester.

GRAINDOR, M. J. 1957. Le Briovérien dans le nord-est du Massif armoricain. *Ménr. serv. Explic. Carte géole dét. Fr.:* 1-211 Paris.

_____ 1960. Existence vraisemblable du Penthévrien dans les Iles anglo-normandes et la Hague. *Bull. Soc. linn. Norrnandie, (10), 1:* 44-46.

_____ 1962. Définition du Briovérian sensu stricto. *Bull. Soc. linn. Normandie,* (10),3: 88-91.

_____ **and WASSERBURG, G. J.** 1972. Déterminations d'ages absolus dans e nord du Massif armoricain. *C.r. hebd. Séanc. Acad. Sci. Paris.* 254, 3875-3877.

HENDRIKS, E. M. L., HOUSE, M. R. and RHODES, F. H. T. 1971. Evidence bearing on the stratigraphical successions in South Cornwall. *Proc. Ussher Soc..* 2, 270-275.

Table of Contents

HOUSE, M. R. and SELWOOD, E. B. 1966. Palaeozoic palaeontology in Devon and Cornwall. *In: Present views on some aspects of the geology of Cornwall and Devon:* 45-86. Oscar Blackford Ltd., Truro.

JOHNSON, G. A. I..1973. The Tectonic Environment of South West England. *Contrib. to discussion of paper by P. A. Floyd. Proc. Geol. Ass..* 84**,** 237-219.

JONIN, M. 1973. Les différents types granitiques de la Mancellia et l'unité du balholite manceau (Massif armoricain). C. *r. hebd. Séunc. Acad. .Sci. Paris,* 277, 281-284.

JUNG, J. and ROQUES, M. 1936. Les zones d'isométatmorphisme dans le terrain crislalluphyllien du Massif central français. *Rev. Sci. nat. Aurergne..* 1, 1-50.

KREBS, W. and WACHENDORF, H. 1973. Proterozoic-Palaeozoic geosynclinal and orogenic evolution of Central Europe. *Bull. geol. Soc. Am..* 84, 2611-26,30.

LAMBERT, J. L. M. 1965. A reinterpretalion of the breccias in the Menage crush zone of the Lizard boundary, south-west England. *Quart. .Jl geol.* Soc. *Lond..* **121,** 339-J57.

LEUTWEIN, F. and SONET, J. 1965. Contribution à la Connaissance de l'évolution géochronologique de la partie nord-est du Massif armoricain français. .Sci. *Terre. Nancy.* 10, 345-367.

_____ **POWER, C., ROACH, R. and SONET, J.** 1973. Quelques résultats géochronologiques obtenus sur des roches d'âge précambrien du Cotentin. *C. r. hrbd. Seanc. Acad. Sci. Paris.* 276, 2121-2124.

MATTHEWS, S. C. 1966a. Lower Carboniferous stratigraphy in the St. Mellion area. *Proc. Ussher* Soc., 1, 227-229.

_____ 1966b. Remarks on the geology of the St. Mellion area. *Proc. Ussher. Soc..* 1, 245-247.

MILLAR, J. A. and GREEN, D. H. 1961a. Preliminary age determinations in the Lizard area. *Nature,* 191. 159-160.

_____ 1961b. Age determinations of rocks in the Lizard (Cornwall) area. *Nature.* 192, 1175-6.

NICOLAS, A. 1972. Was the Hercynian belt of Europe of the Andean type? *Nature.* 236, 221-223.

PELHATE, A. 1967. Le Carbonifère inférieur du Bassin de Laval, Massif Armoricain. *These Fac. Sci. Univ. Rennes.*

_____ 1970. Caractères sedimentologiques des Schistes de Châteaulin aux environs de Locmaria-Berrien et Poullaouen (Finistère). *Bull. Soc. géol. minér, Bretagne,* (C),2, 1-10.

Table of Contents

_____ 1973a. Précisions sur l'âge de la sediment carbonatee dans Touest du bassin du Châteaulin et conséquences paléotgéographiques. C.r. *hebd. Acad. Sci. Paris.* 277. 2305-2307.

_____ 1973b. A propos de la microfaune dimantienne des calcaires du Dourduff (Nord-Finistère. France). C *r. somm. .Seanc.*I *geol Fr..* 1973.

_____ **and PONCET J. J.** 1970, précisions sur l'âge de la partie basale du Dinantien du synclinal de Montmartin (Manche). C.r. *hebd.* Seanc *Soc. geol.. Fr..* 4, 109- 110.

PEUCAT, J. J. 1973. Les schistes cristallins de la Baie d'audierne, études pétrographique et structurale. *These. 3e cycle. Univ. Rennes.*

PHILIPOTT, A. and CHAUVEL, J. J. 1957. Relations entre les niveaux de la base du Paléozoïque et les assises inférieures dans les synclinaux de sud de Rennes. *Bull. Soc. géol. minér. 3, 43-46.*

PONCET, J. 1972. Les biohermes éodévoniens de l'horizon récifal de Baubigny (Manche). Etude d'un paleamilieu. *Bull. Bur. Recher.. géol. minér..* 3, 43-65.

RAMBERG, H. 1972. Theoretical models of density stratification and diapirism in the earth. *J. geophys. Res..* 77, 877-889.

RAST, N. and CRIMES, T. P. 1969. Caledonian orogenic episodes in the British Isles nnd northwestern France and their tectonic and chronological interpretation. *Tectonophysics*. 7, 277-307.

READING, H. G. 1973. The tectonic environment of South-west England. *In: contribution in the discussion of a paper by P. A. Floyd. Proc. Geol Ass.* 84, 239-242.

RENOUF, J. T. 1965. The geology of the Presqu'île de Plougastel. (Finistère). *Unpublished. Thesis, Univ. London.*

_____ 1972. Branchiopods from the Grès a Orthis Monnieri Formation of northwestern France and their sigificance in Gedinnian/ Siegenian stratigraphy of Europe. *Palaeontographica.* A. 139. 89-133

ROACH, R. A. 1957. The geology of the Metamorphic complex of South and Central Guernsey. *,Unpublished. Thesis, Univ. Nottingham.*

_____ 1966. Outline and guide to thegeology of Guernsey. *Rep. soc. guernesiaise, 18. 751-776*

ADAMS, C. J. **D., BROWN, M., POWER, G. and RYAN, P.** 1972. The Precambrian stratigraphy of the Armorican Massif. Northwest France. *Int. geol. Congr., 24, Montreal: 246-252*

Table of Contents

ROBARDET, M. 1964. Sur les couches comprises entre le Wenlockien et le Siegenien dans le Cotentin. *Bull. Soc. géol Fr..* 6, 87-90.

ROBLOT, M. 1963. Découverte de sporomorphes dans les sédiments antérieurs à 550 m.a. (Briovérien). C. *r. hebd. Seanc. Acad. Sci. Paris, 256,* 1557-1559.

_____ 1964. Valeur stratigraphique des sporomorphes du Précambrien armoricain. *C r. hebd. .Seanc. Acad. Sci. Paris, 259,* 4090-4091.

RYAN, P. 1973 *Unpuhlishcd Ph. D. thesis Univ. Keele.*

SADLER, P. M. 1973a. A proposed stratigraphical succession for the Roseland area of south Cornwall. *Unpublished Ph. D. thesis, Univ. Bristol.*

_____ 1973b. An interpretation of new stratigraphie evidence from south Cornwall. *Proc. Ussher Soc., 2,* 535-550.

_____ 1974. Trilobites from the Gorran Quartzites, Ordovician of south Cornwall. *Palaeontology,. 17,* 71-93.

SANDERSON, D. J. and DEARMAN, W. R. 1973. Structural zones of the Variscan fold belt in south-west England, their location and development. *Jl geol. Soc. Lond.. 129,* 527-536.

SMITH, A. G., BRIDEN, J. C. and DREWRY, G. E. 1973. Phanerozoic world maps. *In:* Hughes (ed.). Organisms and continents through time. *Spec. Pap. Palaeont..* 12, 1 42.

SPJELDNAES, N. 1961. Ordovician climatic zones. *Norsk. geol. Tiddskrift.* 41, 45--77.

1967. The palaeogeography of the Tethyan region during the Ordovician. In: *C.* G. Adams and D. V. Ager (eds): Systematics Assoc. Publ. 7, Aspects of Tethyan biogeography: 45-57.

SQUIRE, A. D. 1973. Discovery of late Precambrian trace fossils in Jersey. Channel Islands. *Geol. Mag..* 110, 223-226.

_____ 1974. *Unpublished Ph. D. thesis Univ. London:* in preparation.

_____ **and RENOUF, J. T.** 1972. Geological map of Jersey. *Soc. Jersiaise. Jersey.*

SUTTON, J. and WATSON, J. 1957. The structure of Sark, Channel Islands, *Proc. Geol. Ass.,* 68, 179-203.

_____ and 1970. The Alderney Sandstone in relation to the ending of plutonismin the Channel Islands. *Proc. Geol.Ass..* 81, 577-584.

TAYLOR, R. T. 1970. The geology of the south-west Pays de Léon, northwest Finislére. France. *Unpublished Ph. D. thesis Univ. London.*

Table of Contents

VERDIER, P. 1968. Etude pétrographique et structurale du Trégor occidental (Baie de Lannion. Côtes-du-Nord-Finistère). *These 3c cycle. Strasbourg*

WHITE, E. I. 1956. Preliminary note on the range of pteraspids in western Europe. *Bull. Inst .Sci. nat. Belg.,* 32, 1-10.

WHITTINGTON, H. R. and HUGHES, C. P. 1972. Ordovician geography and faunal provinces deduced from trilobite distribution. *Phil. Trans. Roy. Soc. Lond.,* B263**,** 235-278.

WINTERER, E. L. 1964. Late Precambrian pebbly mudstune in Normandy, France: tillite or tilloid? *In:* Nairn (ed.). *Problems in Palaeoclimatology Proc. NATO Conf.*. Newcastle upon Tyne, 159-178.

WOOLDRIDGE, S. W. 1925. The petrology of Sark. *Geol. Mag.. 62,* 241-252.

WRIGHT, A. E. 1969. Precambrian rocks of England. Wales, and South-east Ireland. *In:* Kay, M. (ed.). *North Atlantic - Geology and Continental Drift* Mem. Ass. Petrol. Geol., 12, 93-109.

Société Jersiaise
The Museum
9 Pier Road
St. Helier
Jersey
Channel Islands

Table of Contents

A progress report on geological investigations in the Liskeard area of south east Cornwall (Abstract)

by C. J. Burton

The structure, lithostratigraphy and the broader aspects of the palaeontology and chronostratigraphy of the Middle Devonian rocks of an area sowth of Liskeard (Figs. 1 and 2) have been investigated. Within this area there is a strongly folded sequence of slates, limestones and tuffs, the lower part of which was found to contain faunas of Eifelian age. Further partially investigated faunas from the Eifelian and higher levels suggest the possibility of a detailed chromostratigraphy for the whole of the Middle Devonian, leading via an unbroken lithological sequence into known Frasnian beds.

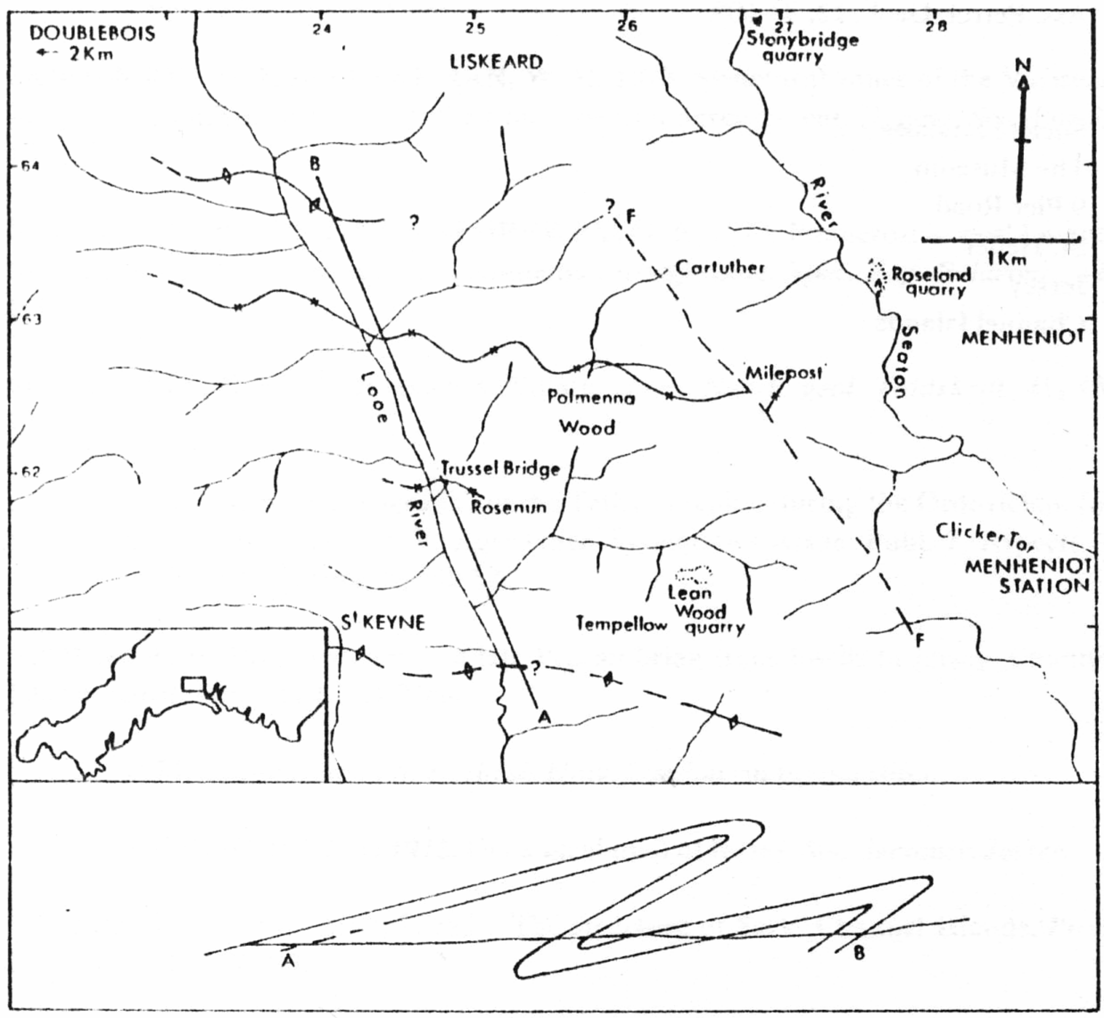


FIGURE 1. Localities, main (F_1) fold axial traces and faults in the Liskeard area. Sketch section along A-B to show shape and disposition of the F_1 folds in the area.

Table of Contents

1 . Structure

a) Local fold phases

Three sets of folds are present, each with a well defined axial plane cleavage. The F_1 folds are large (3.2 km wavelength) overturned or nearly recumbent folds with axial traces striking between 093° and 110° (Fig. 1). They face N to NNE and bedding and cleavage dip S to SSW; the axial traces plunge at around 12° eastwards. These folds become progressively tighter and more flat-lying towards the north.

The F_2 folds are smaller than the F_1 folds (0.54 km wavelength) and their axial traces strike E-W, although in detail directions vary a little due to the influence of a later fold set. The F_2 folds incline slightly to the north.

The F_3 folds are intermediate in size (1.08 km wavelength) and their axial traces strike at 150°. There is a strongly developed vertical axial plane cleavage. Also present in the area is a very late kink band set. The above model agrees with the general interpretation of structure worked out for contiguous parts of south east Cornwall.

b) Local structure

In terms of F1 folds the area includes (Fig. 1) the overturned limb of an anticline in the south paralleled further north by an almost recumbent syncline and finally by a further anticlinal trace close to Liskeard.

Only one fault has been observed, trending NNW-SSE between Cartuther (SX 26406320) and SX 28006105 (Figs. 1 and 2), which stratigraphical evidence suggests is an oblique slip dextral wrench fault. The fault appears to be a branch of the Portwrinkle Fault connecting with the latter near Tresulgan (SX 297060G0). Its effect. in conjunction with the main Portwrinkle Fault in the Seaton valley, is to swing the strike of the beds from ESE-WNW in the main part of the area to E-W or even ENE-WSW between Cartuther and the River Seaton (Fig. 2).

Table of Contents

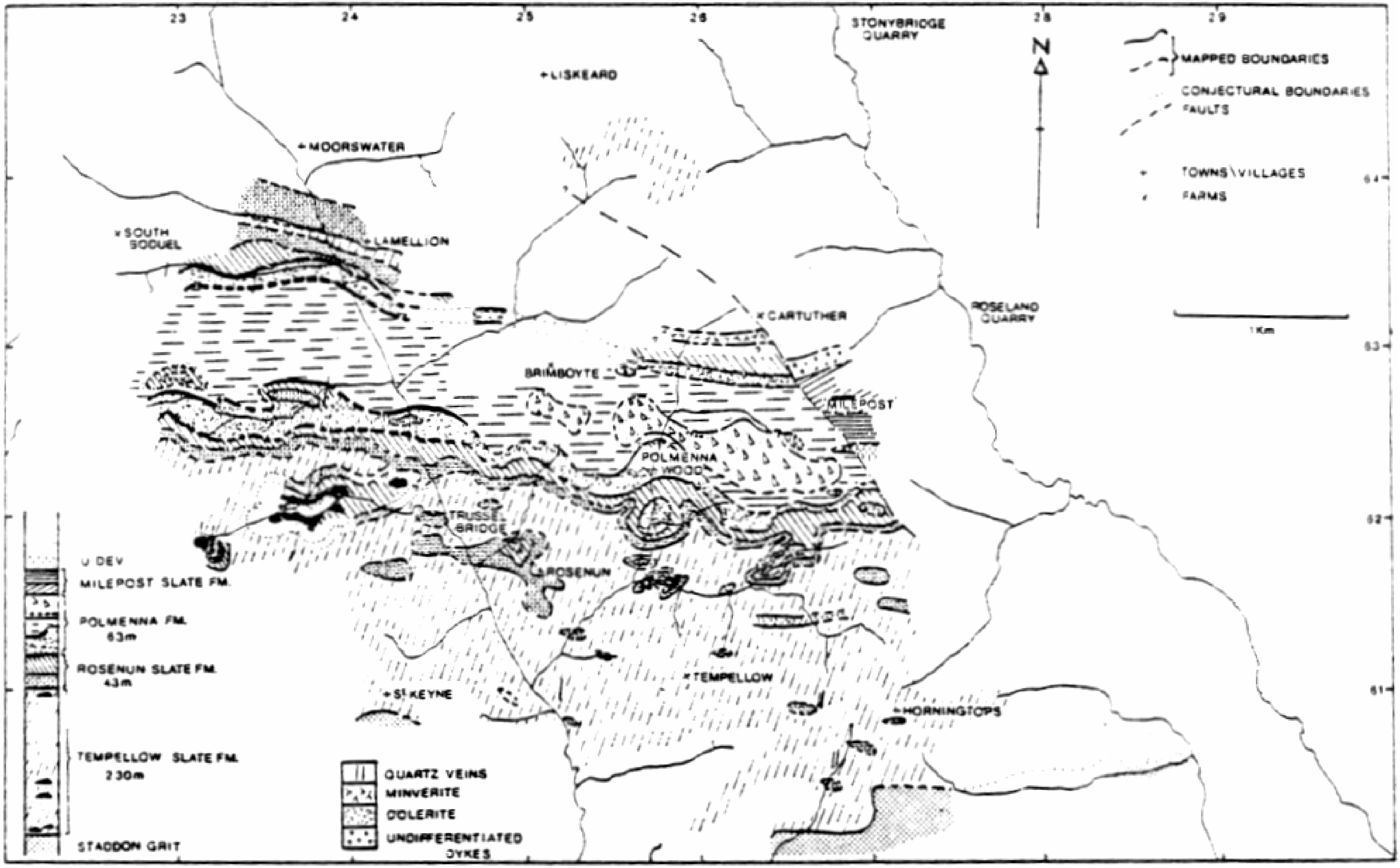


FIGURE 2. The geology of the Liskeard area

2. **Lithostratigraphy and faunas**

Greater knowledge of the lithostratigraphy of the area requires the introduction of new formational units. These, with their lithologies, typical exposures, faunas and approximate ages, are summarised in Table 1.

TABLE 1

Purple and green slates		Frasnian
Milepost Slate Formation (around SX 26706270)	hard grey slates with rare cricoconarids. thin-bedded -splintery slates with cricoconarids of Givelian aspect.	Givetian
Polmenna Formation (from SX 25756210 to SX 25806250)	keratophyric tuffs with a chert cobble horizon. grey slates. black crinoidal slate. limestones with slates, cont. *Neometacathus* aff. *stelliefer* (Burm) *Asteropyge* aff. *perforata* Morz. black crinoidal slate	Boundary uncertain
Rosenum Slate Formation (around SX 24906175)	grey slates. ochre slates with Neometacanthus aff. stelliffer, *Asteropyge* aff. *perforate, Kayserella lepida, Pleurodictyum* sp., branchipods, bryozoans, corals, crinoids and rare gastropods, orthcones and cricoconarids.	Eifelian
Tempellow Slate Formation (around SX 24546169)	Shiny grey slates with small blue limestone lenses. ochre slate lenses with trilobites, brachinpods, crinoids. sandstone lenses.	Boundary uncertain
Staddon Grit		Emsian

Table of Contents

3. Chronostratigraphy

The trilobites Neometacanthus aff. stellifer (Burmeister) and Asteropyge aff. perforata Morzadec, and the brachiopod Karyserella lelpida (Schnur) were used in correlation. Neometacanthus stellifer of Germany is restricted to the Eifelian and Asteropyge perforata of Britanny ranges from highest Emsian to lowest Eifelian. However, a dating conflict arises since Kayserella lepida, restricted to the level of the Upper Eifelian Freilingen beds in Germany, occurs in Cornwall in the same beds as the apparently older Asteropyge aff. perforata. Dating conflicts of this type are not unique to Cornwall having also been reported from Germany where the precise stratigraphical value of other fossils within the Eifelian seems to be in doubt. However, even with this as yet unresolved, the fossils give ranges unequivocally within the span latest Emsian to late Eifelian, and hence the beds below the limestone of the Polmenna Formation belong to that range. The Emsian-Eifelian boundary has yet to be determined precisely, but is thought to be close to the Staddon Grit (Table 1).

The Milepost Slate Formation and the upper members of the Polmenna Formation are most probably referable to the uppermost Eifelian and the Givetian. Their lower limit is known to be Upper Eifelian and their upper limit designated by purple and green slates (Table 1) is thought to be the basal Frasnian by analogy with identical slates of known Frasnian age, close by at Menheniot.

Dept. of Geology
The University
Glasgow.

Table of Contents

FAMENNIAN CONODONTS AND CAVITY INFILLS IN THE PLYMOUTH LIMESTONE (S. DEVON)

by M. J. Orchard

Abstract. Infillings of solution cavities in Lower Frasnian limestones and associated sediments have yielded conodonts indicative of the *triangularis* and *crepida* zones (Famennian). The cavities and infillings are described and their genesis discussed in relation to their inferred age. Environmental conclusions are presented and broader implications noted. .

1. Introduction

The rocks of Western King, Plymouth are steeply dipping (60°S), irregularly bedded, grey and pink limestones. They are associated with subordinate amounts of red (calcareous) shale which in places forms sometimes discordant units up to a metre thick. The more southerly limestones (e.g. grid ref. SX46095326) contain a fauna of lamellar *Alveolites* and stromatoporoids, with thamnoporoids and rugose corals held together by a commonly crinoidal matrix which has yielded *asymmetricus* Zone conodmits (Orchard 1972). The facies found here is interpreted as representing a fore-reef situation.

These limestones form the host for a red, pink and grey laminated limestone which is found in pockets. The pockets are usually irregular with a maximum depth of 20 cms; a single example is known 7 cms deep with a lateral extent of 3 metres. The petrology of the infllling material was described by Braithwaile (1967, p.312), who suggested that the pockets represented infillings of cavities which may have arisen through solution (because in sonic cases the sides of pockets overhang the cavities). The fact that sequences of laminal can be matched in adjacent pockets indicates that the pockets were tilled contemporaneously and thus that they represent an interconnected cavity complex. Continuity is not always apparent however, and totally isolated pockets have been observed, though, of course, the overall three-dimensional picture is lost; they do not obviously represent a single horizon. The wall rock shows evidence of selective dissolution, the coarser skeletal elements having been less affected than the matrix material. The contact between the host rock

Table of Contents

and the infill has been studied and this and other features are illustrated in Fig. 1. The contact zone has a direct bearing on the genesis of the cavities and their subsequent infillings.

2. Sequence

The inferred sequence of events can be summarized thus:- (i) Deposition and (partial?) cementation of the host limestones (deduced from the truncating relationship of Fig. 1C, r). (ii) Dissolution (in part selective) of the limestones. This produced irregularly pitted surfaces (e.g. Fig. 1A, s) as well as overhanging walls. (iii) Formation of micritic envelopes and rims of fibrous calcite, often alternating, up to a combined thickness in places of at least 1 cm. The lower surface follows the irregular wall-rock; the upper is smooth. (iv) Widespread erosion and variable removal of successive layers of the enveloping materials (e.g. Fig. 1, t). This was associated with (v). (v) Infilling of the cavities with (predominantly) extraneous material which built up laminae of variable composition, some rich in particular components (e.g. ostracodes Fig. lA, u). (Fig. 1A, v). (vi) Consolidation and compaction of the infill material

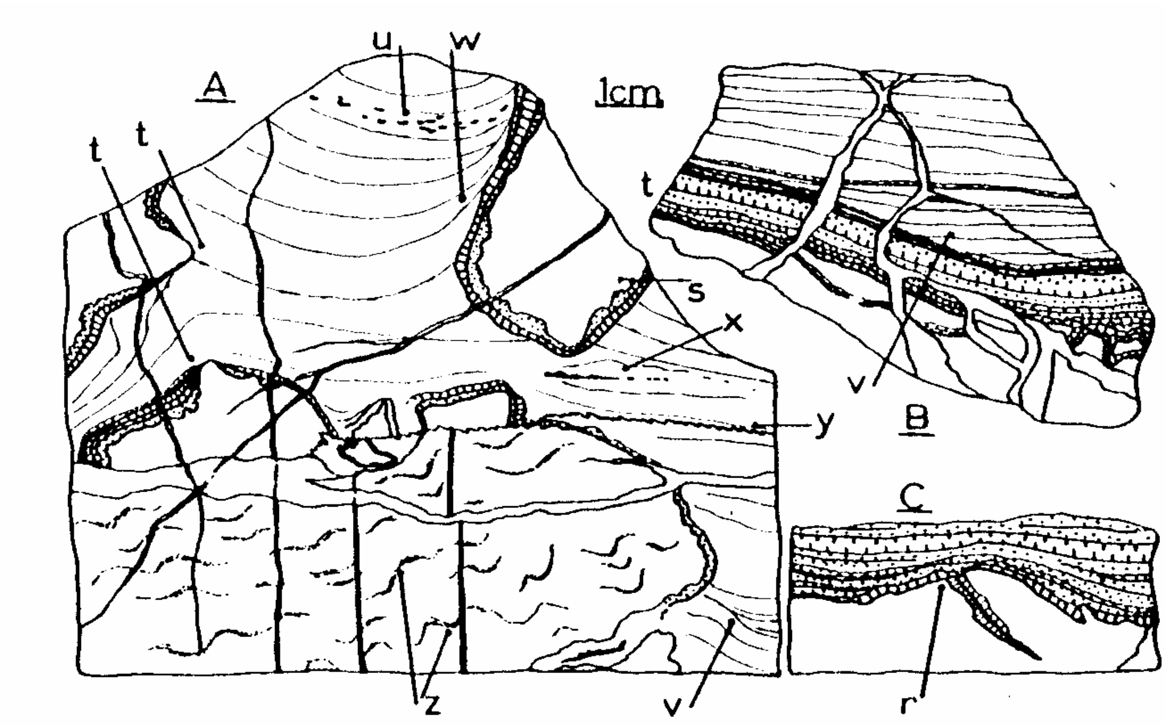


FIGURE 1. (A-C). Detail of cavities and infill. 1A is cut at about 80° to laminae bedding. 1B and 1C are perpendicular sections of a laterally persistent example. Host limestones (mostly skeletal) are blank (except for dolomitized parts), micrilic envelopes are stippled, fibrous calcite lined. Laminae of infill indicated, later cross-cutting calcite veins outlined. z -dolomitizalion, y-styliolitic development. See text for r-x.

Table of Contents

producing upturning of the laminae edges (Fig. 1A, w and Braithwaite 1967, p.312). A single simple "Stromatactis" has been observed within one of the thicker grey bands (Fig. 1A, x).

3. **Depositional environment**

The above observations may be used to deduce the depositional environment. Referring to the same numbers: The host limestones are considered to represent a fore-reef environment. (i) Cementation of the limestones, which preceded dissolution, may have developed quite rapidly while the carbonate accumulate was still in free communication with sea water (as Krebs (1969) has demonstrated for some German fore-reef limestone). (ii) Though submarine dissolution of limestone is well established, a solution phenemenon of this magnitude implies a markedly different composition of water and lots of it (i.e. a large number of "pore-volumes", Blatt, Middleton & Murray, 1972, p.456-59). Exposure to fresh water in the inter-to supra-tidal zone would tit these requirements (cf. Krebs, 1969, p.295). (iii) The micritic envelopes bear a strong resemblance to some of supposed algal origin figured by Krebs (1969, Fig. 7); these were thought to have formed simultaneously with fibrous calcite cementation and internal sedimentation. On the other hand, laminated crusts characterize some recent carbonates in which they are indicative of vadose-zone diagenesis (e.g. those of Bonaire, Netherlands Antilles. Blatt, Middleton & Murray, p.466). Whichever is the case here (and there are limits of certainty in such recrystallized limestones) the environmental implications are as in (ii). (iv) (v) Erosion of the wall rock would be favoured by currents of moderately high velocity. According to Blatt, Middleton & Murray the production of such currents would be difficult in rocks with their pore-space filled with water. Pulses of (variously) sediment-laden water could produce the observed features. (vi) "Stromatactis" development was possibly a response to later dewatering and non-uniform compaction, as Heckel (1972) has postulated for the Tully Limestone of New York.

In summary then, the indication is that during the interval represented by events (ii) - (v), the older, host, limestones were situated in at least a very shallow water environment, an environment which may well have been emergent at times.

Table of Contents

4. Age and discussion

The infill material has been separated and processed for conodonts, and has yielded poor, though recognizable, specimens of the diagnostic form-species *Palmatolepis tenuipunctuta* and *Pa. clelicatula*. The overlap in range of these conodonts (Ziegler, 1971, chart 5), and the inferred age of the infilling, is the Upper *triangularis* or *crepida* Zone

Some of the host limestones can be assigned to the Middle *asymmetricus* Zone, though younger horizons may be represented as the unproductive coarser skeletal limestones. Assuming cementation was achieved quite rapidly, dissolution may have been effective at any stage during the intervening period up to a time when the micritic/fibrous calcite rims were formed. The development of this envelope was interrupted by the mulling in Lower Famennian times, and so probably did not pre-date it by very much. Hence dissolution would appear to have been active immediately prior to the infilling. Another line of evidence may put a lower time limit on this. The associated red calcareous shale has also been sampled for conodonts, as have related beds in which this shale forms the matrix of a breccia (containing fragments comparable with the grey host limestones). The angularity and relative position of some clasts suggests that the sediments are not always a normal sedimentary breccia, but rather a result of (?synsedimentary) tectonic effects. Elsewhere (SX416225332) there is an argillaceous unit some 50 cms thick which contains a large allochthonous limestone raft - this has the appearance of being a sedimentary megabreccia. In all cases the sometimes crinoidal, calcareous shale has produced a mixed conodont fauna which dominantly comprises forms indicative of the Lower *crepida* Zone. The fauna includes *Palmatolepis quadrantinodosalobata, Pa. delicatula perlobata. Pa. tenuipunctala, Pa. minuta minuta, Pa. delicatula delicatula, Pa. delicatula clarki. Pa. superlobata, Pa. triangularis* and *Icriodus cornutus*. Also present are a few forms indicative of earlier zones of which *Ancyrodella curvata, Ancyrognathus cryptus* and *Palmatolepis gigas* are notable. The nature of these rocks is complex and their origin most likely lies both in slumping and in later "tectonic squeezing". It is suggested, however, that the conodont fauna may include elements which were derived through the dissolution of the older limestones, and thus (of the above forms) *A. cryptus* may represent

Table of Contents

the age of the latest depositional phase before the emphasis changed to dissolution. This form is confined to the Middle *triangularis* Zone in Germany.

5. Summary and conclusions

During the Lower Famennian, and probably throughout the Frasnian, parts of the Plymouth area constituted a shallow marine area which may have been emergent during the later part of this interval. Limestone deposition was followed, in the Western King area, by widespread dissolution probably in mid *triangularis* Zone times. (This dissolution may have been active along cracks and fissures resulting from uplift, along bedding planes, and along lines of weakness resulting from compaction differential between skeletal and matrix material.)

Dissolution ceased and possible algal activity in association with rim cementation began, perhaps in response to slight subsidence. This was interrupted during U. *triangularis* or (lower half of the) *crepida* Zone time by the influx of sediments which finally filled up the solution cavities. There must have been a pause to allow for partial consolidation of the infill material. However, the influx may in effect have heralded further reefal subsidence (represented by megabreccia formation in association with the muddier sediments of the *crepida* Zone), and perhaps the change of conditions which led to the development of the purple and green slate facies (though there is no evidence for the precise timing of this event, nor, indeed, for its development at all).

6. Regional implications

A marked contrast between the Upper Devonian shallow water environment here invoked for the Plymouth area, and the deep water argillite equivalents of much of south Devon and Cornwall is apparent. For example the Padstow successions of north Cornwall (see Gauss and House, 1972) are very different, though the Gravel Caverns Conglomerate (Pentire succession) dates from a time when the Plymouth area was probably experiencing uplift (though no derivation is suggested). Also there is evidence of regional volcanicity

Table of Contents

at these levels and this may be associated with, and provide one cause for, the inferred instability. The contrast in facies is seen to be all the more striking in the light of recent work done by Gooday (1974) which indicates that the widespread deep water 'ostracode slate' facies was established during the Frasnian in the Torpoint area, west of the Tamar. This, in addition to the mid-Frasnian age for the goniatite-bearing slates of Warren Point on the east bank of the Tamar, clearly demonstrates the contrasting nature of the, now adjacent, Plymouth and Tamar successions during the Frasnian and Lower Famennian. The present juxtaposition of the two successions is best explained tectonically, as in the case of the Padstow successions.

BLATT, H., MIDDLETON, G. and MURRAY, R. 1972. *Origin of Sedimentary Rocks*. Prentice Hall, 634pp.

BRAITHWAITE, C. J. R. 1967. Carbonate environments in the Middle Devonian of South Devon, England. *Sediment Geol.*, **1**, 283-320.

GAUSS, G. A. and HOUSE, M. R. 1972. The Devonian successions in the Padstow area. North Cornwall. *Jl Geol. Soc.* **128,** 151-172.

GOODAY, A. J. 1974. Ostracode ages from the Upper Devonian purple and green slates around Plymouth. *Proc. Ussher Soc.*, **3.**

HECKEL, P. 11. 1972. Possible. inorganic origin fur Stromatactis in calcilutite mounds in the Tully Limestone, Devonian of New York. *J. Sedim. Petrol.* **42, 7-**18.

KREBS, W. 1969. Early void filling cementation in Devonian fore-reef limestones (Germany). *Sedimentology,* **12,** 279-299.

ORCHARD, M. J. 1972. The conodont biostratigraphy of the Plymouth limestones about the Middle/Upper Devonian boundary. *Proc. Ussher Soc.* **2**, 471-474.

ZIEGLER, W. 1971. Conodont stratigraphy of the European Devonian. *Mem. Geol. Soc. Am.,* **127**, 227-284.

Dept. of Geology
The University
Downing Street
Cambridge

Table of Contents

OSTRACOD AGES FROM THE UPPER DEVONIAN PURPLE AND GREEN SLATES AROUND PLYMOUTH

by A. J. Gooday

Abstract. Purple and green slates around Plymouth yield locally abundant but poorly preserved ostracods. No Frasnian ostracod index fossils have been recognised although Frasnian slates probably occur extensively, particularly west of the Tamar. Famennian ostracods are better preserved; the *serratostraita- nehdenis*-Zone, *hemisphaerica-dichotoma*-Zone and probably the *intercostata*-Zone have been recognised, mainly east of the Tamar.

1. Introduction

Purple and green slates crop out extensively cast and west of Plymouth. In the Plymouth and Ivybridge Memoirs, Ussher (1907, 1912) placed these rocks in the Upper Devonian but no evidence has been published regarding their stratigraphic range. However, the slates have long been known to yield locally abundant Entemozoidae which form the basis of a detailed chronology in Germany. Since these planktonic ostracods are the only commonly occurring zonal fossils in the purple and green slates, they probably offer the only hope of working out the stratigraphy in this region (Goldring 1964, p.77).

The ostracods have been obtained from 74 localities but only 24 of those sampled yielded determinable ostracods. However, the species which were identified clearly show that the Frasnian and at least-most of the Famennian is represented.

The ostracod zonation used here was established by Rabien and his co-workers (Rabien 1954, 1956b, 1960, 1970; Rabitz and Rabien 1958; Krebs and Rabien 1964). The zones are summarized in Table 1 which also shows their correlation, as suggested by Rabien (1970), with the ammonoid and conodont chronologies. The most important ostracod localities are shown on Map 1 and their National Grid references are given in the text. All numbers lie in the square SX.

Table of Contents

TABLE 1

Ammonoid Stufen	Ammonoid Zones	Conodont Zones	Ostracod Zones	Stages
Gattendorfia-Stufe		triangula triangula-Z	latior-Zone	TOURN-AISIAN
		triangula inaequalis-Z		
		kockeli dentilineata-Z	hemisphaerica\latior Interregnum	
Wocklumeria-Stufe	sphaeroides-Zone	U costatus-Zone	Upper hemisphaerica-dichotoma-Zone	FAMENNIAN
	subarmata-Zone	M costatus-Zone		
Clymenia-Stufe	speciosa-Zone	L costatus-Zone		
	hoevelensis-Zone	U, M styriacus-Zone	Lower hemisphaerica-dichotoma-Zone	
Platyclymenia-Stufe	annulata-Zone	L styriacus-Zone	intercostata-Zone	
	delphinus-Zone	U, M velifer-Zone		
	sandbergeri-Zone	L velifer-Zone	serratostriata\intercostata Interregnum	
Cheiloceras-Stufe	pompeckji-Zone	U, L quadrantinodosa-marginifera-Zone	serratostriata-nehdensis-Zone	
		rhomboidea-Zone		
	curvispina-Zone	U, M crepida-Zone		
		L crepida-Zone	sigmoidale-Zone	
Manticoceras-Stufe	holzapfeli-Zone	U, M, L P. triangularis-Zone	variostriata-Zone: splendens-Zone	FRASNIAN
		U gigas-Zone	variostriata-Zone: reichi\splendens Interregnum	
			variostriata-Zone: reichi-Zone	
			variostriata-Zone: schmidti-Zone	
			variostriata-Zone: volki-Zone	
			variostriata-Zone: materni-Zone	
			variostriata-Zone: barrandei-Zone	
	cordatum-Zone	L gigas-Zone	cicatricosa\barrandei Interregnum	
		A. triangularis-Zone	cicatricosa-Zone	
		U asymmetricus-Zone		
	lunulicosta-Zone	M asymmetricus-Zone	cicatricosa\torleyi Interregnum	
		L asymmetricus-Zone		
		hermanni-cristatus-Zone	torleyi-Zone	

TABLE 1. Ammonoid, conodont and ostracod zones of the European Upper Devonian and basal Carboniferous. Based on Rabien (1970, Tables 6 and 11; Carboniferous conodont zones after Matthews (1969, fig. 1, from Voges), Devonian ammonoid zones after House (1963, Table 1).

Table of Contents

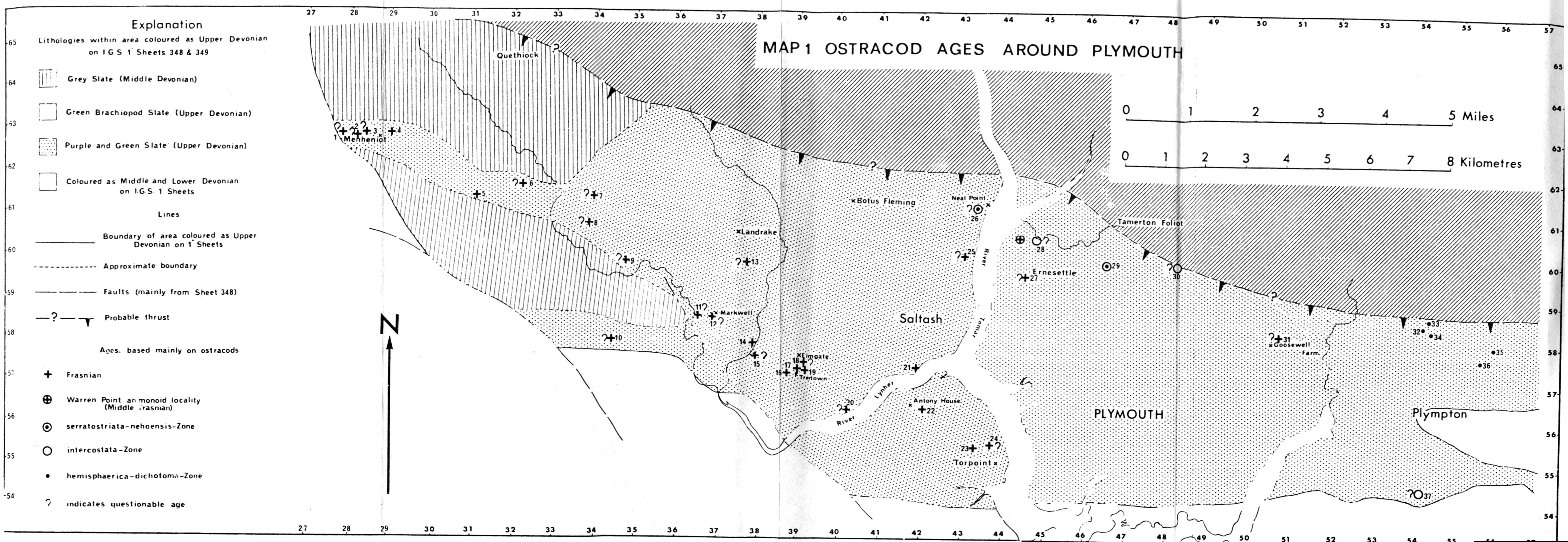


Table of Contents

2. The geological setting

The purple and green slates of the Plymouth area are part of an east-west belt of such slates extending from Padstow to Newton Abbot. They are of a deep water facies comparable to the Cypridinen-Schiefer of the German Upper Devonian (see Rabien 1956a, pp. 37-43) and are characterised by a dominantly pelagic fauna.

The outcrop area of the purple and green slates is shown on Map I which is based on Sheets 348 and 349 of the I.G.S. 1 inch series. They are bounded to the west and south by Lower and Middle Devonian rocks, mainly grey slates and limestones. The map shows extensive tracts of Middle Devonian within the region coloured as Upper Devonian on the I.G.S. sheets; these have been known for some time (House 1963, p.14; House and Selwood 1966, p.54) and are only approximately delineated on Map 1.

To the north, the purple and green slates are bounded by green and greyish green slates (of probable Upper Devonian age) which are comparable with the Kate Brook Slate east of Dartmoor (Waters 1970, p.193) and the Tredorn Phyllites of the Tintagel area (see Selwood 1971, p.283). East of Dartmoor, Waters (1970) has shown that a major thrust (T4) carried purple and green slate northwards over the Kate Brook succession; a similar situation appears to exist in the Plymouth area.

3. The ostracod succession

a. Frasnian

No Frasnian ostracod zone can be positively identified in the Plymouth area although species which typically occur in this stage are known from a few localities. Indeterminate entomozoids or probable entomozoids are abundant, particularly west of the Tamar. The common occurrence of tentaculitids with these unidentified entomozoids strongly suggests a Frasnian age because the entomozoids increase dramatically in abundance at the base of the Frasnian while tentaculitids became almost extinct at the close of the Frasnian (Krebs and Rabien 1964, p.91, Zagora 1964).

Table of Contents

(i) Lower Frasnian. The occurrence of indeterminate enlomozoids with *Styliolina* at Cutcrew Farm (locality 8, 33836080), near Tideford School (locality 9, 34735998) and by Poldrissick Lane (locality 13, 37775985) may mean that these localities are no younger than the middle of the *cicatricosa*-Zone, since *Styliolina* does not range above this level in Germany (Krebs and Rabien 1964, p.91).

(ii) Middle Frasnian. A few poorly preserved specimens resembling *Bertillonella (Rabienella) cicatricosa,* the *cicatricosa*-Zone index, are known from near Menheniot (locality 2, 28146290).

(iii) Upper Frasnian. The topmost Frasnian *splendens*-Zone probably occurs near Tredown (localities 17, 38955735 and 16, 38735723) where *Entomoprimitia (E.)* cf. *splendens* has been found. In addition the presence east of Menheniot (locality 4, 29006296) of a single *B. (R.)* aff. *reichi* with several narrowly ribbed richterinids resembling *Richterina (Volkina) zimmermanni* and tentaculitids, suggests the *reichi*-Zone.

At the following localities there occur specimens placed definitely or tentatively in *Entomozoe (Nehdentomis) pseudorichterina* or *E. (N.) tenera.*

1. North of Padderbury Top (locality 5, 31086151); *E. (N.) cf. pseudorichterina,* abundant tentaculitids.

2. By River Lynher, north of railway bridge (locality 14, 36986414); *E. (N.) pseudorichterina, E. (N.)* cf. *tenera,* common tentaculitids.

3. South of Elnrgate (locality 18, 3910574); E. (N.) *cf. tenera.*

4. South of Elmgate (locality 19, 39125727); *E. (N.) pseudorichterina,* uncommon tentaculitids.

5. By R. Lynher, south of Saltash (locality 21, 41925735); *E. (N.)* cf. *pseudorichterina,* rare tentaculitids.

6. E.S.E. of Antony House (locality 22, 41925735); *E. (N.)* cf. *pseudorichterina,* common tentaculitids.

7. South of Thanckes House (locality 23, 43304(k16); *E. (N.) pseudorichterina.*

8. By Thanckes Lake (locality 24, 43705553); *E. (N.) cf. pseudorichterina.*

Table of Contents

E. (N.) tenera ranges from *the cicatricosa/torleyi* Interregnum to the top of the *serratostriata-nehdensis*-Zone (Rabien 1954, Table 2) and *E. (N.) pseudorichterina* from the *cicatricosa*-Zone to just into the *sigmoidale*-Zone (Koch and others 1970, p.695) while tentaculitids only rarely extend above the top of the Frasnian. Thus these localities all probably belong to the Frasnian although whether to the middle or upper part is not certain.

Indeterminate ostracods are commonly associated with tentaculitids. On the Cornwall side of the Tamar these fossils occur together at localities 1, 3, 6, 7, 10, 11, 12, 15, 20 and 25 and on the Devon side of the Tamar at localities 27 and 31. For the reasons discussed above, these localities are all indicated as being tentatively of Frasnian age on Map 1.

(b) Famennian

Although Famennian ostracods are less abundant than those of Frasnian or probable Frasnian age, they are better preserved and usually identifiable.

(i) serratostriata-nehdensis-Zone. On the Devon side of the Tamar, buff to greyish shales near Ernesettle (locality 29, 46475991) have yielded *Entomozoe (Richteria)* cf. *serratostriata, E. (Nehdentonris)* cf. *nehdensis* and *Entomoprimitia*? cf. *sandbergeri,* an assemblage indicative of the *serratostriata-nehdensis-Zone.* West of the Tamar there is no firm evidence of this zone although fragmentary specimens from the north shore of Kingsmill Lake (locality 26, 43346116) are referred tentatively to the index species *E. (N.) nehdensis.*

(ii) *intercostata-Zone.* Purple slates by Tamarton Lake (locality 28, 44746049) have yielded abundant and fairly well preserved examples of a spineless richterinid with ribs of unequal strength which compares well with Rabien's (1954, pp.118, 119) *Richterina (Richterina)* cf. *costata* from the Hemberg-Stufe (in part equivalent to the *intercostata*-Zone). In the absence of the characteristic *serratostriata-nehdensis* and *hemisphaericadichotoma*-Zone faunas, this richterinid suggests that the *intercostata-Zone,* or at least the middle part of the Famennian, is present.

Table of Contents

Two other faunas may be of similar ages. One is from northwest of Plympton (locality 30, 51295886) and comprises *R. (R.) striatula. R. (R.)* aff. *costata* and *Maternella* aff. *dichotoma.* The other was found south of Plympton (locality 37, 54115442) and consists of *R. (R.) striatula, R. (R.)* aff. *costata* and *M.* aff. *hemisphaerica.*

(iii) *hemisphaerica-dichostoma*-Zone. This zone has been clearly demonstrated around Newham Park, north of Plympton. Here three localities (32, 54185857; 34, 54305842 and 35, 55835799) have yielded well preserved *M. dichotoma, M. hemisphaerica, R. (R) striatula* and *R. (R.) costata,* a typical *hemispitaerica-dichotoma*-Zone assemblage; at a fourth locality (36, 55335772), *M. dichotoma* occurs by itself. The absence of *R. (Fossirichterina) semen* from these faunas, suggests the upper part of the Zone. The lower part may be present at locality 33, (54315877) where *R. (R.) semen* is found with *R. (R.) striatula.*

4. Discussion

On the Cornwall side of the Tamar it seems that Frasnian purple and green slates crop out in the southern part of the area investigated, for example around Menheniot, Doddycross, Markwell, Tredown and Torpoint. There is probably a complete succession from the Middle Devonian, which occurs extensively in the west part of the region investigated, up into the Upper Devonian slates.

To the north of a line approximately from Landrake to Saltash, the situation seems more complex. Middle Devonian slates with styliolinids crop out around Botus Fleming, and at Neal Point (43576136) limestones have yielded Middle Devonian conodonts (Matthews 1962). The rocks around Neal Point have been resampled by Mr. M. J. Orchard who has informed me that lower *quadrantinodosa*-Zone (lower to middle Famennian) conodonts also occur here in limestones associated with greyish green shales. The purple and green slates north of Saltash and Landrake have nowhere been accurately dated but the Frasnian and at least the lower part of the Famennian are probably represented.

East of the Tamar all dated localities lie in the northern part of

Table of Contents

the purple and green slate outcrop area, near Ernesettle, Goosewell Farm and Newnharn Park. The *cordatum*-Zone of ammonoid chronology (Middle Frasnian) has been demonstrated 110 yds. (100.58m) south of Warren Point (44336057) (House 1963, p.16). .The *serratostriata-nehdensis* and *hemisphaerica-dichotoma*-Zones and probably the *intercostata*-Zone are present and in addition there are a few patches of grey slate with styliolinids which may be Middle Devonian (for example on the south shore of Tamarton Lake at 45426030). Thus this narrow tract of slate, 2-3km wide, yields a wide range of ages spanning the Upper Devonian and pfobably ranging down into the Middle Devonian. The juxtaposition of these rocks of varying ages suggests considerable tectonic complications immediately south of the (? thrust) boundary between the purple and green slates and the green brachiopod slates. A good deal of minor thrusting may be involved.

ACKNOWLEDGEMENTS. I am grateful to Dr. E. B. Selwood who supervised this work and gave helpful advice. The study was supported by a N.E.R.C. Studentship.

GOLDRING, R. 1964. The bathyal lull: Upper and Lower Carboniferous sedimentation in the Variscan geosyncline. *In* Coe, K. (Ed.) *Some aspects of the Variscan Fold Belt.* 75-91. Manchester.

HOUSE, M. R. 1963. Devonian ammonoid successions and facies in Devon and Cornwall. *Q. Jl. geol. Soc. Lond..* **119,1-27.**

HOUSE, M. R. and SELWOOD, E. B. 1966. Paleozoic Palaeontology in Devon and Cornwall. *In* Hoskins, K. P. G. and Schrimpton. G. L (Eds.): *Present views on some aspects of the Geology of Devon and Cornwall.* 45-86. Penzance.

KREBS, W. and RABIEN, A. 1964. Zur Biostratigraphie und Fazies der Adorf-Stufe bei Donsbach. *Notizbl. hess. L.-Amt. Bodenforsch.,* 92, 75-119.

MATTHEWS, S. C. 1962. A Middle Devonian conodont fauna from the Tamar Vatlley. *Proc. Ussher Soc.. 1,* 27-28.

RABIEN, A. 1954. Zur Taxonomie und Chronologie des oberdevonischen Ostracoden. *Abh, hess. L.Amt. Bodenforsch.,* 9,1-268.

Table of Contents

_____ 1956a. Zur Stratigraphie und Fazies des Ober-Devons in der Waldecker Hauptmulde. *Abh. hess. L.-Amt. Bodenforsch.*, **16,** 1-83.

_____ 1956b. Die stratigraphische Bedeutung der uberdevonischen Ostracoden. *Z. deutsch, geol. Ges.,* **106,** 217-226.

_____ 1960. Zur Ostracoden-Stratigraphie und der Devon/Karbon-Grenze im Rheinischen Schiefergebirge. *Fortschr. Geol. Rheinld. U. Westf.* ***3,*** *61 –106.*

_____ 1970. Oberdevon. Erl. geol. kte. Hessen; B1. 5215. Dillenbrug: 78-83. 103-235.

RABIEN, A. and RABITZ, A. 1958. Das Ober-Devon von Meschede. *Notizbl. hess. L.-Amt. Bodenforsch.,* **86**, 159-184.

SELWOOD, E. B. 1971. Successions at the Devonian-Carboniferous boundary between Boscastle and Dartmoor. *Proc. Ussher Soc.,* **2,** 278-285.

USSIIER, W. A. E. 1907. The Geology of the country around Plymouth and Liskeard. *Mem. Geol. Surv. U.K.*

USSHER, W. A. E. 1912. The Geology of the country around Ivybridge and Modbury. *Mem. Geol. Surv U.K.*

WATERS, R. A. 1970. The Variscan structure of eastern Dartmoor. *Proc. Ussher Soc.* **2,** 191-197.

ZAGORA, K. 1964. Tentaculiten aus dem thuringischen Devon. *Geologie*, **13,** 1235-1273.

Institute of Oceanographic Sciences
Wormley
Godalming
Surrey

Table of Contents

THE AGE OF THE UPPER PALAEOZOIC VOLCANICS BETWEEN BODMIN MOOR AND DARTMOOR

by E. B. Selwood

Abstract. Some volcanic horizons between Bodmin Moor and Dartmoor are dated palaeontologically. Within the Devonian, igneous activity is concentrated in the Upper Famennian, though a probable Frasnian occurrence is also recorded. Carboniferous volcanicity is less important than was thought formerly: the only significant horizon identified represents an eastward continuation of the Tintagel Group. The present disposition of the volcanics indicates considerable tectonic disruption in the area. Thrusting is thought to have played an important part in the structure.

1. Introduction

Current Geological Survey maps of the country lying between Dartmoor and the north Cornwall coast show important volcanics within the Upper Palaeozoic rocks. These rocks, which are well exposed on the coast near Padstow and Tintagel, have figured prominently in the geological literature, not only because of their intrinsic interest as volcanic rocks, but also because of arguments focussed on their age.

In recent years definitive dates have been obtained for the coastal volcanics; work in the Padstow area, reviewed by Gauss and House (1972), clearly indicates an important period of Frasnian volcanic activity in a succession including purple and green slates. Farther to the north the Tintagel Group, for long thought to include pillow lavas of Upper Devonian age, has been shown to be mainly agglomeratic and of Lower Carboniferous age (Freshney *et al.* 1972). To the east, on the north flank of Dartmoor, the Meldon Volcanic group is included within a Lower Carboniferous succession. In recent surveys by I.G.S. the Tintagel Group has been mapped eastwards to the limit of the Boscastle (322) and Camelford (336) sheets, and the Meldon Volcanic Group has been mapped westwards to the limit of the Okehampton (324) sheet. This leaves the position of the volcanics between Dartmoor and Bodmin Moor unrevised.

Although undifferentiated in terms of age on the Tavistock (337) sheet, the accompanying Memoir (Reid *et al.* 1911) indicates the presence of both Devonian and Carboniferous volcanics. No

Table of Contents

direct faunal evidence is quoted, but the view is taken that if the volcanics rest on Carboniferous strata, they are Carboniferous in age, and if they are included within the Devonian or underlie Carboniferous rocks, a Devonian age is indicated. This interpretation takes too simple a view of the geology. In a region of complex tectonics, the superposition of strata does not necessarily give correct stratigraphic sequences; this, added to the fact that the dating of shales shown on the Tavistock sheet is confused, means that little reliance can be placed on published age determinations of the volcanics.

As part of a wider program of research into the stratigraphic and structural problems of the area, attention has been directed to these volcanics and a search has been made for interbedded sediments in the hope of locating faunas. Some measure of success can be reported and this is recorded here. An attempt has been made to determine the relation of the volcanics to the adjacent sediments, but new maps have not been prepared. It has been found, however, that though the Tavistock sheet is inadequate in many ways, it gives a reasonable representation of the distribution of the volcanics and Lower Carboniferous Cherts. No petrological account of the rocks is included.

2. Carboniferous volcanic activity

(a) Tintagel Group

The Tintagel Group enters the north-west corner of the Tavistock sheet where it is infaulted into green-grey Upper Devonian Slates that probably represent an easterly continuation of the Tredorn and Woolgarden Slates. Tuffs and agglomerates with subordinate lavas are spectacularly displayed in crags on the north bank of the River Inney. The lithologies and structural setting are identical with those described from the Boscastle sheet area. The formation maintains its identity south-eastwards towards Plusha (SX 252801), where it is abruptly terminated against a fault that forms a branch of the Otterham wrench fault system (Selwood 1971); it does not reappear again on the Tavistock sheet. Black and grey slates are locally interbedded with the volcanics, but these have yielded no fauna. However, the continuity of outcrop and identity of lithology makes the Dinantian age, established on the coast,

Table of Contents

acceptable for the formation in this area.

(b) The radiolarian chert outcrop

Known Lower Carboniferous rocks, principally represented by radiolarian cherts, are widely distributed on the Tavistock sheet, but they bear few volcanics. Tuffaceous horizons, a few centimetres thick, can be identified at a number of isolated localities and a coarse agglomerate is recorded in an overgrown pit in Lifton Park (SX 38138485) and again in a road cutting (SX 31308237) near South Petherwin. Apart from a locality near Tibridge (454 847) in the north-east corner of the map where Dearman (1962) notes tuffs and interbedded black shales, there is no evidence for the presence of the impressive series of tuffs and agglomerates of the Meldon Volcanic Group which appears at levels below the main chert horizons in the Okehampton district. Spilitic lavas are associated with the cherts, but nowhere are they seen to be actually interbedded. South-east of Launceston, and particularly between Bradstone (SX 380810) and Woodmanswell (SX 488830), lavas arc mapped testing on cherts; this suggested a Carboniferous age to the authors of the Memoir. In the absence of faunal evidence, this age cannot be denied, but the possibility exists that these lavas have been transported to their present position by thrust faulting and may represent part of the volcanic series identified between Stoke Climsland and Tavistock, which is in part at least, of Upper Devonian age.

3. Devonian volcanic activity

(a) Larrick lavas

The volcanics represented south-east of Plusha, which are described in the Memoir as a continuation of the volcanics here identified as Tintagel Group, are not only lithologically distinct from this formation, being spilitic lava rather than tuff and agglomerates, but they also structurally overlie Upper Carboniferous rocks. The outcrops are less extensive than shown on the map, capping hill tops at Trevadlock Cross (SX 26602957), near Example Cross (SX 27707900) and King's Camp (SX 28907775). A more or less flat base is indicated, which when followed eastwards dips down to the River Inney near Larrick. At this point the river flows through a gorge carved from the lavas. These lavas show interbedded greenish-grey slates with thin siliceous lenticles which yield a fauna of topmost

Table of Contents

Devonian age *(Wocklumeria Stufe).* This is a lithology identical to the Stourscoulbe Beds, of similar age, occurring near Launceston. The low-lying contact separating these Devonian lavas from the underlying Upper Carboniferous is interpreted as a thrust.

(b) Launceston volcanics

An identical situation to that at Larrick exists to the north, where isolated patches of lava capping hill tops are mapped westwards from Launceston to Piper's Pool. Everywhere these lavas rest at a low angle on Upper Carboniferous rocks and clearly once formed part of a continuous sheet, now dissected by erosion. Interbedded dark grey and green slates yield rare fossils; a precise date has not yet been obtained but richterinid ostracods indicate that the beds belong to the Upper Famennian and are not older than the *costata* zone. There is nothing lithological or palaeontulogical to suggest that the lavas are not of the same age as those at Larrick.

Additional small masses of lava are exposed at much lower topographic levels in the Launceston area; they appear from beneath the Upper Carboniferous rocks referred to above, in the floor of the valley of the River Kensey. These lavas are interbedded with the Stourscombe Beds which yield a fauna indicative of the *Wocklumeria Stufe.* Although these beds are highly deformed, the contact with the overlying Carboniferous rocks is low-lying and is interpreted as a thrust; the Upper Devonian rocks are exposed through a window in this thrust. A "trap" rock, described by Phillips (1841) and discussed in the Memoir (p.28), was formerly exposed beneath Lower Carboniferous limestones at Cannapark (SX 306855) in the Kensey valley. Almost certainly this "trap" was present beneath the thrust and belongs to the Stourscombe Beds rather than to the Cannapark Limestone.

(c) Lewannick lava

Lava with some associated agglomerate forms the high ground around and to the east of the village of Lewannick. The lower limit of the mass is well marked on the southern side of the valley of the River Inney, where it can be observed to lie on various Lower Carboniferous and Upper Devonian formations thought to belong to the lowest (probably autochthonous) structural unit represented on the Tavistock sheet. The contact is low lying and is interpreted as a thrust. The purple slates, which are interbedded with the lava, are

Table of Contents

distinctive and of particular interest for they are unknown elsewhere on the Tavistock sheet. Similar slates are, however, extensively developed off the southern margin of the sheet and in the Padstow district; in both areas a Frasnian age is indicated. Although no fossils have been obtained from the purple slates at Lewannick during the current investigation, styliolinids are reported in the Tavistock and Launceston Memoir (p.9); these suggest a Frasnian age. As Frasnian faunas have not been identified elsewhere on the Tavistock sheet, it makes the palaeontological-lithological association at Lewannick remarkable. This, together with observed thrust relations with the underlying rocks, suggests that the Lewannick volcanics form part of a thrust mass which, from regional considerations, can only have had a southerly origin.

The detached lava west of Lewannick appears to belong to the underlying tectonic unit. It can be seen overlying grey slates belonging to the Petherwin Beds *(Clymenia Stufe)* in a roadside cutting (SX 26658085).

(d) Stoke Climsland and Tavistock lavas

The lavas occurring about Stoke Climsland (SX 360744) and westwards to Penhole (SX 280764) are interbedded with dark *grey,* black and occasionally greenish slates. Locally the slates are siliceous and have been mapped as cherts; none, however, is as siliceous as the radiolarian cherts which are developed on the northern part of the Tavistock sheet. On the map the cherts are indicated as Lower Carboniferous and the shales in some places mapped as Devonian and in others as Carboniferous. The age of the volcanics is not resolved in the Memoir. Shales, lavas and "cherts" are interbedded, and although the overall lithological impression is of a Lower Carboniferous sequence, clymenid and ostracod faunas from the slates reveal an Upper Famennian age; there is no indication of beds older than the upper part of the *Clymenia Stufe.* These lithologies are quite distinct from beds of comparable age to the north (Stourscombe Beds and Petherwin Beds) and indicate the presence of important facies changes within the Upper Devonian.

East from Stoke Climsland, similar slates with occasional lavas extend towards Tavistock. North of the town they are extensively developed and spilitic lavas, formerly quarried as a building stone, are prominent. On the Dartmoor Forest sheet (338) these beds extend

Table of Contents

eastwards into the aureole of the Dartmoor granite. Here they have been identified and described by Dearman and Butcher (1959) as the Tavistock Calcareous Group - a series of slates, lavas, agglomerates and tuffs. The formation has been correlated with the Meldon Calcareous Group (Dearman 1959) and referred to the Lower Carboniferous. However, the slates yield rare Upper Famennian faunas identical with those at Stoke Climsland. Although there is no positive evidence for a Carboniferous age, the dark siliceous slates, many of which bear a radiolarian fauna (Hinde and Fox 1895, 1896), are reminiscent of Carboniferous lithologies in South-west England; possibly the beds range in age from the Devonian into the Carboniferous.

(e) Brent Tor and Rowden Lavas

In the Brent Tor region, Sherlock (in Reid *et al.* 1911:51) points out that "the lavas belong to two (or possibly more) periods" and observes that they occur at different topographic levels. Volcanics at the lower level are referred to the Upper Devonian and the upper horizon, which is represented in the crags of Brent Tor, is placed in the Lower Carboniferous because it rests on Lower Carboniferous Cherts.

The volcanics at the lower horizon are of restricted occurrence and are represented in a faulted inlier between North Brentor and South Brentor. They include tuffs, no longer visible but recorded below fossiliferous slates now ascribed to the *Clymenia Stufe* (House 1960), and the lavas disposed about Rowden House (SX 47248156). These lavas seem to be inletbedded with black slates bearing siliceous nodules and yielding a few poorly preserved ostracods and a single specimen of the genus *Cymaclymenia*. Beds in the inlier can be matched lithologically and palaeontologically with the Petherwin and Stourscombe Beds in the Launceston district. At the northern limit of the inlier the Upper Devonian Beds seem to appear from beneath Upper Carboniferous rocks. The geological setting is found to be identical with that described west of Launceston, where the Stourscombe Beds appear through a window in overthrust Upper Carboniferous rocks.

The Brent Tor lavas, which occur at the higher topographic level, can be traced westwards (albeit discontinuously in the eastern outcrop) to Dunterton; they are underlain by Lower Carboniferous

Table of Contents

cherts and overlain by Upper Carboniferous rocks. The Lower Carboniferous age of the lavas quoted in the Memoir, has never been positively proved, but they are interbedded with black slates, many of which are crowded with radiolaria. These lithologies are identical with those observed immediately north of Tavistock which are now known to bear an Upper Devonian fauna. Sherlock emphasises the complex setting of the volcanics and notes that they are "bordered by thrusts or faults on every side". Current observations tend to confirm Sherlock's view and it becomes increasingly likely that the Brent Tor - Dunterton lavas and the Tavistock volcanics form part of the same series that has been overthrust by Upper Carboniferous rocks.

4. Conclusion

Although it is still not possible to date precisely all of the volcanic rocks appearing between Dartmoor and Bodmin Moor, it is clear that the main activity was concentrated in the Upper Famennian; this contrasts with adjoining areas where Frasnian and Dinantian activity was more important.

The determination of the ages of the volcanics in this area through their associated sediments is of structural interest, for it emphasises the broad pattern which is beginning to emerge. Stratigraphic units are piled one on top of another, in irregular sequences which can now be recognised over wide areas. No simple explanation of folding involving normal and inverted strata is possible; rather, it is becoming increasingly evident that thrust tectonics play an important role in determining the present disposition of strata.

DEARMAN, W. R. 1959. The structure of the Culm Measures at Meldon, near Okehampton, North Devon. *Q. Jl Geo1. Soc. Lond.*. **115** 65-106.

_____ 1962. Dartmoor. *Geol. Ass. Guide No.* **33**.

_____ and BUTCHER, N. E. 1959. The geology of the Devonian and Carboniferous rocks of the north-west border of the Dartmoor Granite. *Proc. Geol. Ass.*, **70,** 51-92.

Table of Contents

FRESHNEY, E. C., McKEOWN, M. C. and WILLIAMS, M. 1972. Geology of the coast between Tintagel and Bude. *Mem. geol. Surv. Gt. Br.*

GAUSS, G. A. and HOUSE, M. R. 1972. The Devonian succession in the Padstow area. North Cornwall *Jl.geol.Soc. Lond.,* **128,**151-172.

HINDE, G. J. and FOX, H. 1895. On a well marked horizon of radiolarian rocks in the Lower Culm Measures of Devon, Cornwall and West Somerset. *Q. Jl. geol. Soc. Lond..* **51,** 609-668.

_____ 1896. Supplementary Notes - the radiolarian rocks of the Lower Culm Measures to the west of Dartmoor. *Rep. Trans. Devon. Ass. Advmt Sci.,* **28** 774-89.

HOUSE, M. R. 1959. Upper Devonian ammonoids from north-west Dartmoor. Devonshire. *Proc. Geol. Ass.,* **70,** 315-21.

SELWOOD, E. B. 1971. Successions at the Devonian -Carboniferous Boundary between Boscastle and Dartmoor. *Proc. Ussher Soc.,* **2,** 275-285.

PHILLIPS, J. 1841. *Palaeozoic Fossils of Cornwall. Devon and West Somerset.* London, 231 pp.

REID, C., SHERLOCK, R. L., MacALISTER, D. A. and DEWEY, H. 1911. The geology of the country around Tavistock and Launceston. *Mem. geol. Surv. U.K.*

Dept. of Geology
The University
North Park Road
Exeter

Table of Contents

AN APPRAISAL OF THE "LIZARD- DODMAN-START THRUST" CONCEPT

by P. M. Sadler

Abstract. The concept of a Lizard-Dodman-Start Thrust seems untenable. Available outcrops include no trace of overthrusting at the Start Schist boundary and no metamorphic basement in the Roseland-Dodman area. A single, large-scale thrust cannot be identified north of the Lizard complex, where a sedimentary succession can be recognized in alleged crush-breccias. A zone of shallow basement between the Lizard and Start peninsulas would seem to run oblique to the fundamental basement configuration.

1. Introduction

In 1852 Sedgwick postulated a single "mineral axis" bringing pre-Devonian rocks to outcrop along the line of the south coasts of Cornwall and Devon. He sought to explain not only the already well-known metamorphic rocks of the Lizard and Start areas, but also newly-discovered Ordovician (his Upper Cambrian) faunas from the Roseland and Dodman district. In the latter area the "mineral axis" was seen as either a major inversion, or a thrust-fault of large dimensions. Teall (in Reid 1907) revived Sedgwick's idea after the work of the Geological Survey had introduced the notions that the Dodman peninsula comprised an exotic phyllite unit and that crush-breccias were widespread in the Lizard and Dodman areas.

A "Lizard-Dodman-Start" concept has subsequently attracted numerous authors and a variety of interpretations. Following Hendriks's (1937, 1939) mapping of several thrust-faults in S. Cornwall, the notion of a "Lizard-Dodman -Start Thrust" has gained much uncritical popularity. As the English Channel region becomes increasingly a focal point of speculative plate-boundary reconstructions, a statement of the tangible field evidence seems opportune. The petrological variety encountered in the metamorphic basement outcrops is already extensively documented and is not of immediate pertinence to this discussion.

Table of Contents

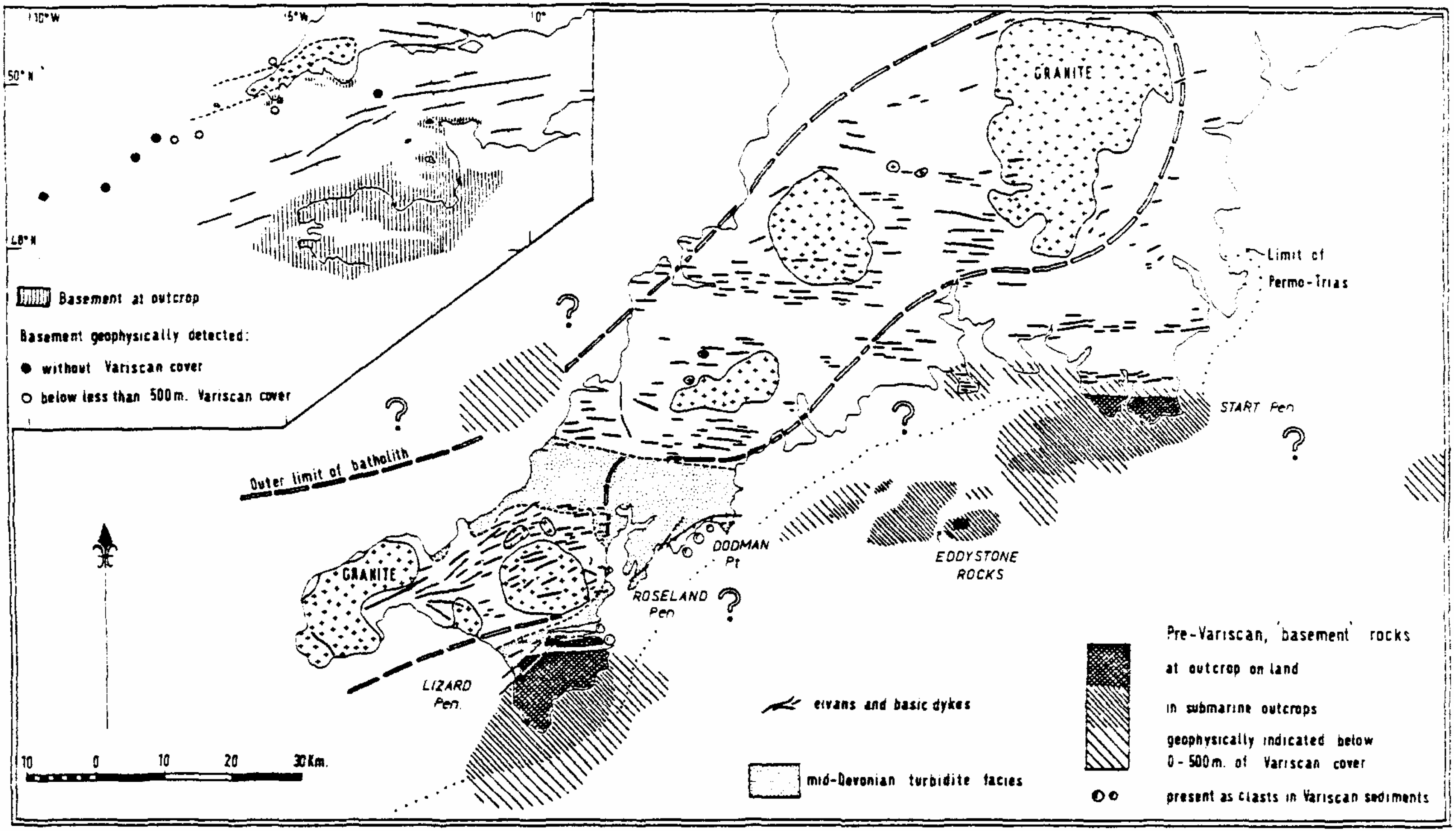


FIGURE 1. Distribution of evidence of shallow. pre-Variscan basement around S.W. England after correction for dextral wrench-faults. Inset: wider setting in the English Channel and its Western Approaches. (uncorrected).

2. The Start-Bolt peninsula

There is no evidence for significant thrust-faulting in the outcrops of the Start-Bolt district (Tilley 1923, Phillips 1961, Marshall 1965). The northern limit of the Start Schists is a steep, north-dipping normal fault, expressed as one of a series of narrow shear zones (S2 of Richter 1968). If the parallel shear-zones farther north are similarly interpreted, the Start peninsula becomes the top of an E-W basement block, bounded to the north by a series of step-faults. The abrupt commencement of the gravity anomaly several kilometres north of the Start boundary outcrop (Bolt and Scott 1966) suggests that the main displacements occurred on file more northern faults. Narrow, E-W zones of basic dykes, as from Torcross to T'hurlestone, may be a surface expression of such a fault.

South of the Start peninsula the upper surface of the metamorphic basement may fall gradually to a plateau it a depth of about 2km (Hill and King 1953). However, the seismic refraction survey-line on which this model was based proved "basement" (layer 4) at only three points and a model with a steep block and rift morphology is equally possible (Allan 1961). Such an interpretation is more in accord with the model developed by Hill and Vine (1965) following a magnetic survey of the Western Approaches.

3. The Roseland-Dodman district

The Start Schists represent basement faulted against a region of upright to-steeply inclined, often rather open folds. The Dodman area, by contrast, is one of steeply to gently inclined, tight to isoclinal folding with steep and variable axial plunges. The Dodman peninsula comprises slates and greywackes (McKeown 1962), which are not metamorphic basement in the sense of either the Lizard complex or the Start schists. Quite to the contrary, they are a conformable part of the local Devonian sequence (Sadler 1973a, 1973b). Shallow reefs up to 2.5km south of the Dodman Point comprise Variscan sediments and spilites.

Thrust faults can be confidently identified in the Roseland-Dodman district. As the result of a steep plunge depression, a series of thrust-faults which carry mid-Ordovician quartzites (Sadler 1974)

Table of Contents

over Devonian rocks, and represent locally a relatively high structural level, are brought down to outcrop around Veryan Bay. However, the emplacement of Ordovician upon lower and mid Devonian is no simple guide to the magnitude of the thrusting. In the succession above the quartzites, Upper Ordovician and Silurian are apparently absent and the Lower and Lower-Middle Devonian is represented by a very condensed, essentially volcanic sequence. This means that a minimum displacement along the thrusts may be as small as 2-3km. The thrust sheets probably resulted by décollement off a basement high to the south.

Metamorphic basement rocks are not entirely absent from the Roseland-Dodman district. They are represented by allochthonous pebbles and boulders in conglomerates throughout the condensed sequence from Gedinnian to Eifelian, with particular abundance in the Eifelian parts. They commonly have the well-rounded form of beach gravel and would appear to have been deposited amid deeper water facies by submarine sliding (Sadler 1973a). The association indicates a pronounced relief and exposed metamorphic basement, probably to the south. Any attempt to identify the Lizard complex as the source must be tempered with caution. The Kennack Gneiss, which is usually interpreted as a late event in the history of the complex, has a radiometric, K/Ar, age (age of cooling to 200-100°C, Harper 1964) of 390-360m yrs. Since this approximates to the time span of the conglomerates, the current level of exposure in the Lizard complex must have been still at some depth during the critical period. However, the argument demonstrates that the attainment of tile present state of outcrop of metamorphic basement includes a component of uplift, which postdates the establishment of a crystalline rise in the Devonian basin.

4. The Lizard peninsula

Flett (1946) has convincingly argued that there is no metamorphic transition between the Devonian greywackes of south Cornwall and the high-grade schists and amphibolites of the Lizard complex. He proposed that the two units are separated by a major thrust zone occupied by crush-breccias, which allegedly outcrop in

Table of Contents

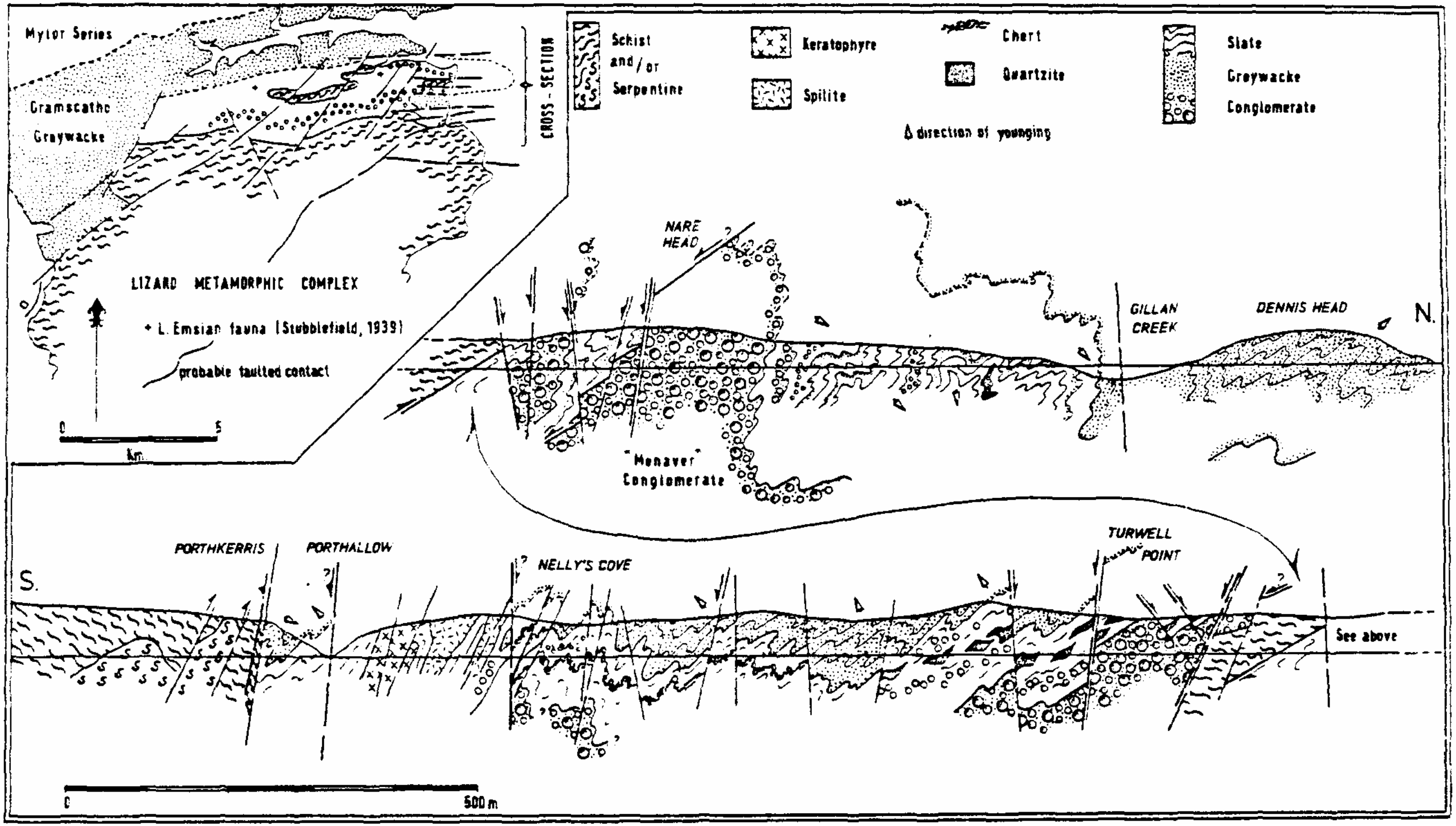


FIGURE 2. A composite cross-section from cliff and foreshore exposures in the East Meneage district. NE Lizard peninsula. Inset: faults and faunas in the Meneage district.

the Meneage district north of the Lizard complex. Subsequent radiometric age determinations have confirmed that most of the metamorphic history of the Lizard complex is indeed pre-Variscan. However, Flett's map of the supposed crush-breccia zone shows a striking E-W ordering of "clast" types. A detailed petrographic study by Lambert (1965) showed that many of the supposed clastmatrix boundaries are primary sedimentary contacts. Lambert also recognized many features of submarine sliding, and was able to remap the coastal exposures of the "crush-breccia" in terms of bedded sediments, true conglomerates and pebbly mudstones, intraformational breccias, and slates-with-greywacke-phacoids. He pointed out the importance of normal faulting in determining the current outcrop pattern.

Consideration of the fold history of these outcrops permits a significant modification of Lambert's extensive slate-with-greywacke-phacoids unit. Most of the lithological boundaries here are certainly sedimentary and slump features are locally unambiguously developed, but the lensoid and phacoid shapes include numerous F_1 fold masses and are closely related to the F_1 cleavage planes (S_1). A compilation of these minor folds produces a consistent picture of F_1 folding. Further, it can be shown that most of the greywacke bodies were not lenses prior to folding, but were flat beds which can be seen to persist at least as far as outcrops are available. The ends of the "phacoids", as they now appear, are not true sedimentary contacts, but are sharp truncations of bedding in both the greywacke and the adjacent slate. A critically important point is that the truncated sedimentary features can be picked up again in neighbouring phacoids. In the water-worn exposures on the extensive wave-cut platform accessible at low spring tide, it can be seen that the lens form relates to movement along S_1 and other steep slip surfaces oblique to S_1. S_1 dips S to SE at 20-60° according to the influence of later structures. The F_1 axes show steep and variable, but predominantly E, plunges. Extensively developed, steeper, S_2 surfaces strike NE-SW and are associated with NW verging minor folds.

Such a combination of sedimentary and tectonic facies is typical of large tracts of the Gramscatho greywackes to the north. It is therefore proposed that, in the absence of contradictory palaeontological evidence, the greywackes of the East Meneage section must be included in this unit (*cf* Hendriks 1937). The

Table of Contents

remaining facies of the East Meneage district also have parallel developments in the Roseland-Dodman sections, but the faunal evidence (Stubblefield 1939) remains too sparse to propose firm correlations. In particular the volcanic rocks north of Porthallow (Fig. 2) remain ambiguous. Although they closely resemble the Lower and Lower-Middle Devonian Roseland Volcanics unit, a correlation with the Frasnian spilites of Mullion Is., off the west coast of the Lizard, cannot be ruled out. The coarse Menaver conglomerate resembles strikingly the conglomerates of the Roseland area, and also includes clasts derived from a metamorphic landmass.

The base of the Gramscatho greywackes and the demonstrably older, coarse conglomerate unit provide two guides to the primary structural pattern north of the Lizard complex (Fig. 2). The major structure comprises a syncline followed northward by an overturned anticline. Normal faulting has considerably modified this configuration. The syncline is occupied by Gramscatho greywackes at the east coast, but as it plunges eastward its inland trace may be represented by the outcrop of conglomerate. Metamorphic rocks (Lambert 1965) occupy the modified core of the main anticline, and inland outcrops of schist seem to define the westward continuation of this structure. At the coast the metamorphic rocks appear to ride a thrust-plane but, as argued above, such a thrust may involve a relatively small movement - the accommodation of relatively competent basement rocks in the fold-nose. Although precise interpretation is hindered in this section by a deep hacinatite staining related to the normal-fault surfaces, the conglomerate clearly rests directly on the metamorpbic basement. This may be direct evidence of the shallow unconformity inferred from the basement pebbles. However, a flal-lying normal fault could also form the contact (Fig. 2).

The metamorphic inlier demonstrates that the Lizard boundary cannot be resolved into a single fault line and illustrates a possible model for the boundary of the main metamorphic complex. The steep, south-dipping faults seen there in both coastal sections can be simple normal faults if the Lizard complex also represents basement caught up in an early anticline and accommodated by overthrusting. It is certainly clear that the currently exposed boundary faults are separate, late-stage structures.

Table of Contents

In inshore outcrops the Lizard basement is rapidly replaced east and west by Variscan sediments (Curry, Hamilton and Smith 1971). Off the east coast the magnetic anomalies associated with the Lizard complex (Allan 1961) continue beyond this boundary, suggesting that the basement extends under shallow Variscan cover. Immediately south of the inshore outcrops of the Lizard complex, basement has been seismically detected 350m deeper, beneath about 300m of Variscan cover (Day *et al.* 1956). Clearly, the present outcrop of metamorphic basement around the Lizard peninsula results from the combined effects of several different structural trends. The largest total movement may have accumulated on the southern boundary.

5. **Discussion**

It is clear that the available evidence contradicts a simple "Lizard-Dodman-Start Thrust" concept, and emphasises fundamental differences between the three areas. The Roseland-Dodman area offers only indirect evidence of basement. Thrust-faults can be readily identified there in a condensed and varied lithological sequence, but may involve relatively small displacements. Similar thrusting within the thick, monotonous, Gramscatho greywacke unit would be difficult to detect. In the Lizard area, an already shallow basement has been accommodated in early anticlinal folds by local thrust-faulting, but the present outcrop distribution relates to a complex of later normal faults. In the Start-Bolt peninsula, basement rocks occur without obvious relation to the local stratigraphical or structural environment, but also without evidence of overthrusting. If the gravity anomalies (Bott and Scott 1966) are really only compatible with a model involving a shallow wedge of basement riding a south-dipping thrust-plane, then the over-riding unit must encompass large tracts of S. Cornwall and S. Devon and the outcrop of the thrust is to be sought well north of the Start and Lizard peninsulas. Alternatively, the proposed geophysical models must be regarded as tailored to an inappropriate synopsis of the surface geology.

Any consideration of a possible link between the Start and Lizard basement highs must take account of the results of submarine prospecting, and preferably after restoration of the horizontal component of the displacements along NW-SE faults, as

Table of Contents

in Figure 1. The known wrench-faults have been extrapolated southeastward with some support from outcrop and magnetic anomaly patterns, but there seems little justification for locally assuming homogeneous shear in areas devoid of obvious transcurrent displacements (Dearman 1963). Thus the Start Schist outcrop arrives at the latitude of shallow basement detected off the north Cornish coast (Merriweather 1958).

Devonian palaeogeography is also instructive, indicating that an important sedimentary basin separated the Lizard and Start areas. During Lower Devonian times, strong subsidence in the Start area kept apace with thick continental and shallow-marine sedimentation, while to the south a thinner, deeper-water succession accumulated in basins and on the flanks of rises, as seen in the Meneage area. In mid-Devonian times, this basin accommodated a thick turbidite sequence, which overstepped the earlier relief, while the accumulation of shelf sediments north of the Start region became relatively slow, and was locally overtaken by deeper-water conditions.

Thus, while the zones of intrusives thought to mark the northern flank of the Start basement high can be traced farther west into Cornwall, the southern limit of this high lines up with the northern edge of the Gramscatho greywackes. This latter line can now be regarded as an important hinge-line in Devonian sedimentation, as well as a local feature in elvan frequency, a tectonic discontinuity (Sanderson 1971) which could be resolved by vertical displacement (Henley 1973), and approximately the line of an anomalous re-entrant in the south wall of the granite batholith. An eastward extension of the Start feature could be sought in E-W faults in the post-Variscan cover.

In any attempt to contour the depth of pre-Variscan basement in the English Channel and its Western Approaches (Day *et al* 1956, Hill and Vine 1965), it is immediately tempting to link the Start, Eddystone and Lizard outcrops with a seismic station ESE of the Start and a line of stations WSW of the Lizard (Fig. 1). This implies a single, continuous, arcuate zone in which the basement either crops out or forms the immediate subcrop of post-Variscan sediments. In detail this zone must include large areas with some Variscan cover. Evidence set out above shows that the level of basement in this zone must result from a complex of factors. The

Table of Contents

somewhat speculative discussion was designed to show that other attractive basement configurations can be argued, and that a Lizard-Start ridge runs oblique to basement features deduced from Devonian facies distributions. The present lines of shallow basement run alongside the granite batholith and may be a rim effect associated wilh the intrusion and superimposed on an earlier pattern of basement blocks.

ACKNOWLEDGEMENTS. Sincere thanks are due to Dr. S. C. Matthews whose interest and discussion stimulated this contribution. The review is partly based on work undertaken with financial support from N.E.R.C. while at the University of Bristol.

ALLAN, T. D. 1961. A magnetic survey in the western English Channel. *Q. Jl geol. Soc. Lond.,* **117,** 157-170.

BOTT, M. H. P. and SCOTT, P. 1966. Recent geophysical studies in south-west England. *In* Present views of some aspects of the geology of Cornwall and Devon. *R. geol. .Soc. Corn., C ommem. Vol. for 1964:* 25-44.

CURRY, U., HAMILTON, D. and SMITH, A. J. 1971. Geological evolution of the western English Channel and its relation to the nearby continental margin. *Rep. Inst. geol. Sci.,* 70/14, 129-142.

DAY, A. A., HILL, M. N., LAUGHTON, A. S. and SWALLOW, J. C. 1956. Scismic prospecting in the Western Approaches to the English Channel. *Q. Jl geol. Soc. Lond..* **112,** 15-42.

DEARMAN, W. R. 1963. Wrench-faulting in Cornwall and South Devon. *Proc. Geol. Ass.*, **74**, 265-287.

FLETT, J. S. 1946. Geology of the Lizard and Meneage, (2nd. edition). *Mem. geol.Surv. Gt. Br.*

HARPER, C. T. 1964. Potassium-argon ages of slates and their geological significance. *Nature:* **203**, 468-470.

IIENDRIKS, E. M. L. 1937. Rock succession and structure in south Cornwall: a revision with notes on the central European facies and Variscan folding there present. *Q. Jl. geol. Soc. Lond.,* **93**, 322-360.

_____ 1939. The Start-Dodman-Lizard boundary zone in relation to the Alpine structure of Cornwall. *Geol. Mag.,* **76**, 385-401.

HENLEY, S. 1973. The structure of the Perranporth area, Cornwall. *Proc. Ussher Soc.,* **2**, 521-524.

HILL, M. N. and KING, W. B. R. 1953. Seismic prospecting in the English Channel

Table of Contents

and its geological interpretation. *Q. Jl.geol. Soc. Lond.,* **109**, *1-20.*

HILL, M. N. and VINE, F. J. 1965. A preliminary magnetic survey in (he Western Approaches to the English Channel. *Q. Jl geol. Soc. Lond.,* **121**, 463-475.

LAMBERT, J. L. M. 1965. A reinterpretation of the breccias in the Meneage crush zone of the Lizard boundary, south-west England. *Q. Jl geol. Soc. Lond.,* **121**, 339--358.

MARSHALL, D. 1965. The Start Boundary problem. *Unpbl. Ph.D. Thesis, Univ. Bristol,* 2 vols.

McKEOWN, M. C. 1962. Structural studies at Dodman Point, Cornwall. *Proc. Ussher Soc.,* **1,** 22-23.

MERRIWEATHER, A. S. 1958. A seismic refraction-shooting survey off the north coast of Cornwall. *Geophys. J.,* **1**, 73-91.

PHILLIPS, F. C. 1961. Structural petrology of the schists of the Start Point area. *Abstr. Proc 4thh. Conf. Geol. Geomorph. SW England. 7-8.*

REID, C. 1907. Geology of the country around Mevagissey. *Mem. Geol. Surv. U.K.*

RICHTER, D. 1968. Die tektonische Baugeschichte von Sud-Devonshire als Beispiel einer mehrphasigen variszischen Prägung. *Geol. Rdsch.,* **57**, 434-445.

SADLER, P. M. 1973a. A proposed stratigraphical succession for the Roseland area of south Cornwall. *Unpbl. Ph.D. Thesis Univ. Bristol.*

_____ 1973b. An interpretation ol'new stratigraphic evidence from soulli Cornwall. *Proc. Ussher Soc.,* **2**, 535-550.

_____ 1974. Trilobites from the Gorran Quarlzites, Ordovician of south Cornwall. *Palaeontology,* **17**, 71-93.

SANDERSON, D. J. 1971. Superposed folding at the northern margin of the Gramscatho and Mylor Beds, Perranporth, Cornwall. *Proc. Ussher Soc.,* **2**, 266-269.

SEDGWICK, A. 1852. On the slate rocks of Devon and Cornwall. *Q. Jl geol. Soc. Lond.,* 8, 1-19.

STUBBLEFIELD, C. J. 1939. Some Devonian and supposed Ordovician fossils from south-west Cornwall. *Bull. geol Surv. G. B.,* **2**, 63-71.

TILLEY, C. E. 1923. The petrology of the metamorphosed rocks *of* the Start area, (South Devon). *Q. Jl geol. Soc. Lond.,* **79**, 172-204.

Geologisch-Paläontologisches Institut
der Georg August Universität
Göttingen 34
Germany

Table of Contents

EXMOOR THRUST? VARISCAN FRONT?

by S. C. Matthews

Abstract. The negative gravity anomaly known in the Exmoor-Quantock region has been taken to be due to a large thrust which carries Devonian northward over Devonian and Carboniferous. It is now suggested that this Exmoor Thrust may not exist. Devonian sequences thickening northward from the line of a deep fracture situated south of Exmoor may suffice to explain the observed effects.

The Variscan Front is readily identifiable in Belgium. A comparable situation is found in southwest Wales, where again there is a coincidence of thrusting and shallowing basement. No such relationship can be suggested in the Exmoor region. The notional Variscan Front refers to different things in different places - to thrusts where basement is shallowing (Belgium, southwest Wales, perhaps New Brunswick), elsewhere to a northward increase of thickness, plus facies-change, with consequent changes of fold-style (southern Ireland, Westphalia).

1. Introduction

An interesting problem exists at Cannington Park, near Bridgwater, where Trias outcrop 200m. wide conceals whatever is the junction between Devonian on the south (Webby 1965: Rodway Beds, presumed Upper Devonian) and Carboniferous Limestone on the north (S_1 according to Wallis 1924). Usher (1891), who first identified the problem, suspected that the Devonian must have been thrust northward over the Carboniferous. Falcon (1952) opened a modern phase of discussion of the question and introduced a larger view of what might be involved. He referred to a northward decrease of gravity values across the Quantocks and suggested that this gave support to the idea of a major thrust.

2. Gravity surveys

Bott, Day and Masson Smith (1958) showed that a negative anomaly exists in the whole Exmoor/Quantock region. They suggested that there are four possible interpretations:

1. Crustal variation - This view Bott, Day and Masson Smith rejected, holding that the cause of the anomaly must be at relatively shallow depth.

Table of Contents

2. Unexposed granite - This, too, they rejected: the steady gradients and the shape of the contours do not conform with what is characteristic of anomalies over granite bodies.

3. Stratigraphic cause - Bott, Day and Masson Smith doubted whether thicknesses of Lower Devonian rocks under Exmoor would be sufficient to explain the anomaly. They advised that the requirement is at least 4 km of sandstone stratigraphically below the oldest rocks exposed. They also suggested that underlying pre-Devonian rocks are likely to be of relatively high density and so would make no contribution to the effect observed.

Two comments may be inserted here. First, the required thickness of Lower Devonian is not entirely improbable. The Exmoor succession has a much greater thickness of Middle and Upper Devonian than is found in South Wales, and it is conceivable that Lower Devonian in the Exmoor region might include coarse sedimentary material in thickness comparable with what is found in Pembrokeshire (see a figure of the order of 4 km for that area in Allen, Dineley and Friend 1967, table IV).

Secondly, there is the question of the character of the pre-Devonian rocks. Bott, Day and Masson Smith (1958, p.184) refer to these as being, in general, of rather higher density than the Devonian rocks of Exmoor, and suggest that since they are non-porous they would have been incapable of undergoing any significant change in bulk density. In fig. 11 of their paper. Bott, Day and Masson Smith indicate that below Exmoor "older metasediments?" may underlie a relatively light body of rocks. Their remarks perhaps assume that the pre-Devonian of the Exmoor region has some kinship with the pre-Devonian of the southern most parts of Cornubia. An alternative possibility is that the Exmoor Devonian may be underlain by a Silurian succession (see Holland 19b9, 211-2, for remarks on the regional context of such a case). Nevertheless, it should be acknowledged that there is no reason to suspect that Silurian in this region would include any significant proportion of sandstone. There is therefore no indication, however indirect, that a Silurian succession might assist in explaining the gravity anomaly.

Table of Contents

4. Tectonic cause - Bott, Day and Masson Smith finally prclerred a tectonic explanation, proposing that the Exmoor Devonian might have overridden a considerable thickness of Devonian and Carboniferous coarse sedimentary rock. They observed that on this model the suspected thrust must have brought about horizontal tectonic transport of at least 14 km, and noted that the Charriage de Condroz in Belgium and France (occupying "a comparable position in the Hercynian chain" in their view: see below) involved, on Fourmarier's (1933) estimate, at least 30 km northward transport of Devonian rocks.

Bott and Scott (1965) again favoured a tectonic explanation. The suggestion now was that any stratigraphic alternative would require Lower Devonian or earlier arenaccous rocks to thicken by 6 km northward across Exmoor. Bott and Scott remarked that anomalies on the scale encountered are conspicuously absent over thick O.R.S. or Lower Palaeozoic basins in Great Britain, although they can be found over Carboniferous basins.

More recently, Brooks and Thompson (1973) have published the results of a gravity survey of the Bristol Channel area. A particularly important matter is their identification of a regional effect in the gravity field. When allowance is made for this the amplitude of the Exmoor anomaly is much reduced. Brooks and Thompson, referring to their Porlock profile, propose that the maximum thickness of the low density rocks causing the anomaly is 2.2 km on one assumption of density contrast and 3.6 km on another (compare the estimates of 5 and 6 km, on the same assumptions, that arose out of the earlier gravity work). These are figures which do a great deal to revive thoughts of a stratigraphic explanation of the Exmoor anomaly. Indeed Brooks and Thompson (1973, p.261) allow that their findings can support either a tectonic or a stratigraphic hypothesis, and suggest that the choice between these two must be based on regional geological considerations. Their own choice is again the thrust hypothesis and they conclude that movement on the thrust is likely to have exceeded 25 km. But there are some matters of stratigraphy and of regional geology that deserve further examination.

Table of Contents

3. Stratigraphy

Discussions of the Exmoor Thrust often involve mention of a facies-contrast thought to distinguish stratigraphic successions north of the presumed fracture-line (Mendips and South Wales) from those on the south (Devon and Cornwall). Ramsbottom(197(1), attempting a reconstruction of lower Carboniferous facies-relationships in the southwest England/southern Ireland region, has assumed the existence of the thrust (which he identified as the Hercynian Frontal Thrust) and has plotted his series of palaeogeographies on base maps "stretched" by some 25 km. Brooks and Thompson (1973), with a similar estimate of movement in mind, have remarked that an adjustment of this kind would leave a wide transition zone in which major changes of facies, from continental 0.25. to marine Devonian, and from Carboniferous Limestone to "Culm Measures", might have occurred. This provision is unnecessary. The Devonian on Exmoor, south of the line of the presumed fault, includes two major insertions of O.R.S. facies, the Middle Devonian Hangman Grits and the Upper Devonian Pickwell Down Sandstone, each estimated to be ca 1.3 km thick in Goldring, House, Selwood, Simpson and Lambert (1967). Conversely, there is marine Devonian in Oxfordshire (Poole 1969, 1972). In the case of the Lower Carboniferous, it is now known that in southern Ireland the two major facies exist in close apposition and that this situation owes nothing to the operations of a major thrust (Naylor 1969; see some adjustments of age-information in Matthews and Naylor 1973, and note that these.adjustments should be applied to Ramsbottom 1970 also). In the Lower Carboniferous of Germany, too, there is a rapid facies-transition and diminution of thickness southward across the strike (Conil and Paproth 1968). If the Irish model applies to North Devon, the following possibilities exist:

1. Carboniferous Limestone facies probably extends southward from the Mendips as far as Cannington Park. There, the succession might approach the character seen around Cork City, might include Waulsortian rocks at horizons lower than those now exposed and might have a thickness of the order of 1.7 km, as at Cork, rather than 1 km, the maximum seen in the Mendip area.

2. Southward from Cannington Park, the Lower Carboniferous

Table of Contents

(now stripped off) would have passed into a thick Cork Beds succession (approaching the character of the Old Head of Kinsale succession in Ireland) before thinning southward into the Pilton Beds, Codden till Cherts and associated rocks (ca. 0.35 km thick?: see Goldring 1970; see also Naylor, Jones and Matthews, 1974).

The stratigraphic arrangements envisaged here - Lower Devonian possibly of thickness sufficient to satisfy the geophysicists' requirements, Middle and Upper Devonian swollen by two insertions of O.R.S. rocks, and a Lower Carboniferous arrangement in the Exmoor region which though now removed, would, in its time, have been thickening northward - suggest that the Exmoor gravity anomaly might well be interpreted in terms of a major fracture (not necessarily a thrust) situated along the southern margin of Exmoor. If several parts of the Upper Palaeozoic succession thickened northward from the neighbourhood of this line, a gravity anomaly of the scale proposed by Brooks and Thompson might result. Such a proposal would explain the steep southern termination of the anomaly (Bott, Day and Masson Smith 1958, p.184-5 and fig. 11). Bott, Day and Masson Smith interpreted this as being due to a southward steepening of the thrust plane (an unsatisfactory proposal, and less satisfactory still if the Devonian is underlain by a dominantly fine-grained Silurian succession), but also mentioned stratigraphic variation or an abrupt southward rise of the rocks forming the floor of the autochthonous low-density mass as possibly having contributed. It is this last suggestion that now seems attractive. A deep fracture would have the further merit of explaining Bott, Day and Masson Smith's (1958, p.186) observation that magnetic anomalies decrease in a northerly direction towards Exmoor - this finding, too, is better accommodated in a proposal of basement fracture than in the concept of an Exmoor Thrust. Any such deep structure may have expression at the present surface in faults such as the Brushford Fault (Prentice 1966) or one in ground farther to the west mentioned by Burne and Moore (1971, p.296) and again by Freshney and Taylor (1972, p.470) who have suggested several hundred metres downthrow to the north.

4. Regional geology

When considering the structure of the Exmoor area in its

Table of Contents

regional (west European) setting, it is necessary to ask whether a fault-complex comparable with the Belgian Charriage de Condroz might be present (cf. Bott, Day and Masson Smith 1958). In Belgium, the Charriage de Condroz intervenes between the Namur syncline on the north and the Dinant syncline on the south. Within the Namur syncline Middle Devonian oversteps pre-Devonian rocks and the succession ranges up to include a thick Silesian sequence. The Dinant synline has a full Devonian succession, which is followed by the original Dinantian (whose facies-characteristics, it will be understood, invite comparisons with the Mendips and South Wales rather than with Devonshire). Core situations produce relatively little Silesian outcrop. The work of Fourmarier (1954 and earlier) has clearly revealed the character of the faulting and the scale on which it operated. Graulich (1961) has unravelled the complexities that exist in the southern part of the Namur syncline, where Lower Palaeozoic rocks (down to Tremadoc) are involved in the sheeted structures. Rutten (1969) reviewed the question of attributing these structural developments to the influence of the Ardennes Massif on the south and the Brabant Massif on the north. He argued that since the Brabant Massif has no effect on the Upper Carboniferous successions (and cited in this connection the views of van Leckwijk 1956 and Patijn 1963 - unfortunately, in redrawing Patijn's sections, Rutten 1969, p.101, introduced a wrong indication of north and south) the Massif must have been of later establishment and could not have acted as a buttress during the Variscan orogeny. He viewed the Belgian structures as the product of gravity tectonics driving northward off the Ardennes Massif. It seems likely, however, that Rutten dismissed the Brabant Massif too readily. The overstepping Middle Devonian gives a clear indication that the basement was shallowing northward in the area in which the late Palaeozoic fold and fault structures came into being.

Bouroz (1960) has supplied the most detailed account so far available of Palaeozoic subcrop in Artois and the Boulonnais, where the major thrust structure carries (mainly) Devonian northward over (mainly) Upper Carboniferous and runs westward to the Channel coast at a point between Boulogne and Calais. Wallace (1968) suggests that the same relationship between thrusting and a massif rising in the north may exist in the southeastern part of England. Westward from the Straits of Dover, however, it is increasingly difficult to rind a means of identifying the margin of any

Table of Contents

continuation of the massif and more difficult still to find evidence of major thrusting within the buried Palaeozoic. Wallace (1968) suspects that the thrusting (the "Variscan Front") may diverge from the massif in this direction and may have diminishing effect. The point essential to the present discussion is that if the southwestern parts of the British Isles include any recurrence of a closer relationship between thrusting and a massif on the north, a Variscan Front, it lies in South Wales (especially Pembrokeshire, where thrusts cut an Upper Palaeozoic succession that is thinning northward on to pre-Devonian rocks: Jones, 1956, p1.15) rather than within the thick Devonian succession of the Exmoor area.

The Variscan Front is customarily regarded as continuing westward front Pembrokeshire to cross southern Ireland. However, no such structure is necessary in the neighbourhood of Cork City, where there is a rapid transition from one major Lower Carboniferous facies to another (Matthews and Naylor 1973). Thrusting may be in evidence again further west. It is present at Mallow, according to Gill 1962 (one of the few authors who has - made a specific proposal on the location of the Variscan Front in Ireland in recent years) and along the southern limit of the Kanturk coalfield (van Waterschoot van der Gracht 1938). In these latter two areas there need be no suggestion that the thrusting has brought two deeply different facies-associations together.

This discussion of regional geology is of a kind frequently found in the literature of the last fifty years or so (see early examples in Stainier 1922, Fourmarier 1924): one refers to Belgian structures and attempts to extrapolate westward from them. The possibility of extrapolating eastward can be treated with less expense of words. As von Gaertner and Watznauer (1964, 160) have remarked, the Faille du Midi becomes less significant in that direction. It can still be recognised near Aachen (Herbst, 1971: fig. 1), but east of the Rhine it is quite unknown (see the 1:100,000 Geologische Ubersichtskarte des Niederrheinisch-Westfalischen Karbons, published by G. L. Nordrhein-Wesifalen, Krefeld in 1971). It may be thought to end where the Brabant Massif ends, in the neighbourhood of the Peel Horst (van Waterschoot van der Gracht 1938) or of the Krefelder Gewölbe, eastward from which Namurian thickness rapidly increases from 1 km to over 3 km (Hedemann, Fabian, Fiebig and Rabitz 1972, fig. 2).

Table of Contents

5. Variscan Front in North America?

Bailey (1929) recognized both the Caledonian and the Variscan belt in northeastern North America. Fitch (1965) referred part of that region to a Variscan sub-chelozone on the basis of radiometric datings. Recently Rast and Grant (1973) have suggested that the Variscan Front is present in New Brunswick, where they find a resemblance to the Pembrokeshire arrangement of structures. Ager (1973:90: "The so-called 'Hercynian Front' . . . can be traced, rather precisely, from New England, through southwest Ireland, via south Pembrokeshire and the Gower Peninsula, under the University College of Swansea, then south of the Kent Coalfield to the Boulonnais and on as the *Grande Faille du Midi* far into the European continent") is of the, same general persuasion. Cherkis, Fleming and Massingill (1973) take magnetic data as their justification for running the Variscan Front through Massachusetts, New Hampshire, Maine, the Maritime Provinces of Canada and on to Newfoundland. They have proposed that the course of this major Palaeozoic structure determined the site of the later Gibbs Fracture Zone, an Atlantic transform fault. Others hesitate to propose any representation of the Variscan Front in the geology of the northeastern part of onshore North America. Marshall Kay (1969), for example, has suggested that the Variscan Front runs through the continental shelf southeast of Newfoundland. Kennedy, Neale and Phillips (1969) adopt a similar treatment of the Variscan Front (fig. 1 of their paper), and so do Day and Williams (1970) who indicate closest approach to the present coast in the vicinity of Cape Cod. Evidently, there is more than one school of opinion on questions of the nature and the location of any North American continuation of the Variscan Front.

6. Variscan Front?

What should one think to be the nature of the Variscan Front? If it is a belt of thrusts, as seen in Belgium, in Pembrokeshire, and perhaps again in New Brunswick, there are problematical areas remaining - southern Ireland for example, possibly southern England too, and certainly Westphalia - where no good case for major thrusting exists. The suggestion in section 4 above is that the thrusts may have arisen only in areas where shallowing basement induced the development of such structures. What Rast and Grant

Table of Contents

(1973) have found in New Brunswick is perhaps a further local example of that relationship (see Rodgers 1970 for remarks on a basement high) rather than a North American segment of one continuous thrust-front. Rast and Grant accept that the Variscan Front is not in evidence in Newfoundland (they propose that the Chedabuclo Fault has shifted it into the Grand Banks area). An alternative possibility is that the thrusting may fade toward the northeast, where the Carboniferous thickens from 2 km to more than 8 km in the Fundy Basin (Hacquebard 1972), just as the *Faille eifeliènne* fades eastward toward the thick Namurian basin in Westplialia.

If a belt of thrusting is not everywhere available as a means of determining a Variscan front, is there an alternative possibility of recognising any such limit? The distribution of slaty cleavage is not decisive. Planar structures are well developed in the Devonian rocks of Exmoor, but are not widely available in South Wales (although they do occur in south Pembrokeshire: Jones 1956, Hancock 1974). Whether the development of slaty cleavage (Jones 1956) is due to any consideration of load or of rock-type (the strong cleavage on Exmoor perhaps seeded in rock-types such as the original Ilfracombe Beds and Morte Slates, which were not available in south Wales) is not clear; but an indication of the possible significance of rock-type is found in the penetrative slaty cleavage that occurs in the finegrained Lower Carboniferous rocks at Rush, north of Dublin. This same example suggests that slaty cleavage should not everywhere be taken as an indication of a fold-belt situation.

The line drawn on large-scale maps to show the course of the Variscan Front refers to different things in different places - to thrusting in some areas (Belgium, Pembrokeshire), but elsewhere (southern Ireland, Westphalia) to a northward increase of stratigraphic thickness, accompanied by the entry of particular rock-types such as the Carboniferous Limestone, changes which have had an influence on fold-styles subsequently developed.

Dunning (1964) has proposed that the northern limit of the Variscan foldbelt should be regarded as running through South Wales (although he concedes that the line is clearer in southwest Wales than in the "almost anorogenic area of southeastern Wales": Dunning 1964, p.99), and it is this treatment that appears on the

Table of Contents

Tectonic Map of the British Isles. It is fortunate that the Exmoor Thrust was not taken as the Variscan limit. Dunning (1964) remarked that that fracture might be regarded as marking the northern limit of the eugeosynclinal zone of the fold-belt; but his suggestion is not in good accord with the character of the Exmoor succession, nor with the almost total lack of volcanic rocks there. Anyone wishing to identify that particular boundary would do well to look farther south. One recent author who has referred to ground farther south is Johnson (1973) who wishes to identify a subduction zone in north Cornwall. This he names the Hercynian Front Suture.

There are questions of the nature of the northern limit of the Variscan foldbelt and of the location of that limit that are not yet fully understood. There remains also the question of the structural relationship at Cannington Park - note how Webby's (1965, fig. 4) map shows that there is only a rather restricted 'window' through which any fault separating Devonian from Carboniferous must pass, and note too that a westward projection of any such fault runs toward what is apparently an unbroken belt of Hangman Grits outcrop near the northern end of the Quantocks.

AGER, D. V. 1973. *The nature of the stratigraphical record.* 114 pp. Macmillan.

ALLEN, J. R. L., DINELEY, D. L. and FRIEND, P. F. 1967. Old Red Sandstone basins of North America and Northwest Europe, pp.69-98: In Oswald, D. H. (Fd.): *International symposium on the Devonian System.* Calgary.

BAILEY, E. B. 1929. The Palaeozoic mountain systems of Europe and north America. *Rep. Br. Ass. Advmt. Sci.,* 90th Meeting, 57-76.

BOTT, M. H. P. and SCOTT, P. 1965. Recent geophysical studies in south-west England, pp. 25-44: *In* Hosking, K. F. G. and G. J. Shrimpton (Eds.): Present views of some aspects of the geology of Cornwall and Devon. *Royal Geological Society of Cornwall.*

DAY, A. A. and MASSON SMITH, D. 1958. The geological interpretation of gravity and magnetic surveys in Devon and Cornwall. *Phil. Trans. R. Soc., Series A.* **251**, 161-191.

BOUROZ, A. 1960. La structure du paléozoique du Nord de la France an Sud de la Grande Faille du Midi. *Annls. Soc. Géol. N.* **80,** 101-112.

BROOKS, M. and THOMPSON, M. S. 1973. The geological interpretation of a gravity survey of the Bristol Channel *Jl. Geol. Soc. Lond.* **129,** 245-274.

Table of Contents

BURNE, R. V. and MOORE, L. J. 1971. The Upper Carboniferous rocks of Devon and north Cornwall. *Proc. Ussher Soc.* **2**, 288-298.

CHERKIS, N. Z., FLEMING, H. S. and MASSINGILL, J. W. 1973. Is the Gibbs Fracture Zone a westward projection of the Hercynian Front into North America? *Nature Phys. Sci* **245**, 113-115.

CONIL, R and PAPROTH, E. 1968. Mit Foraminiferen gegliederte Profile aus dem nordwest-deutschen Kohlenkalk und Kulm. *Decheniana* **119**, 51-94.

DAY, G. A. and WILLIAMS, C. A. 1970. Gravity compilation in the N.E. Atlantic and interpretation of gravity in the Celtic Sea. *Earth Plan. Sci. Newsl.* **8**, V5-213.

DUNNING, F. W. 1964. The British Isles, pp.87-103: *In* A. A. Bogdanoff, M. V. Mouratov and N. S. Schatsky (Eds.) *Tectonique de l'Europe.* Nauka-Nedra, Moscow.

FALCON, N. L. 1952. pp.303-304: *In* A. H. Cook and H. I. S. Thirlaway. A gravimeter survey in the Bristol and Somerset coalfields. *Q. Jl Geol. Soc. Lond.* **107**, 225-30b:

FITCH, F. J. 1965, pp.191-193: *In* P. M. S. Blackelt, Sir E. Dullard and S. K. Runcorn (Eds.). *A symposium on continental drift.* The Royal Society.

FOURMARIER, P. 1922. L'évaluation de l'importance des phénomènes de charriage en Belgique et dans les régions voisines. C.R. 13e. Int. Geol. Cong., **1**, 507-516.

_____ 1933. Observations sur l'estimation de l'importance du transport suivant le charriage de Condroz. *Annls. Soc. Geol. Belg.* **56**, 249-259.

_____ 1954. *Prodrome d'une description géologique de la Belgique.* 826 pp. Société géologique de Belgique.

FRESHNEY, E. C. and TAYLOR, R. T. 1972. The Upper Carboniferous stratigraphy of north Cornwall and west Devon. Proc. Ussher Soc. **2**, 464-471.

von GAERTNER, H R. mid WATZNAUER, A. 1964. The Central European Variscides, pp.158-177: *In* A. A. Bogdanoff, M. V. Mouratov and N. S. Schatsky (Eds.). *Tectonique de l'Europe.* Nauka-Nedra, Moscow.

GILL, W. D. 1962. The Variscan fold belt in Ireland, pp.49-64: *In* K. Coe (Ed.). *Some aspects of the Variscan fold belt.* University Press, Manchester.

GOLDRING, R. 1970. The stratigraphy about the Devonian-Carboniferous boundary in the Barnstaple area of north Devon, England. C.R. *6e Cong. Intern. Strat. Géol. Carb.*, Sheffield 1967, **2**, 807-816.

HOUSE, M. R., SELWOOD, E. B., SIMPSON, S. and LAMBERT, R. St. J. 1967. Devonian of southern Britain, pp.l-14: *In* D. H. Oswald (Ed.). *International Symposium on the Devonian System.* Calgary.

Table of Contents

GRAULICH, H. M. 1961. Le sondage de Wépion. *Mem. Expl. Cart. Geol. Min. Belg*. **2**, 102 pp.

HACQUEBARD, P. A. 1972. The Carboniferous of eastern Canada. *C.R. 7e Cong. Intern. Strat. Geol. Carb.*, Krefeld 1971. **1,** 69-90.

HANCOCK, P. L. 1974. Structural zones in Pembrokeshire. Proc Ussher Soc. **2**, S(19520.

HEDEMANN, H. A., FABIAN, H. J., FIEBIG, H. and RABITZ, A. 1972. Das Karbon in marin-paralischer Entwicklung. *C.R. 7e Cong. Intern. Strat. Geol. Carb.*, Krefeld 1971. **1,** 29-47.

HERBST, G. 1971. Das Revier von Aachen-Erkelenz. (a) Stratigraphic und Tektonik. *Fortschr. Geol. Rheinld Westf.* **19**, 61-68.

HOLLAND, C. H. 1909. The Welsh Silurian geosyncline in its regional context pp.203-217: *In* A. Wood (Ed.). *The Precambrian and Lower Palaeozoic rocks of Wales.* Univ. Wales Press.

JOHNSON, G. A. L. 1973. Closing of the Carboniferous sea in Western Eumpe, pp.843-850: *In* D. H. Tarling and S. K. Runcorn, *Implications of continental drift to the earth sciences*, **2**, Academic Press.

JONES, O. T. 1956. The geological evolution of Wales and the adjacent regions. *Q. Jl Geol. Soc. Lond.* **111**, 323-252.

KAY, M. 1969. Continental drift in North Atlantic Ocean. *Mem. Am. Ass. Petrol. Geol* **19**, 965-973.

KENNEDY, M. J., NEALE, E. R. W., and PHILLIPS, W. E. A. 1972. Similarities in the early structural development of the northwestern margin of the Newfoundland Appalachians and Irish Caledonides. *24th Int. Geol Cong.*, Section 3, 516-531.

von LECKWIJK, W. P. 1956. Tableau d'une aire instabile au Paléozoique supérieur: la terminaison orientale du Massif de Brabant aux confins belgo-néerlandais. *Verhandel. Koninkl. Ned. Geol. Mijnbouwk. Genoot.* Geol. Ser. **16**, 252-273.

MATTHEWS, S. C. and NAYLOR, D. 1973. Lower Carboniferous conodont faunas from south-west Ireland. *Palaeontology* **16**, 335-380.

NAYLOR, D. 1909. Facies change in Upper Devonian and Lower Carboniferous rocks of Southern Ireland. *Geol. J.* **6,** 307-328.

JONES, P. C. and MATTHEWS, S. C. 1974. Facies relationships in the Upper Devonian-Lower Carboniferous of southwest Ireland and adjacent regions. *Geol. J.* **9**, 77-96.

PATIJN, R. J. H. 1963. Het Carboon in de ondergrond van Nederland en de oorsprong van het massief van Brabant. *Geol. Mijnbouw* **42**, 341-349.

Table of Contents

POOLE, E. G. 1969. The stratigraphy of the Geological Survey Apley Barn borehole, Witney, Oxfordshire. *Bull. Geol. Surv. Gt. Br.* **29**, 1-104.

_____ 1972. The Oxfordshire coalfield. Nature, **236**, 394-395.

PRENTICE, J. E. 1966. Facies changes in the Chert Formation (Lower Carboniferous) of North Devon. *Proc. Ussher Soc.* **1,** 247-248.

RAMSBOTTOM, W. H. C. 1970. Carboniferous faunas and palaeogeography of the southwest England region. *Proc. Ussher Soc.* **2**,144-157.

RAST, N. and GRANT, R. 1973. Transatlantic correlation of the Variscan Appalachian orogeny. *Am. Jour. Sci.* **273**, 572-579.

RODGERS, J. 1970. *The tectonics of the Appalachians*. 271 pp. Wiley - Interscience.

RUTEN, M. G. 1969. *The geology of western Europe.* 520 pp. Elsevier.

STAINIER, X. 1920. La bande silurienne du Condroz et la Faille du Midi. *Bull. Soc. Belge. Géol. Paléont. Hydrol.* **30**, 63-76.

USSHER, W. A. E. 1891. On the probable nature and distribution of the Palaeozoic beneath the Secondary, etc., rocks of the Southern Counties, with special reference to the prospects of obtaining Coal by boring South of the Mendips. *Proc. Somerset Archaeol. Nat. Hist. Soc.* **36**, 88-136.

WALLACE, P. 1968. The sub-Mesozoic palaeogeology and palaeogeography of northeastern France and the Straits of Dover. *Palaeogeog. Polaeoclim. Palaeaecol.* **4**, 241-255.

WALLIS, F. S. 1924. The Avonian of Cannington Park, near Bridgwater, Somerset. *Geol. Mag.* **61,** 218-225.

van WATERSCHOOT van der GRACHT, W. A. J. M. 1938. A structural outline of the Variscan Front and its foreland from south-central England to eastern Westphalia and Hessen. *CR. 2e. Cong. Intern. Strat. Géol. Carb.,* Heerlen 1935, **3**, 1485-1565.

WEBBY, B. D. 1965. The stratigraphy and structure of the Devonian rocks in the Quantock Hills, West Somerset. *Proc. Geol. Assoc.* **76,** 321-344.

Dept. of Geology
The University
Bristol.

Table of Contents

Postulated graben structures in southern Britain (Abstract):

by A. Whittaker

Early Mesozoic sediments in the Severn Basin and Central Somerset Basin are disposed in major synclinal structures. Sediments thicken from the margins of the basins towards the troughs, showing that the structures were developing during early Mesozoic times. There is evidence that the basins' margins are steep sided and thus that they may be defined by fault scarps. This, in turn, allows the postulate to be made that the basins are underlain by major post-Hercynian graben structures in the Palaeozoic basement rocks.

In central Devon, the Crediton Trough is an E-W-irending, narrow, fault-bounded structure, with which are associated K-rich lavas of the Exeter Volcanic Series. It may be similar to the "roots" of the structures described above. By analogy with the Severn and Central Somerset basins, both characterized by thick Jurassic sequences, the Weald Basin may also be underlain by a major fault or faults, activity along which may have allowed the Jurassic basin to develop.

It is suggested that uplift or updoming at the close of the Hercynian Orogeny may have initiated a major rift valley system in southern Britain and that faulting of the Palaeozoic basement may have fundamentally controlled some of the early Mesozoic sedimentation in local sags.

This contribution is published by permission of the Director, Institute of Geological Sciences.

Institute of Geological Sciences
Hoopern House
Pennsylvania Road
Exeter

Table of Contents

CHEVRON FOLDING IN TIIE UPPER CARBONIFEROUS. ROCKS OF NORTH CORNWALL

by David J. Sanderson

Abstract. A geometrical model of chevron folds is used to interpret the folding in the Upper Carboniferous rocks of north Cornwall. The tightness of the folds is related to a southerly increase in shortening normal to their axial planes. Detailed features of the folding can be attributed to variation in layer thickness.

1. Introduction

A chevron fold is a straight-limbed, angular fold with a narrow hinge zone. Such folds are common in the interbedded greywackes and slates of the Upper Carboniferous of north Cornwall.

The relatively simple geometry of symmetrical chevron folds allows the shortening normal to the axial plane of the fold (e) to be expressed as a function of the layer thickness (t), limb length (1) and interlimb angle (2θ) (Fig. 1a):

$$1 + e = \left[1 - \left(\frac{\pi}{2} - \theta\right) t/l\right] \sin\theta + t/l \cos\theta$$

(Modified from Ramsay 1967, equation 7-44)

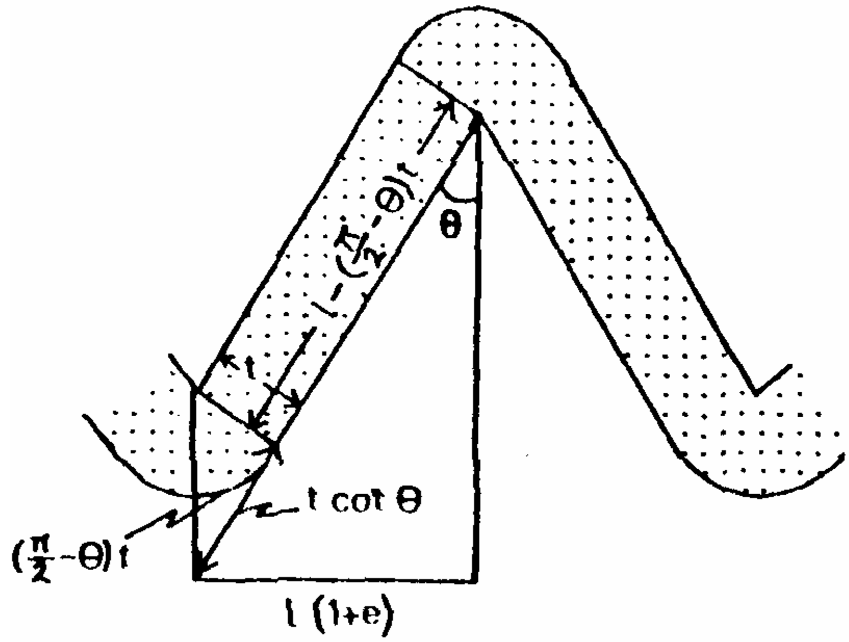
This equation may be solved for different values of t/*l* and a graph of 1 + e against interlimb angle (2θ) drawn (Fig. lb). From this graph it is clear that folds become tighter as:

(1) shortening increases, i.e. 1 + e decreases, or
(2) t/*l* increases

Ramsay (1967) also discusses the shear strain (y) on the limbs of chevron folds and shows that the incremental shear strain ($\frac{d\gamma}{de}$) is infinite when $2\theta = 180^{\circ}$, passes through a minimum at $110° < 2\theta < 130°$, and then increases rapidly as 2θ decreases. Since the incremental shear strain is an indication of the ease with which folding can take place it follows that:

(1) Chevron folds require initial buckling or layer irregularities to initiate. Smythe (1971) has suggested that chevron folds start as buckles with curved arcs, but in layered

Table of Contents



A

FIGURE 1. a) Chevron fold model (after Ramsay 1967, fig. 7-111)
b) Graph of interlimb angle (2θ) against 1+ e for chevron fold model.

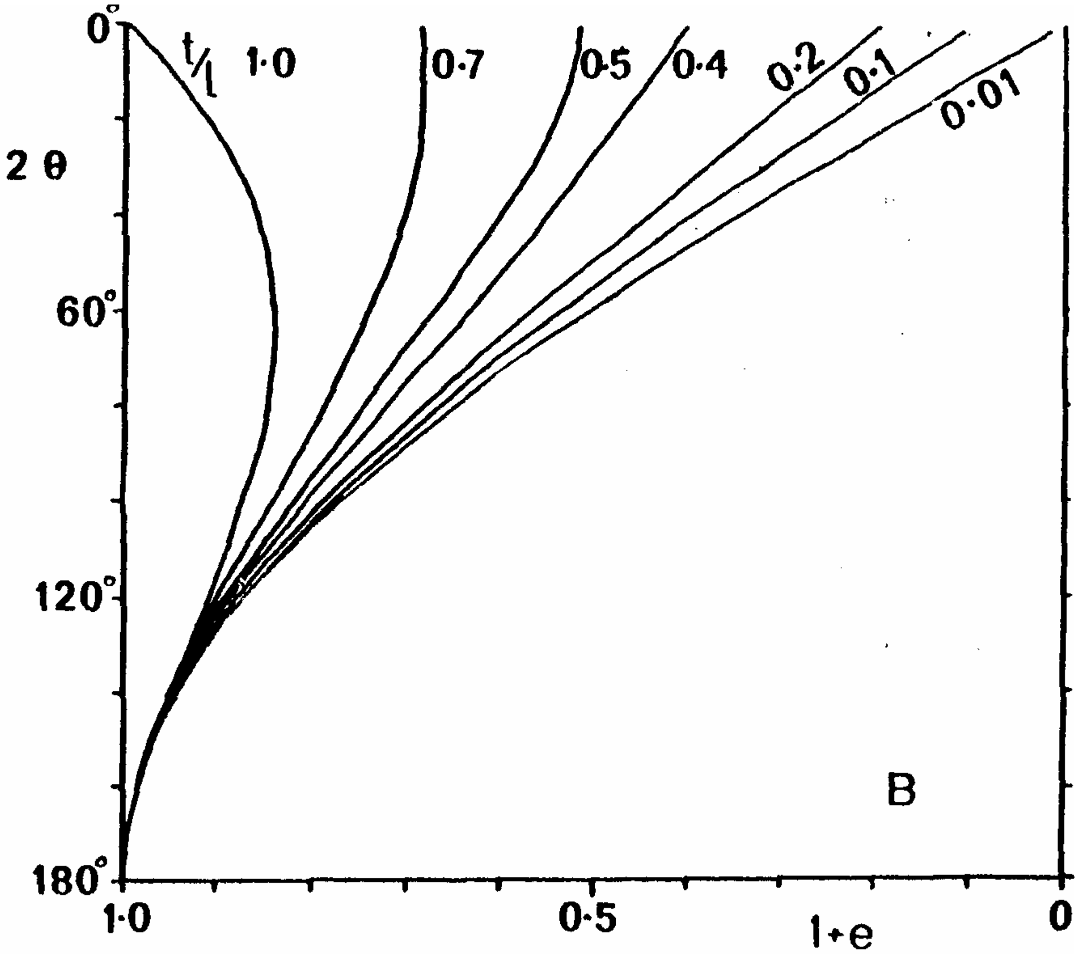


Table of Contents

media under high differential stress, fhrther shortening produces angular folds.

(2) After initiation chevron folding proceeds until the incremental shear on the limbs becomes large again and the fold locks. De Sitter (1958) first suggested locking of chevron folds to explain the common occurrence of folds with interlimb angles of about 60°. Deformation after locking must involve some other mechanism such as passive flattening of the folds.

2. Interlimb angles of chevron folds from north Cornwall

Data have been collected on the interlimb angles of chevron folds exposed on the coast between Clovelly and Boscastle (Fig. 2). The data fall into 3 main groups:

(1) Clovelly to Widemouth: Upright folds in the Bude and Crackington (ξ Welcombe) Formations with interlimb angles between 45° and 90° (mean = 61.6°).

(2) Widemouth to Rusey: Recumbent folds in the Crackington Formation with interlimb angles between 25° and 65° (mean = 42.2°).

(3) Rusey to Boscastle: Recumbent folds in the Crackington Formation with interlimb angles of less than 30°.

The difference in interlimb angles between the folds to the north and south of Widemouth cannot be attributed to different t/l ratios. Indeed, the folds in the Crackington Formation, south of Widemouth, have $t/l \cong 0.03$, which, for the same shortening, should yield more open folds than those in the Bude Formation to the north, where $t/l \cong 0.1$. Using these t/l values we can calculate the shortening across the folds from the above equation and this yields:

Widemouth-Rusey: $1 + e = 0.38$, i.e. 62% shortening
Clovelly-Widemouth: $1 + e = 0.55$, i.e. 45% shortening

Table of Contents

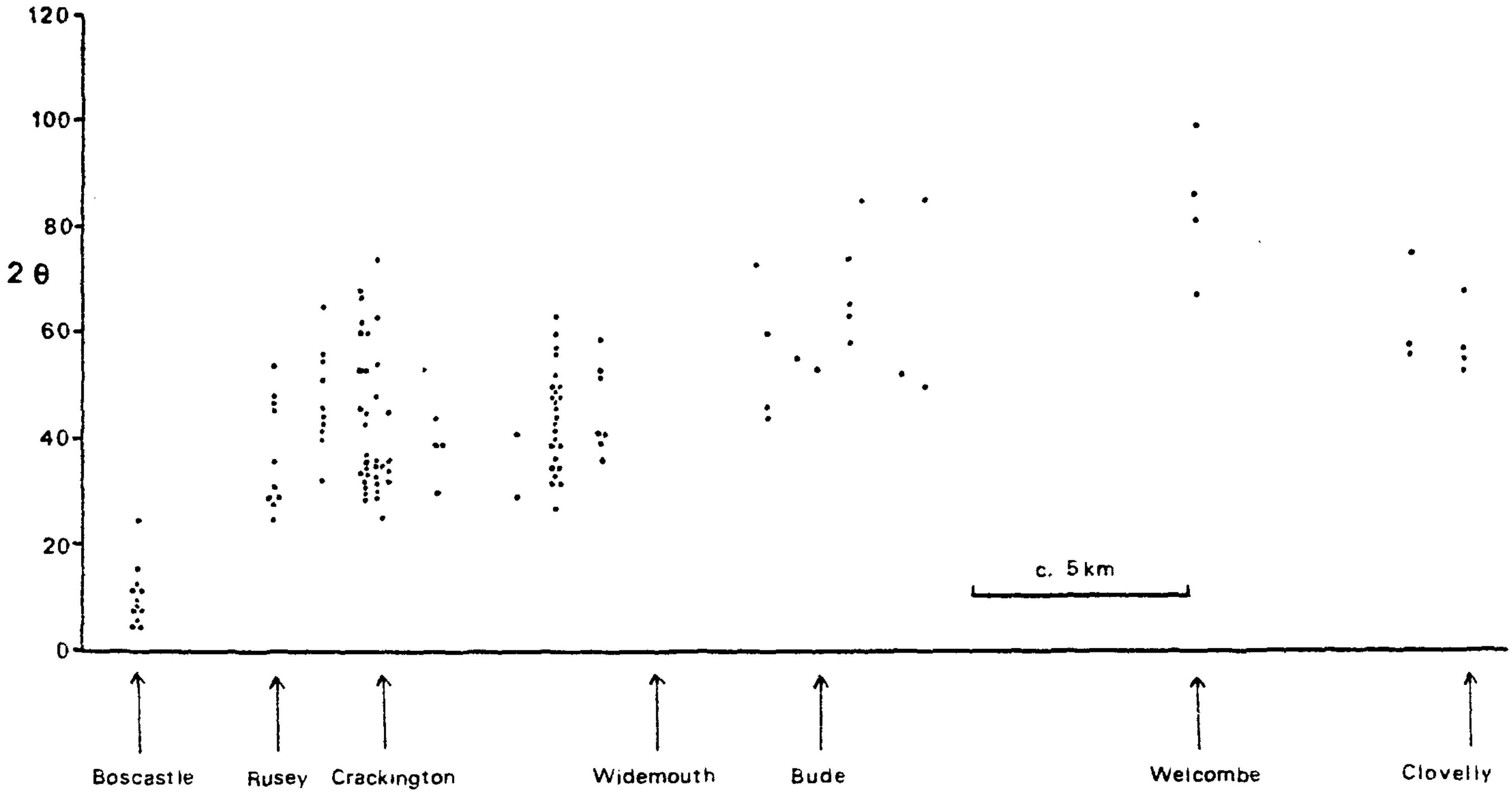


FIGURE 2. Interlimb angle (2θ) of chevron folds from north Cornwall

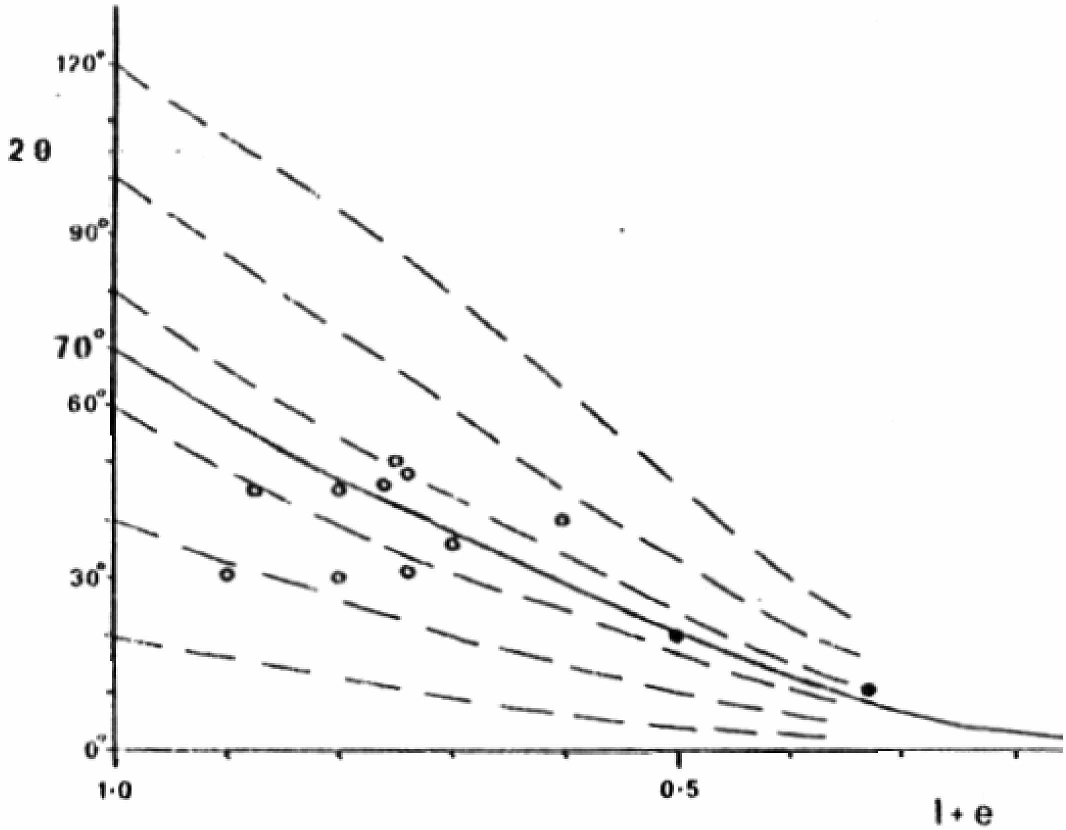


FIGURE 3. Interlimb angle (2θ) against 1 + e determined from orthogonal layer thickness of greywacke beds of individual chevron folds from north Cornwall. Open circles - data from Crackington Formation, south of Widemouth; closed circles - data from Boscastle. Broken lines indicate passive rotation of limbs during irrotational plane strain.

The folds south of Widemouth have interlimb angles which are less than the suggested locking angles for chevron folds. The folded layers show an increase in orthogonal thickness in the fold hinges, whereas chevron folds should have a constant layer thickness. From this change in thickness it can be calculated that the folds have undergone a 20% to 30% flattening, occasionally as much as 50%. A plot of the interlimb angle against flattening (Fig 3) indicates that the folds have been flattened from original folds with $2\theta \cong 70°$. Since the flattening in chevron folds with $2\theta > 70°$ is generally small we can interpret the fold history as one of chevron folding until locking occurs at about $2\theta \cong 70°$ and subsequent passive limb rotation during flattening. Assuming plane strain, the average shortening across the chevron folds south of Widemouth may be recalculated as $1 + e = 0.42$ (cf. 0.38 obtained by the chevron model above).

Graphs of $1 + e$ against 2θ may be constructed for chevron

Table of Contents

folds modified, after locking, by plane strain (Sanderson 1972, Ph.D. thesis, University of Newcastle-upon-Tyne). Fig. 4 illustrates such graphs for the folds from north Cornwall and indicates a southward increasing in shortening from Clovelly to the Tintagel area. The difference in strain between the upright folds, north of Widemouth, and the recumbent folds to the south is not consistent with a simple refolding from one attitude to the other. Instead the change in attitude is best explained by original variation in strain (Sanderson and Dearman 1973).

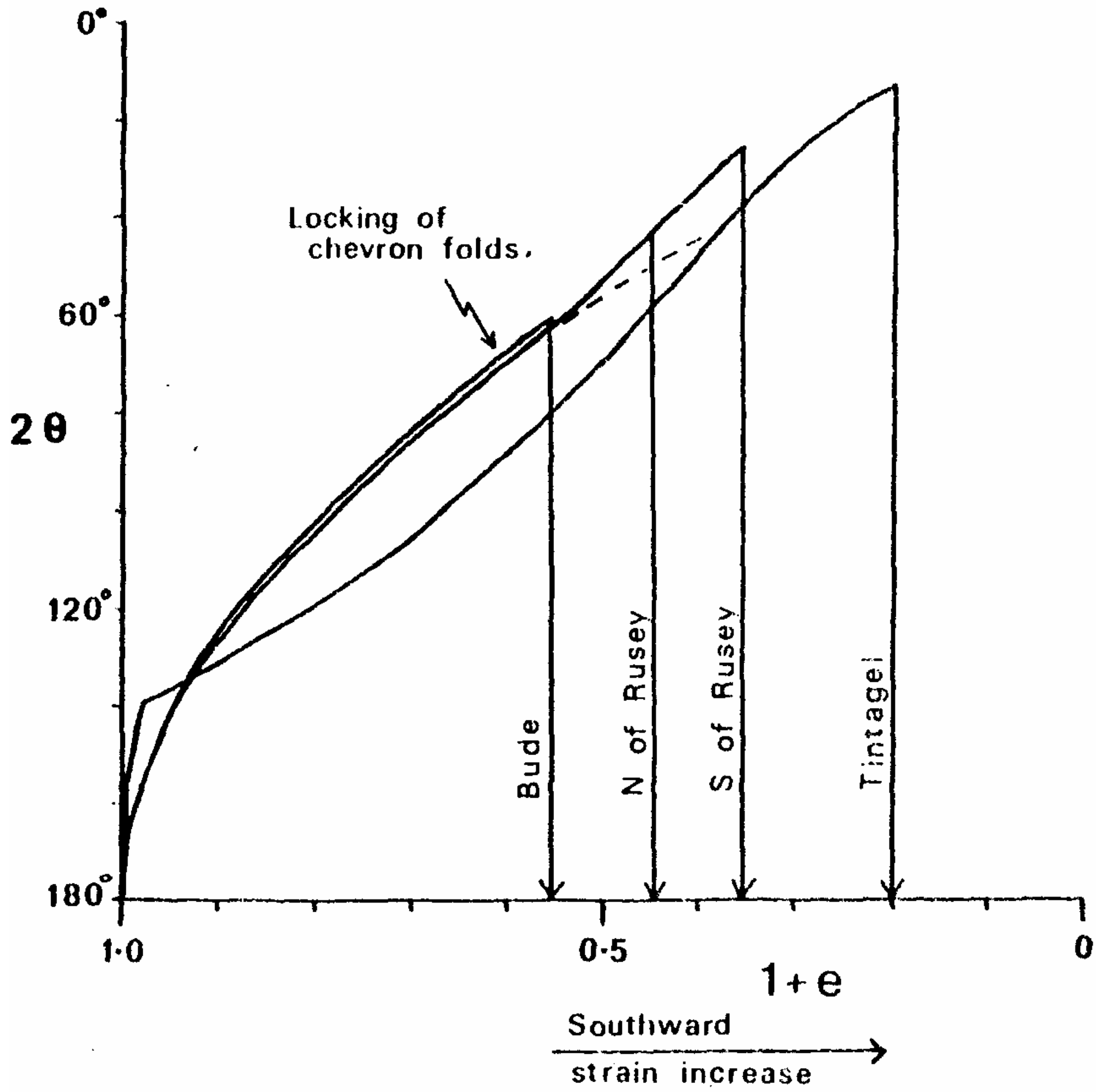


FIGURE 4. Interlimb angle (2θ) against 1 + e for different areas in north Cornwall illustrating southward strain increase towards Tintagel.

Table of Contents

3. Accommodation structures in chevron folds

For two layers of differing thickness in a chevron fold with constant interlimb angle, the thicker layer will allow less shortening. Thus for harmonic folds to develop the thicker layer must accommodate the extra shortening by some other means. This may occur by the development of small amplitude flexures on the fold limbs, by thrusting of the limbs, or by protrusion of the hinge into the surrounding slate. Many such accommodation features are seen in the chevron folds of north Cornwall, especially within the Crackington Formation.

Clearly the limb flexures produced to accommodate different layer thicknesses in chevron folds are a consequence of a single phase of folding and should not be attributed to a later phase of folding. Superposed folds with an associated crenulation cleavage can be found in the Crackington Formation, where they are related to low angle normal faults (Freshney 1965).

4. Conclusions

An examination of the geometry of chevron folds adds much to the interpretation of folds within the Upper Carboniferous rocks of north Cornwall. The tightness of the folds can be related to a southward increase in strain, the recumbent folds to the south showing more shortening normal to their axial planes than the upright folds to the north. Limb flexures and other details of the geometry of the folds can also be interpreted as due to chevron folding imposed on layers of differing thickness.

DE SITTER, L. V. 1958. Boudins and parasitic folds in relation to cleavage and folding. *Geol. Mag.* **20**, 277-86.

FRESHNEY, E. C. 1965. Low-angle faulting in the Boscastle area. *Proc. Ussher Soc.* **1**,175-9.

RAMSAY, J. G. 1967. *Folding and fracturing of rocks*. McGraw-Hill, New York, 568 pp

Table of Contents

SANDERSON, D. J. and DEARMAN, W. R. 1973. Structural zones of the Variscan fold belt in S. W. England, their location and development. *J. geol Soc. Lond.* **129,** 527-36.

SMYTHE, D. K. 1971. Viscous theory of angular folding by flexural flow. *Tectonophys.* **12**, 415-30.

Dept. of Geology
The Queen's University
Belfast

ON THE CORRELATIONS OF THE IIALDON AND ALLER GRAVELS, SOUTH DEVON

by R. J. O. Hamblin

Abstract. The Haldon Gravels comprise three Eocene and one Pleistocene components. The Tower Wood Gravel is an early Eocene residual deposit, the Buller's Hill Gravel is a fluvial deposit tentatively correlated with the Reading and Bagshot Beds, but clay bodies within that gravel are interpreted as originating as an overlying sheet of clay of later Eocene age. The Head Gravel is a Pleistocene solifluction deposit.

The Aller Gravel is a further fluvial deposit occurring in the Bovey Basin west of Haldon; direct correlation of this unit with the Buller's Hill Gravel is considered and rejected. The Aller Gravel is believed to be later in age than the Buller's Hill Gravel but earlier than the Bovey Formation; however, the possiblity cannot be ruled out that it also includes strata of Pleistocene age.

Table of Contents

1. Introduction

During resurvey of the Teignmouth (339) sheet for the Institute of Geological Sciences by geologists of Exeter University, flint gravels were mapped in two distinct areas. The Haldon Gravels occupy the summit of the Haldon Hills, an elongate plateau remnant between the valleys of the Rivers Exe and Teign, while the Aller Gravel occupies the eastern lower slopes of the Bovey Basin north and south of Kingsteignton (see figure 1).

The Haldon Gravels have already been described in some detail (Hamblin, 1973 a, b); they are divided into four components as follows:

1) The Tower Wood Gravel is a residual deposit formed by the *in situ* solution of Chalk. It contains closely-packed unabraded flints in a matrix of clay with little sand.

2) The Buller's Hill Gravel is a fluviatile sediment, characterised by abraded "chatter-marked" flints, closely-packed and frost-shattered, also pebbles of vein-quartz, tourmaline rock, quartzite, and thermally-altered Carboniferous shale and chert, in a matrix of sand and clay. This clay comprises equal quantities of ordered and disordered kaolinite with a little illite, while the sand reveals a granitic heavy mineral suite with a flood of tourmaline.

3) Clay bodies within the Buller's Hill Gravel are composed of disordered kaolinite with a large but variable admixture of illite and silt. They form tabular sheets up to 11 x 8 x 2m in size, and are distributed throughout the Gravel outcrop.

4) Head Gravel is predominantly a solifluction deposit, formed mostly from the Buller's Hill Gravel with a lesser contribution from the Tower Wood Gravel and the Upper Greensand. It contains limited bedded deposits of gravel and sand of fluvial origin.

Table of Contents

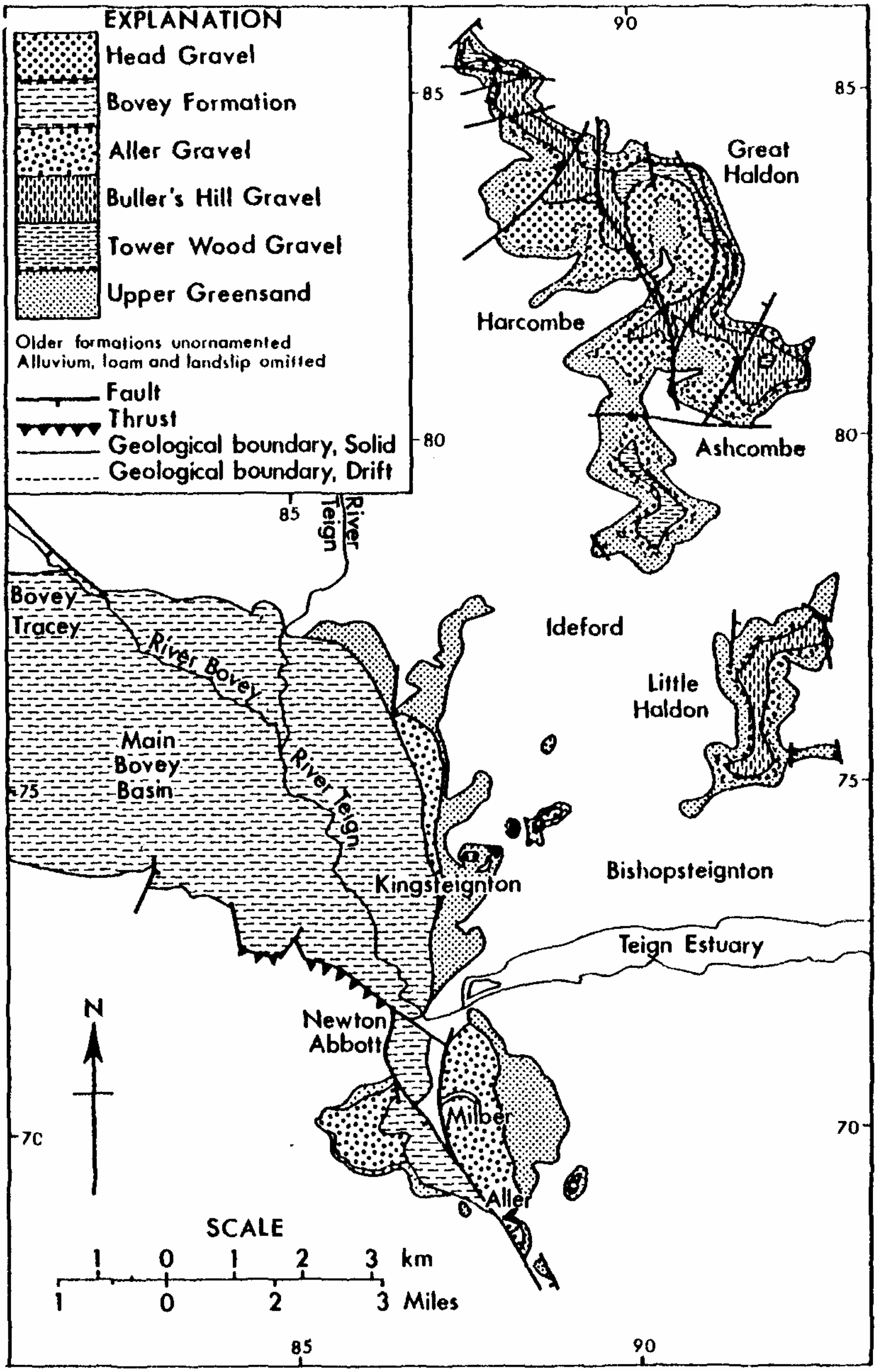


FIGURE 1. Simplified map of the Haldon and Aller Gravels, compiled from Hamblin (1973b), Edwards (1973) and Geological Survey Sheet 339 (in preparation).

Table of Contents

The Aller Gravels are braided fluviatile deposits and were described by Edwards (1973); they comprise gravels and sands with subordinate sills and silty clay. Abraded flints are the most important phenoclasts, hut blocks of Upper Greensand chert, vein quartz, tourmaline, quartz-tourmaline rock, Lower Carboniferous chert, Upper Carboniferous sandstone, dolerite, metadolerite and hornfels are present. Sedimentation units are generally lenticular, marked lateral and vertical changes in grain size are common, and large-scale cross-bedding occurs.

2. The Age of the Haldon Gravels

Detailed absolute dating of the deposits is not practical, but by correlation eastwards with the Dorset Tertiaries it is possible on sedimentological grounds, particularly heavy mineral evidence, to correlate the Buller's hill Gravel with all or part of the Reading and Bagshot Beds (Hamblin 1973b). The Tower Wood Gravel must be earlier than this for two reasons; its clay fraction, comprising well-ordercd kaolinite with a little disordered kaolinite and illite, must have been incorporated before the Buller's Hill Gravel was superimposed, and the absence of any Buller' s Hill Gravel material (abraded flints or exotic pebbles) in the Tower Wood Gravel indicates that solution of the Chalk was complete before these components were introduced to the area; had the Tower Wood Gravel been formed by solution of Chalk below a cover of Buller's Hill Gravel, this overlying material would have been let down and incorporated in the residual deposit. The clay bodies now lying within the Buller's Hill Gravel are believed to have had an origin independent from that of the Gravel, in view of their differing clay mineralogy, the absence of a granitic heavy mineral suite, and the lack of any original sedimentary structures connecting the two. As these bodies are distributed thoughout the length of the Gravel outcrop, because they are generally sheet-like in form, and because the present relationships between the bodies and the surrounding gravel are clearly periglacial, it is considered that the bodies derive from an originally overlying continuous sheet of clay, broken-up and incorporated in the gravel by processes of cryoturbation and solifluction. This sheet of clay would be of lacustrine or river flood-plain origin, and later in age than the Buller's Hill Gravel.

It is thus considered that the Tower Wood and Buller's Hill

Table of Contents

Gravels and the clay bodies represent three distinct Eocene deposits, and all would appear to have been formed before the start of the downwarping of the Bovey Basin, in a long period of tectonic calm. Throughout the 11 km length of the Haldon Hills, no case is recorded of the Buller's Hill Gravel cutting through the Tower Wood Gravel and into the Upper Greensand, and detailed mapping indicates that if this ever happens then the degree of downcutting can only be slight, hence no significant folding can have occurred before formation of the Buller's Hill Gravel. Similarly, the clay bodies occur within the latter gravel throughout the length of Haldon, indicating no significant folding after formation of the gravels and before the formation of the clay sheet. On the outcrop map (figure 1) Buller's Hill Gravel is cpmmonly shown against Greensand, but this does not imply the absence of intervening Tower Wood Gravel. As the latter is often thin and, where it is overlain by the Buller's Hill Gravel, outcrops on a steep slope, its width of outcrop is often negligible; also it is readily obscured by Head Gravel derived from the more easily soliflucted overlying Buller's Hill Gravel. The Head Gravel is, of course, Pleistocene in age and rests unconformably upon the Buller's Hill Gravel, the Tower Wood Gravel and the Upper Greensand.

3. The Age of the Aller Gravels

There are three distinct periods during which flint gravels might reasonably be expected to form in the area now comprising the Bovey Basin: during the Eocene but before the start of the folding and faulting which formed the basin, i.e. contemporaneously with the Haldon Gravels; during and immediately after the formation of the basin, i.e. later than the Haldon Gravels but earlier than the Bovey Formation; or post-Bovey Formation, most likely during the Pleistocene.

Edwards (1973) supports the concept of direct equivalence of the Aller Gravel and Buller's Hill Gravel, and gives three basic reasons, which are discussed below:

(a) Edwards claims that both Gravels rest on the Upper Greensand: but on the contrary, wherever its base has been seen on Haldon the Buller's Hill Gravel rests on the Tower

Table of Contents

Wood Gravel, demonstrating a negligible unconformity. The base of the latter gravel represents the base of the Chalk from which it is derived and rests with slight unconformity on up to 84m of Upper Greensand (Durrance and Hamblin 1969). The Aller Gravel, on the other hand, rests directly on the latter, and has cut down into it to a marked degree; for example, north-east of Kingsteignton, the Greensand is shown to be very thin or even absent beneath gravels referred by Edwards (1973) to the Aller Gravel.

(b) He refers to marked lithological similarities between the Aller and Buller's Hill Gravels. But these are no greater than would be expected between fluvial flint gravels formed in this area at any time in the Eocene, and the marked dissimilarities are of greater significance. Firstly, the Aller Gravel contains much more sand, silt and clay, including distinct beds of these materials, which in the Buller's Hill Gravel occur only as the matrix of closely-packed gravel. Secondly, the Aller Gravel contains a greater variety of exotic pebbles, in particular large qnantities of Greensand chert, present as large blocks. The Buller's Hill Gravel does not appear to contain any such chert; earlier workers who found chert in the Head Gravel on Haldon did not realise that it was not an original Eocene constituent. Thirdly, the Aller Gravel contains large-scale original sedimentary structures, including cross-bedding, piles of channel forms with erosive junctions, and distinct lenticles of sand, silt and clay, while the Buller's Hill Gravel is a notably structureless mass of flint gravel, disturbed only by periglacial structures.

(c) He considers that the position of the Aller Gravel on a westward-dipping surface connecting with Haldon indicates a direct correlation. This argument would not appear to be valid in view of the gentle dips involved and the 2.5km gap between the Buller's Hill and Aller Gravels - the latter would occupy roughly the same position whether formed contemporaneously with the former or at a slightly later date.

Considering that the Buller's Hill Gravel varies not at all along its 11 km outcrop, and that the Aller Gravel varies only slightly along a similar length only 3km farther to the west, the differences which

Table of Contents

exist between them render a direct correlation unlikely; this does not mean that Buller's Hill Gravel was never formed in the area now occupied by the Aller Gravel, but if it was then it has either been destroyed or buried beneath the later strata. There is, however, evidence for the formation of Aller Gravel before the Bovey Formation; it is mapped by Edwards as dipping beneath the Bovey Beds, a borehole at Higher Sandygate entered gravels of Aller type below beds typical of the Bovey Formation (Edwards 1971), and the gravels lie on a dipping surface which slopes up towards Haldon. On the other hand, the increase in sand content of the Aller Gravel compared with the Buller's Hill Gravel, the incoming of Greensand chert, the sedimentary structures within the Aller Gravel and its degree of downcutting into the Greensand, all indicate a more vigorous fluvial regime than that which formed the Buller's Hill Gravel. It is thus suggested that the Aller Gravel was formed during the earliest stages of downfolding of the Bovey Basin, after the formation of the Haldon Gravels on an easterly-dipping plain, but still early enough for the Aller Gravel itself to be downfolded into the Bovey Basin. Further, if it is accepted that the Haldon clay bodies represent a sedimentary unit which once overlay the Buller's Hill Gravel, then the Aller Gravel must be later than that, and there can be no overlap in the formation of the two gravel units.

There remains the possibility of a Pleistocene age for at least a part of the Aller Gravel. The Head Gravel is volumetrically the most important constituent of the Haldon Gravels, but no deposit of equivalent significance has been distinguished in the Bovey Basin, and the possibility must be considered that the Aller Gravel includes laterally equivalent Pleistocene fluvial deposits. While the borehole at Higher Sandygate and the overall distribution of the Gravel within the structural scenario of the Bovey Basin strongly indicate that the larger part of the unit is pre-Bovey Formation, there are certain features within its fabric which could indicate Pleistocene rather than Eocene deposition. Beds of comtninuted angular flint chips were seen by this author at Sands Copse, possibly reworked from a frost-shattered source, and rounded bodies of clay and sand seen in coarse gravel at Royal Aller Vale Quarry are most easily explained as clasts introduced in a frozen state. Although the Head Gravel on Haldon is largely soliflual it does include fluvial deposits, and it contains Greensand chert and sand as well as Haldon Gravels debris, hence it resembles the Aller Gravel much more closely than does the Buller's Hill Gravel. A quarry at Harcombe Plantation (SX

Table of Contents

9040 9200) revealed fluvial gravel and a sand lens within the Head Gravel, which Edwards (personal communication) considered to closely resemble the Aller Gravel. Unfortunately, it is not possible to take this argument any further on present evidence, but. in any case it still appears probable that most, if not all, of the Aller Gravel is Tertiary in age, later than the Haldon Gravels but earlier than the Bovey Formation.

DURRANCE, E. M. and HAMBLIN, R. J. O. 1969. The Cretaceous Structure of Great Haldon, Devon. *Bull. Geol. Surv. Gr. Bt.* No. **30**, 71-88.

EDWARDS, R. A. 1971. *Ann. Rep. Inst. geol. Sci. for* 1969. p.107.

_____ 1973. The Aller Gravels: Lower Tertiary braided river deposits in South Devon. *Proc. Ussher Soc.*, **2**, 608-616.

HAMBLIN, R. J. O. 1973a. The Clay Mineralogy of the Haldon Gravels. *Clay Minerals* **10**, 87-97.

_____ 1973b. The Haldon Gravels of South Devon. *Proc. Geol. Assoc.* **84,** 459-476.

This paper is published by permission of the Director, Institute of Geological Sciences.

Institute of Geological Sciences
5, Princes Gate,
London SW7

Table of Contents

GRADIENTS OF BURIED CIIANNELS IN DEVON

by E. M. Durrance

Abstract. Borehole records and a seismic refraction survey along the proposed line of the M5 motorway crossing of the R. Exe show that rockhead in the main buried channel occurs at an average level of -10.2m, with two minor channels extending to depths of -13.5m and -14m. These channels are considered to be of late Weichselian age and are correlated with the younger channels of the lower Exe estuary, which 10km downstream at Dawlish Warren extend to a depth of -32.2m. An average gradient for the channels of 1 in 540 is thus indicated. This compares with average gradients of 1 in 600, 1 in 470, 1 in 350 and 1 in 140 for the buried channels of the Taw-Torridge, Teign, Dart and Erme estuaries respectively.

1. Introduction

The site investigation for the proposed M5 motorway crossing of the R. Exe has produced a wealth of information about the form of the transverse profile of the buried channels of the R. Exe between Topsham and Exminster. Combined with previous data (Durrance, 1969), this information allows the average gradient of the buried channels of the Exe estuary to be determined. Comparisons may then be made with the buried channels of the Teign estuary (Durrance, 1971), the Erme and Taw-Torridge estuaries (MacFarlane, 1955) and the R. Dart (Codrington, 1898).

To maintain continuity with data previously published for the Exe and Teign estuaries, all levels have been reduced to a datum provided by high water of medium spring tides at Exmouth Dock (2.4m above Newlyn Ordnance Datum).

2. Site investigation

The South-Western Road Construction Unit of the Department of the Environment commissioned the site investigation of the R. Exe motorway crossing in five stages between 1968 and 1973. Stage 1 was a seismic refraction survey of parts of the route carried out by Hunting Surveys Ltd. (report issued in 1968). The positions of these seismic lines are shown in Fig. 1 and their results given in Fig. 2. Three velocity classes were recorded. The stratigraphically highest class (1) possesses transmission velocities between 380ms^{-1} and 610ms^{-1} and everywhere overlies a class (2) with transmission

Table of Contents

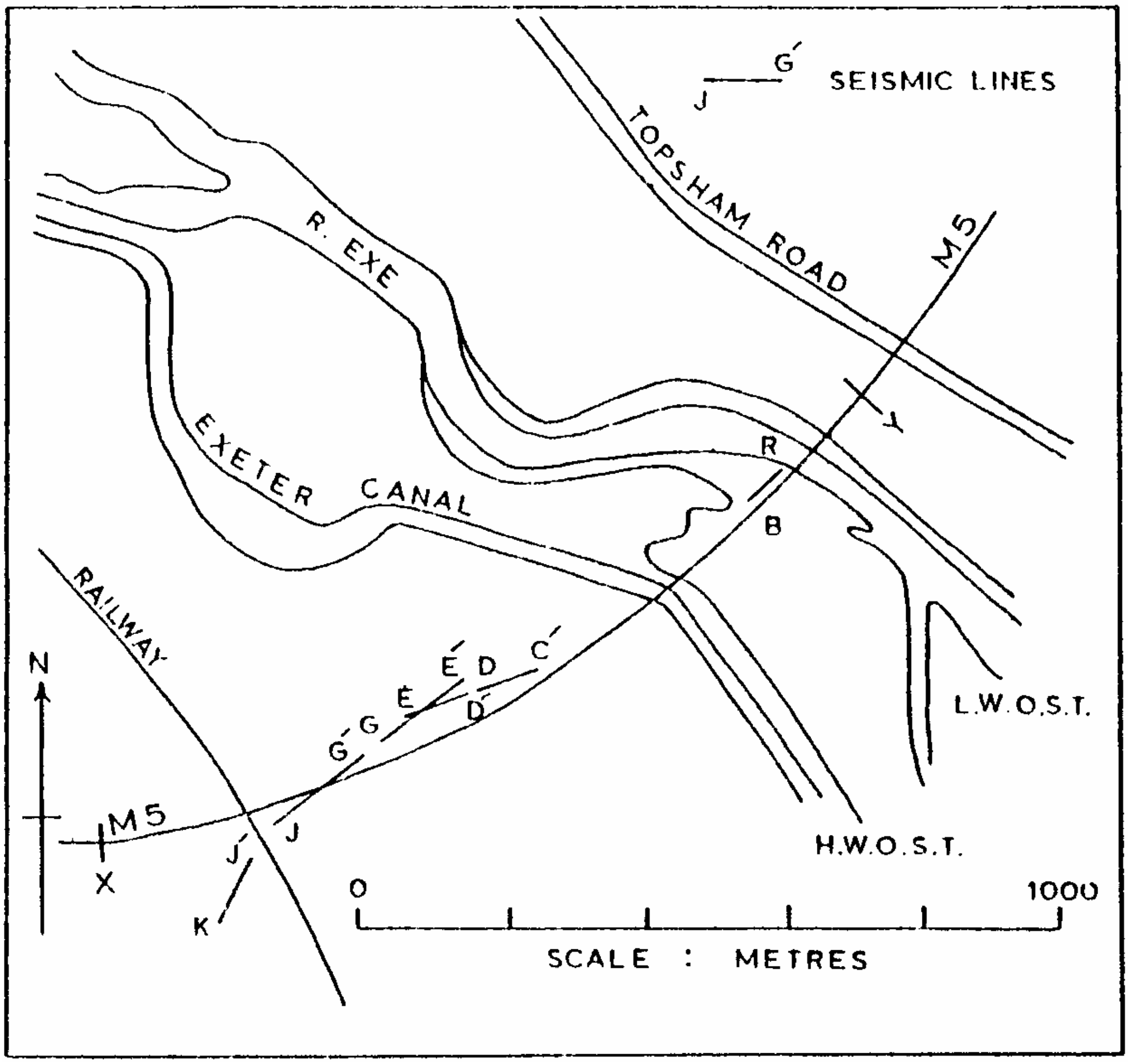


FIGURE 1. The Upper Exe estuary and position of the seismic lines

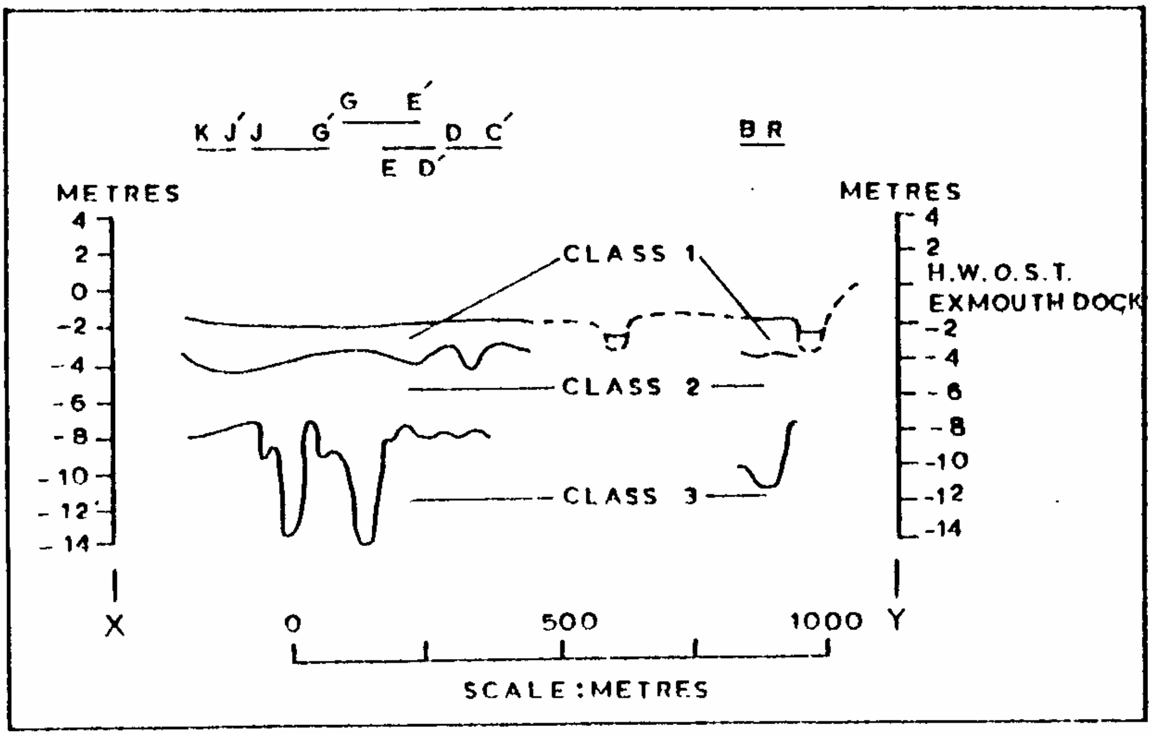


FIGURE 2.The results of the seismic survey

Table of Contents

velocities between 1500ms^{-1} and 1860ms^{-1}. This, in turn, everywhere overlies a class (3) with transmission velocities between 2320ms^{-1} and 3260ms^{-1}. Classes 1 and 2 are considered to represent Quaternary sediments while class 3 is correlated with the New Red Sandstone. The boundary between classes 1 and 2 occurs at an average depth of about -4.5m, while that between classes 2 and 3 has an average depth of about -9.5m, but with two narrow channels extending below this level to depths of about -13.5m and -14m.

The second stage of the investigation involved the sinking of a preliminary series of boreholes by Cementation Ltd. (report issued in 1969); their positions are shown as PI - P6 in Fig. 3. Three other phases-of borehole investigation followed: series F46 - F114A (Fig. 3) were sunk by Soil Mechanics Ltd. (report issued in 1971), series 4003 - 5001 (Fig. 3) were sunk by Low and Parsons Brown Ltd. (report issued in 1972) and series 703 - 710 and R13 - R17 (Fig. 3)

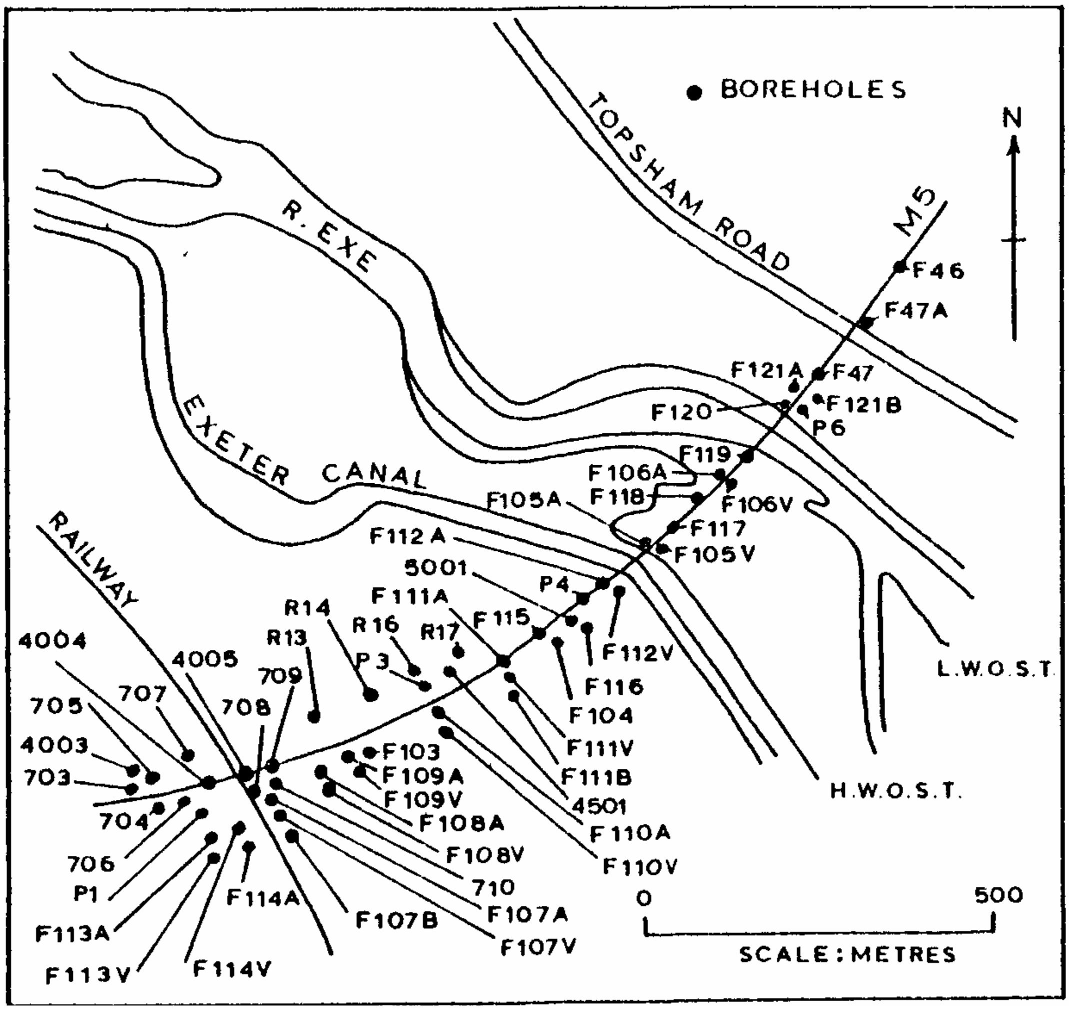


FIGURE 3. Borehole positions along the line of the M5 motorway

Table of Contents

were sunk by Structural Soils Ltd. (report issued in 1973). The borehole records generally confirm the results of the earlier geophysical snrvcy, and indicate an undulating surface of New Red Sandstone (breccia or sandstone) at an average depth of about -10.2m overlain by gravel to a depth of about -4.5m. This gravel, in turn, is overlain by silty clay with a capping of topsoil. A geological section between points X and Y, along the centre of the motorway alignment shown in Fig. 1 and based upon this information, is given in Fig. 4.

3. Correlations

(a) Seismic Velocities

Durrance (1969) records six velocity classes from the Exe estuary near Exmonth and Dawlish Warren. These are designated as follows: Class A, 200 – 300ms^{-1} dry sand; Class A', 600 - 900 ms^{-1} loose gravel; Class B, 1000 - 1400 ms^{-1} wet sand; Class B', 1500 - 1700 ms^{-1} clay; Class C, 2000- 2300 ms^{-1} compact gravel; and Class D, 3000 - 360 ms^{-1} New Red Sandstone (Exe breccia). Classes A, A', B and B' probably represent sediments of Flandrian age. Class C probably represents middle Weichselian sediments.

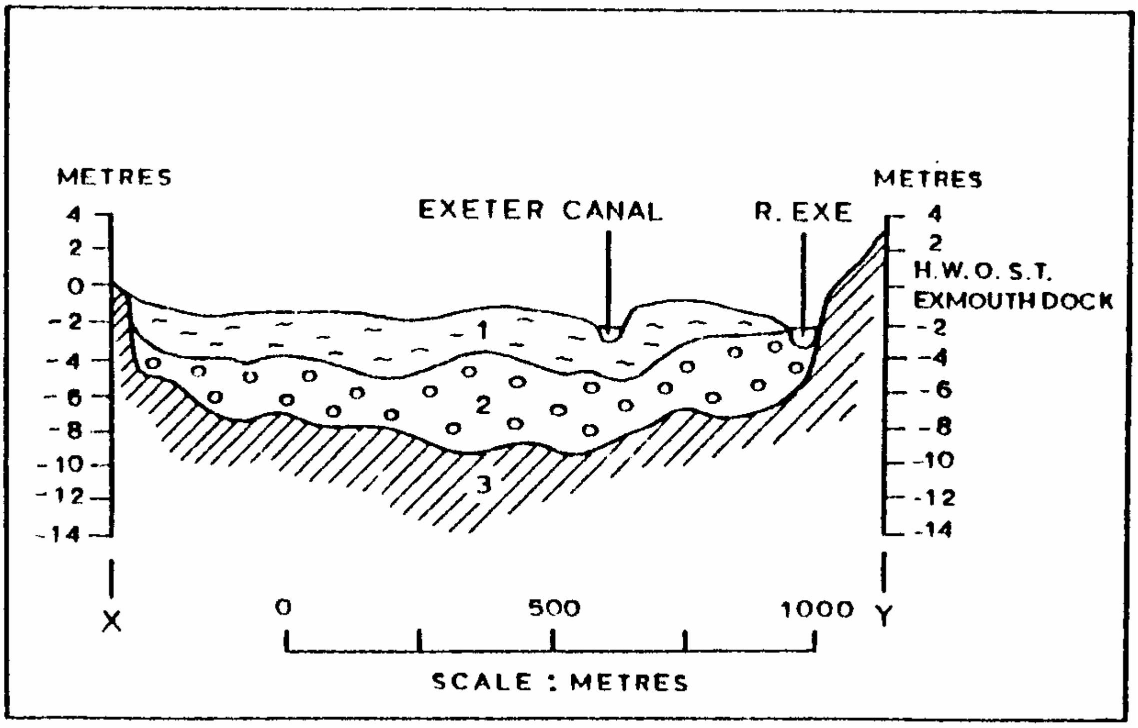


FIGURE 4. Diagrammatic section of the buried channel of the R. Exe along the line of the M5 motorway based upon borehole information. 1. Silty clay overlain by topsoil. 2. Gravel, 3. New Red Sandstone (breccia and sandstone).

Table of Contents

In the Teign estuary Durrance (1971) recognises members that can be correlated with Class A, dry sand with transmission velocities in range 366 - 396ms^{-1}: Class B, wet sand with transmission velocities between 1067ms^{-1} and 1433ms^{-1}; Class B' with transmission velocities in the range 1524 - 1676ms^{-1}, here recognised as semi-compact gravel; and Class D, New Red Sandstone (Oddicombe and Teignmouth breccias) with transmission velocities between 2256ms^{-1} and 2743ms^{-1}. Also recorded are transmission velocities in the range 3200 - 3505ms^{-1}, i.e. similar to the Class D velocities of the Exmouth-Dawlish Warren area. These are designated Class E and interpreted as Devonian slate (Henson, 1972), but they could represent a higher velocity unit within the New Red Sandstone underlying the Oddicombe and Teignmouth breccias.

The transmission velocities recorded from the Exe valley between Topsham and Exminster may be similarly classified, and lithologies assigned from the results of the burehole program. Transmission velocities of Class 1 correspond to Classes A and A', but are here represented by silty clay and topsoil; Class 2 corresponds to Class B', here, as in the Teign estuary, represented by semi-compact gravel; and Class 3 corresponds to Class D, New Red Sandstone.

MacFarlane (1955) records transmission velocities from the Erme estuary between 1200ms^{-1} and 1550ms^{-1} for Quaternary sediments probably corresponding to Classes B and B' in S. E. Devon, and between 2550ms^{-1} and 4700ms^{-1} for Devonian tuffs, slates and sandstones. Similar transmission velocities are also found in the Taw-Torridge estuary, with an additional transmission velocity of about 1830ms^{-1} from the R. Torridge near Instow, which may represent a Class C lithology.

A seismic refraction survey at Tomes by Durrance for the Dart Commissioners (report issued 1971) shows transmission velocities between 1000ms^{-1} and 1200ms^{-1} for Quaternary sediments, corresponding to Class B, and between 2540ms^{-1} and 3050ms^{-1} for Devonian tuffs and slates.

(b) Channel fill succession

The sequence: A Palaeozoic surface overlain by Quarternary

Table of Contents

gravel in turn overlain by Quaternary silty clay, described from the Topsham area of the buried channels of the R. Exe, is identical with that round at Hackney in the tipper reaches of the Teign estuary. At Hackney the Palaeozoic surface (Devonian slate and dolerite) below the R. Teign is at a depth of -10.2m and that of the overlying gravel at about -7.4m. These levels are similar to those of the same boundaries in the Topsham area.

(c) Terrace levels

Terrace levels within the buried channel of the Teign estuary occur at a depth of -10.2m at Flaekney, and at depths of -10.1m, -14.3m and -22.9m at Teignmouth. Within the younger channels of the R. Exe near Exmouth and Dawlish Warren terraces occur at depths of -5.8m, -10.4m, -13.7m and -22.0m, while the results of the motorway site investigation between Topsham and Exminster show their presence at depths of about -10.2m and -13.8m.

The presence of a terrace at a depth of about -10.2m throughout the Teign and Exe estuaries is therefore indicated by this evidence. Similarly, a terrace at a level of about -14m also appears to be well developed throughout the Exe estuary and at least in the lower reaches of the Teign estuary. Levels deeper than this are not recorded at Topsham or Hackney but a connexion of the -22.0m terrace of the Exmouth-Dawlish Warren area with the -22.9m terrace at Teignmouth appears to follow from these higher level correlations.

On the basis of these similar terrace levels it thus appears reasonable to correlate the younger buried channels of the lower Exe estuary with the single episode of buried channel formation seen at Topsham. This correlation, in turn, supports the suggestion made by Durrance (1971) that the buried channel of the Teign estuary is of the same age as the younger buried channels of the R. Exe.

4. Gradients of buried channels

The gradients of the buried channels in the Exe and Teign estuaries can be determined from the levels given above. For the Teign estuary the deepest levels are -10.2m at Hackney and -22.9m at Teignmouth. These two areas are separated by a distance of about 6km, indicating an average gradient of about 1 in

Table of Contents

470. For the Exe estuary, an average depth of -13.8m for the deepest part of the buried channel is present at Topsham, but at Dawlish Warren the younger channels are at a depth of -32.2m. A decrease in level of 18.4m over a distance of about 10km, or a gradient of about 1 in 540, is thus indicated. The gradient of 1 in 150 recorded from the limited area of these channels under Dawlish Warren itself (Durrance, 1969) must therefore only represent a short length of steep gradient and not the general gradient of the buried channels as previously suggested.

It is interesting to compare these results with data given by MacFarlane (1955) for the estuary of the R. Taw in N. Devon. Here the deepest part of the buried channel is recorded in the area of South Gut, where rockhead occurs at a level of -26.5m, but is inclined to the south at a slope of about 1 in 26. Some 600m south of this point rockhead is at a level of about -17.5m showing that the slope is not maintained. By continuing the slope of 1 in 26 south from the -26.5m level, however, and assuming the presence of a similar slope to the north from the -17.5m level, it appears that the deepest part of the buried channel lies about 200m south of the -26.5m level at a depth of -34.5m (this compares with an estimate of -33m made by MacFarlane). Some 8km upstream near Penhill Point, rockhead occurs at a deepest level of -21.3m. An average gradient of about 1 in 600 is therefore present. As in the case of the buried channel of the Exe estuary, gradients of the order of 1 in 250 found in the area of the mouth of the Taw-Torridge estuary probably only represent a short section of steeper than average gradient. An average gradient of about 1 in 140 over a distance of 3.2km is, however, recorded by MacFarlane (1955) for the buried channel of the Ernie estuary; the buried channel reaches its greatest depth of -29.2m near Owens Point.

In the buried channel of the R. Dart, Codrington (1898) reports rockhead at a level of about -38.3m at Maypool. Upstream, at Tomes, rockhead occurs at -9.5m, a level which is possibly part of the -10m terrace so extensively developed in the buried channels of the Teign and Exe estuaries. A distance of about 10km separates Maypool from Totnes and indicates an average gradient of about 1 in 350. If this average gradient is maintained downstream from Maypool, rockhead in the buried channel at the present mouth of the river is at a level of about -52m. On the basis of this argument it is probable that the R. Dart, like the R. Exe, possesses an older

Table of Contents

(deeper) buried channel in its lower reaches in addition to the more extensively developed younger channel.

5. **Conclusions**

From the foregoing discussion the following conclusions can be drawn.

(a) The buried channel fill in the upper reaches of the Exe estuary near Topsham is probably of Flandrian age, and may be directly correlated with the buried channel fill of the upper Teign estuary at Hackney.

(b) The younger buried channels of the Exe estuary and the buried channel of the Teign estuary are both probably of late Weichselian age.

(c) As gradients, depths and seismic transmission velocities are comparable with those recorded from the buried channel of the Teign estuary and the younger buried channels of the Exe estuary, the buried channels of the Erme, and upper Taw--Torridge estuaries are also probably of late Weichselian age.

(d) Terrace levels within the late Weichselian buried channels of E. Devon are well developed. The -10m, -14m and -22.5m levels are recognised in the buried channels of both the Teign and Exe estuaries. The recording of a -9.5m level within the buried channel of the R. Dart at Totnes suggests that the buried channel here is also probably of late Weichselian age.

(e) The presence of only one phase of buried channel formation at Topsham indicates that the deeper, probably early Weichselian, phase recorded from the lower Exe estuary cannot extend far upstream. This conclusion supports the suggestion made by Clarke (1970) and Durrance (1971) that during the late Pleistocene sea-level lows the R. Teign was merely a tributary of the R. Exe. As noted by Durrance (1971), the lesser influence of the tributary R. Teign compared with the mainstream R. Exe in the erosional processes at work during these sea-level regressions probably resulted in the restriction of the older channels to the seaward of the present

Table of Contents

mouth of the R. Teign. Their development in only the lower reaches of the Exe estuary is therefore not unexpected. The evidence now available thus argues against the possibility that the older channels were present in the lower reaches of the Teign estuary only to have been completely removed by erosion during the younger period of channelling.

(f) The great depth of the buried channel of the R. Dart at Maypool and its projected depth of -52m at the mouth of the river, compares very well with the same depth (-52m) recorded from the older channels of the Exe estuary under Dawlish Warren. On this basis, the older phase of channel formation recognised in the lower Exe estuary is also probably present in the lower Dart estuary. Similarly, the presence of a lithology possessing seismic transmission velocities of Class C (probably middle Weichselian gravels) within the lower reaches of the Taw-Torridge estuary suggests that here too the remains of the earlier phase of channel fill may exist.

ACKNOWLEDGEMENTS. I would like to thank Mr. J. R, Jefferson, Deputy Director, South-Western Road Construction Unit of the Department of the Environment, for permission to publish the results of the seismic survey and the borehole records for the M5 motorway crossing of the R. Exe. I should also like to thank Mr. D. N. Holt of Freeman Fox and Partners for his help in gathering the information contained in the individual reports to the South Western Road Construction Unit.

CLARKE, R. N. 1970. Quaternary sediments off south-east Devon. *Q. Jl. geol. soc. Lond..* 125,277-318.

CODRINGTON, T. 1898. On some submerged rock valleys in south Wales, Devon and Cornwall. *Q. Jl. geol. Soc. Lond.,* **54.** 251-725.

DURRANCE, E. M. 1969. The buried channels of the Exe. *Geol. Mag.,* **106**,174-89.

_____1971. The buried channel of the Teign estuary. *Proc. Ussher Soc.,* **2,** 299-306.

HENSON, M. R. 1972. The form of the Permo-Triassic basin in soulh-east Devon. *Proc. Ussher Soc.,* **2**, 447-57.

MacFARLANE, P. B. 1955. Survey of two drowned river valleys in Devon. Geol. Mag., 92, 419-29.

Department of Geology
University of Exeter
Exeter EX4 4QE
Devon

SOME ASPECTS OF QUATERNARY FLUVIAL ACTIVITY IN SOUTH-WEST CORNWALL, ENGLAND

by Alan C. Wilson

Abstract. Recent fluvial deposits are described and interpreted as accreting in a wetter climate than the present one. A history of alluvial terrace construction succeeded by stream incision is noted. The anomalous topographic Forms of the drainage basins within the area are described.

1. General

The author is carrying out a resurvey of part of the Penzance (351/8) area on behalf of the Institute of Geological Sciences. The particular area discussed below is situated east of the Land's End Granite and lies between St. Ives' Bay and Mount's Bay. The highest summits of the granite mass attain heights of about 266m O.D., but the area is deeply dissected by N.W.-S.E. trending, joint - and fault-controlled streams. The watershed lies near the north coast of the Land's End peninsula and consequently the north-westerly flowing streams are short and commonly have steep gradients whereas the south-easterly draining streams are longer and have moderate to low gradients. To the east, in the slates and greenstones, the terrain rarely rises above 76m O.D., and the streams which cross this tract are winding and have moderate to low gradients.

2. **Present and recent stream regimes**

All the streams in the area are shallow (about one metre maximum in their lowest reaches) and only a metre or so broad, but they flow in relatively wide and deep valleys. Within the area studied the streams are paralleled by an over-bank tract which is usually about one metre above the present stream surface. The overbank tract is absent or poorly defined in short steep reaches where there are major bed-rock changes, e.g. the granite - slate contact [SW 526 365]. The occurrence of one continuous overbank tract throughout a given length of stream implies that alluviation and overbank accretion were effected by a stream having a gradient parallel to that tract. However, it seems likely that under the present climatic regime the streams have a lower maximum discharge than at some previous times and are now probably incapable of regularly

Table of Contents

flooding their overbank tracts. A recent analysis of wood collected from deposits near Trannack Farm at [SW 5647 3297] gave a radiocarbon date of 1810±45 B.P., that is A.D. 140. Thus it is believed that in the recent past, during historical times, the overbank tracts went through a transition phase during which they were progressively less liable to flooding and can now be considered as recently abandoned terraces. Sections through these terraces show considerable vertical variation in sediment type, ranging from tine clay and peat to poorly-sorted coarse gravel. The proportion of fine-grained sediment preserved in the sections, the degree of size segregation effected and the apparent lack of rapid lateral grain-size and textural changes (at the bed level) suggest deposition from a non-braided stream system. Some exceptions to this generalisation are known however, e.g. at [SW 522 329]. The rapid vertical changes in sediment calibre and sorting indicate a hydraulically diverse fluvial system, with strictly delineated environments and modes of accretion. These characters imply deposition from a single, moderately sinuous channel, with well-developed slough and overbank areas (for the accretion of peat and clay).

3. Former stream systems

Older, abandoned terraces occur around the headwaters of the low - to moderate - gradient streams and are common up to four metres above present stream level; above this level the origins of the sub-horizontal hillside features are not clear. Peat collected from one of these higher terraces at [SW 5161 3737] near Trink Cottage gave a radiocarbon date of 10,202±50 B.P., that is 8252 B.C. Thus, these particular deposits are late Devensian in age. All these older terraces (including particularly those recorded in the area to the west by Mr. A. J. J. Goode of I.G.S.), were probably related to a more distant shoreline or a higher sea-level; in the latter case the drowned drainage basins would have created a ria coastline. The distance between the back-terrace features is often considerable, and some of the higher and presumably older terraces were probably associated with larger rivers having greater discharges and perhaps not closely related to the present topography. Some of the very broad, open basins now found at the stream headwaters (see below) are almost entirely surrounded by gently rising ground except at the drainage outlet where there can be bluffs [SW 501 393, SW 530 3261. It is evident from the marginal terraces within these depressions that the

Table of Contents

streams must have ponded within these areas (e.g. Bussow [SW 501 3841]) and formed extensive exteriorly-drained lakes. (Goss Moor [SW 950 600], ten kilometres north-west of St. Austell is probably a large example of one of tltese basins.)

There are few good section-, within these terraces but those present show similar grain-sizes and peat accumulations to the younger lerraces. In the mainly slate country, the broad headwater basins (see below) and their associated marginal terraces are underlain by a thick layer of pale grey silty clay which can contain cobbles of some of the harder country rocks, e.g. elvan and greenstone. This deposit has not been observed in a clean section but it lacks good stratification and its origin is not understood, as yet.

4. Topographic forms of the basins

The shorter, north-westerly flowing streams have upper and lower reaches flowing in moderately steep valleys, between which there is a middle reach developed on the low-dipping platform commonly between 122 and 91 m above O.D. Many of the longer, moderate - to low - gradient streams flow through drainage basins whose topographic forms exhibit consistent features along their lengths. The upper reaches lie in a broad, open, concave - upward, spoon-shaped basin, commonly with a low gradient; this passes downstream into a reach of moderate gradient with steeper, convex valley sides; but the lower reaches flow in a broad valley with a low gradient and a concave - upward cross-valley profile. The headwater basins of these streams may be the remnants of previously more extensive, low-dipping surfaces. The downstream changes in gradient and cross-valley profile indicate that the stream systems of the district have not evolved in a simple manner. At present it is not proposed to deal with the history of this development, but preliminary studies suggest that the two forms of drainage basin represent stages in a grading process, being effected on a preexisting topography dominated by a few low-dipping surfaces.

This account is published by permission of the Director. Institute of Geological Sciences.

Institute of Geological Sciences
Hoopern House
Pennsylvania Road
Exeter

Table of Contents

DISCORDANT CALC-SILICATE BODIES IN THE BOTALLACK AREA

by N. J. Jackson and D. H. M. Alderlon

Abstract. Severe internal metasomatism has affected the volcanic (greenstone) sequence within the aureule of the Laud's End granite. In the Bolallack area the redistribution and fixalion of calcium within the metabasite sequence has produced a rock type with a skarn mineral assemblage· Morphologically these rocks form conformable horizons and discordant subvertical fissure veins.

1. Introduction

The St. Just metamorphic aureole forms a narrow coastal strip, about 6 km long and 0.5 km wide, on the northern flanks of the Land's End granite. The aureole sequence, of uncertain age, consists of two groups of rocks: a sedimentary unit of fine grained metapelites and an interbedded sequence of basic volcanics. Deformation during the Hercynian orogeny has produced folds trending NNE.

During contact metamorphism there occurred a large-scale redistribution of several major components within the metabasite horizons. The result of this redistribution and later fixation of the mobilized components, was the production of a series of metasomatic hornfelses. In the south (Kenidjack area) the metabasites are depleted in Si, Ca, Na and K, and relatively enriched in Mg, Al and Fe. North of this area, near Botallack, the local fixation of Ca and Fe has produced horizons containing skarn mineral assemblages. Farther north still (Levant) the metabasites are enriched in Si and alkalis.

Mapping of the aureole rocks has revealed several veins of calcsilicate material. These were studied to see if they could be related to the mineralization of the area, and to observe the metasorualic process by which the metabasites may have been converted to rocks containing calc-silicate assemblages. The bodies occur at Carn Vellan (SW364341), Stamps and Jowl Zawn (SW364340), Wlieal Cock Zawn (SW363340), and Crowns rock (SW362336). Smaller veins and lenses of a similar composition, including a pod of pure calcite, occur throughout the area; it is presumed that these have an origin similar to the main bodies.

Table of Contents

2. **Mineralogy**

The host rocks are hornblende hornfelses in the northern part, and conformable calciferous hornfelses at Crowns rock.

The mineralogy of the bodies is as follows:

Carn Vellan: garnet 60%, diopside 20%, epidote 10%, axinite 10%.

Stamps and Jowl: garnet 80%, calcite 10%, sulphides 5%, epidote 5%.

Wheal Cock: garnet 30%, axinite *45%,* hornblende *15%,* apatite 3%, (epidote, calcite, sphene, diopside, sulphides, tourmaline, chlorite, idocrase = 7%).

Crowns garnet 80%, tourmaline 10%, (axinite, epidote, hornblende, diopside, calcite = 10%).

In hand specimen the garnets occur as deep red-brown crystals, up to 2 cm in diameter and zoning is visible. In thin section the garnets are anisotropic; zoning and sector twinning are very common. In the Wheal Cock body all the minerals are coarsely crystalline, the apatite being especially distinctive (up to 5 cm in length). It is notable that many of the minerals are zoned in thin section. Electron microprobe traverses across zoned garnets and axinites have so far failed to locate any marked variation in major elements.

Thin section studies have been used to establish an "order of formation" from the numerous replacement textures present.

3. Geochemistry

Nine of the minerals were analysed for major and trace elements to see if their chemistry could help to elucidate the mode of formation. The minerals were four garnets, two amphiboles, one axinite, one apatite and one epidote.

In regard to the major elements, the notable feature is the close similarity in composition between the garnets. They all have more than 91% of the grossular-andradite molecule, falling in the range

Table of Contents

$Gr_{76}An_{24}$ (Crowns) to $Gr_{70}An_{30}$ (Stamps and Jowl). Water is low (less than 0.25%), ruling out the possibility of any appreciable amount of the hydrogrossular molecule.

Tin is highly concentrated in all nine minerals. The Crowns garnet has a concentration of 2300 ppm, while the garnets from the other bodies, and the apatite, have a concentration of 200-350 ppm. Epidote, amphiboles and axinite contain 750-950 ppm tin; the significance of this is discussed below.

Copper concentrations are relatively low, at 91 ppm in the apatite and less than 50 ppm in the remainder. It seems that there is no positive correlation between tin and copper.

Beryllium amounts to less than 10 ppm in all the minerals except the axinite from Wheal Cock, which has 43 ppm. "Average" rock samples from the Wheal Cock body have 30-70 ppm beryllium, suggesting that axinite was introduced with beryllium-rich solutions. It is possible that other beryllium-rich phases are present. This situation seems to be similar to that of the axinite-rich veins at Meldon (Mackenzie 1972). It is pertinent to note that Kingsbury (1961) found helvine on the dumps near Wheal Cock Zawn; in places it was partly altered to herderite (a Ca-Be phosphate) and this would correlate well with the observation that apatite replaces axinite in the Wheal Cock body. Kingsbury reported the presence of manganese and zinc in the helvine; the Wheal Cock axinite has 4.20% MnO, and 220 ppm zinc (concentrations of zinc up to 700 ppm are present in the Wheal Cock rocks).

4. Formation of the calc-silicate bodies

Major component profiles across the calc-silicate bodies indicate that the main component introduced was calcium. All other major components are depleted (or remain constant) within the bodies relative to the host rocks. As the adjacent rocks are not depleted in calcium compared with the same rocks several metres away it is probable that this element was derived from lower tectonic horizons.

Most of the original calcium must have been located in either the anorthite component of the plagioclase feldspar or a calcic

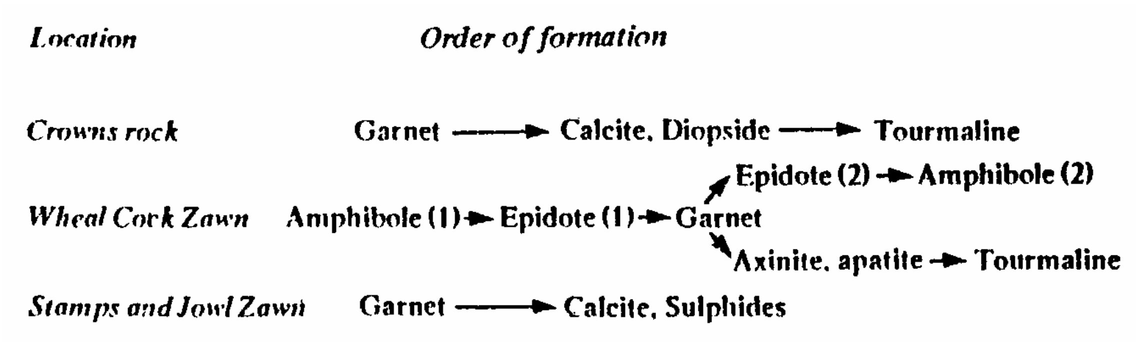
Table of Contents

hyroxene. Degradation of these two phases during low-grade regional metamorphism would liberate considerable amounts of calcium as would several prograde reactions during contact metamorphism. The most likely conversions are in the nature of:

Hornblende = Cummingtonite/anthophyllilc + Ca
Hornhlende + K = Biotite + Ca
Plagioclase + (Fe + Mg) = Cordierite + Ca

As the calc-silicate bodies cut the mekasomatic hornfelses, and later are seen to replace earlier hornblende-hornfels facies assemblages, it seems probable that much of the calcium could have been derived from remobilized calciferous hornfels material. The higher than average tin and boron contents of many of the calc-silicate phases indicate that the probable transporting mechanism for the calcium was of a hydrothermal nature, at least part of which emanated from a granitic source.

Macroscopic and microscopic mineralogical studies reveal that the bodies must have formed by a complicated metasomatic process. Most of the phases show good crystal form and exhibit strong zoning, suggesting that crystal nucleation and growth were extremely rapid. The zoning also indicates that the composition of the fluids was changing continuously whilst the bodies were forming. The main phases of each of the main bodies are shown below in their probable order of formation.



The two garnetiferous bodies at Crowns Rock and Stamps and Jowl Zawn show garnet as the only major phase. No earlier phases were detected, although there are several periods of garnet growth. However, both bodies show retrogressive reactions as the calcium content of the environment decreases. The Wheal Cock body

Table of Contents

displays a well-defined, though complicated, sequence of mineralogical events. Unmetasomalised blocks of hornblende hornfels within the main body suggest that the host is first converted to a coarse amphibole-rich rock. The leaching of alkalis and silica, and the introduction of calcium, cause this assemblage to be replaced by one containing epidote as the dominant phase. Continued leaching of Si, Na, K, Mg and Fe, and the introduction of Ca, produce the calc-silicate assemblage containing grossular-andradite garnet. Boron was also introduced at this stage, and axinite was produced at the expense of all the earlier phases. As the fluids became depleted in calcium, retrogressive clinozoisite, diopside and amphibole formed. In common with the other bodies the final phase to form was tourmaline.

Floyd (1971) suggested that the contact hornfelses at Botallack were formed at temperatures of about 570°C at a total pressure of 1kb. However, experiments on the stability fields of hydrogrossular/grossular-andradite (Cotton 1973) suggest that at the temperatures and pressure envisaged by Floyd only hydrogrossular could be produced. If, however, the pressure is increased to 1.5 kb, grossular-andradite may be produced.

5. Conclusions

Leaching (and later re-deposition) of calcium from the metabasite horizons has produced several calc-silicate bodies. This occurred after the main phase of contact metasomatism but before the hydrothermal lode mineralisation.

The material was transported by hydrothermal fluids at about 570°C and 1.5 kb.

ACKNOWLEDGEMENTS are due to Professor R. A. Howie for critically reading the manuscript, and to the N.E.R.C. for the aid of a research grant.

COTTON, M. T. 1973. The geochemistry of wall-rock alteration in West Cornwall, with particular reference to Mount Wellington Mine. *Ph.D. Thesis, University of London.*

FLOYD, P. A. 1971. Temperature distribution in the.Land's End granite aureole. Cornwall. *Proc. Ussher Soc..* **2**, 335-51.

Table of Contents

KINGSBURY, A. W. G. 1901. Beryllium minerals in Cornwall and Devon: helvine, genthelvite and danalite. *Miner. Mag.,* **32**, 921-40.

MACKENZIE, D. M. 1972. The mineralogy and chemistry of arinife reaction veins cutting the Meldon aplile. *Proc. Ussher. Soc..* **2**, 410-16

Dept. of Geology
Universily of London
King's College
London WC2

GEOCHEMISTRY OF DEVONIAN SEDIMENTS IN THE PERRANPORTH AREA, CORNWALL

by S. Henley

Abstract. Analyses of 96 samples show that Devonian sediments vary widely in composition. Potassium and tin, however, are consistently high, whereas calcium and sodium are low in most samples. Trace element studies indicate marked geochemical differences belween the Meadfont Beds and rocks which have been mapped as Gramscatho. A horizon of chert-banded slates in the latter is markedly enriched in manganese and cobalt. Metasomatism around the Cligga granite has given rise in caesium values of up to 560 ppm, and has caused enrichment of rubidium and tin in aureole rocks. Twelve factors identified by geological interpretation may have influenced the geochemistry.

1. Introduction

No published account exists of any large-scale study of the geochemistry of Devonian sediments in south-west England. In an attempt to bridge this gap, ninety six samples of sedimentary rocks were collected from the area around Perranporth (covering about 100 km^2). Twenty four came from north of the Meadfoot/Gramscatho boundary, and seventy two from the south. The rocks to the south of this boundary in places resemble Mylor lithologies more than they do Gramscatho. It is considered that the more argillaceous beds may be usefully termed Perran Shales, after Reid *et al.* (1906); greywackes and coarse siltstones are prominent in the eastern part of the area, near Ladock, and likewise may best be

Table of Contents

TABLE 1. Summary of the geochemistry of Devonian sediments in the Perranporth area. Major elements in percent oxide, traces in ppm.

Element	Median (All)	Minimum (All)	Maximum (All)	Median (GSL)	Median (GSK)	Median (GCH)	Median (MSL)
SiO_2	67.6	50.1	94.1	66.1	77.1	67.8	59.5
TiO_2	.72	.28	1.48	.74	.59	.73	.79
Al_2O_3	16.81	3.10	28.67	17.50	11.41	15.10	20.15
Fe_2O_3*	6.92	.46	21.87	6.72	5.29	7.60	844
MnO	.08	.00	2.49	.08	.03	.20	.09
MgO	2.13	.00	10.03	2.13	1.28	2.38	2.64
CaO	.03	.01	7.24	.02	.03	.03	.05
Na_2O	.34	.07	5.16	.36	.22	.25	.91
K_2O	3.33	.21	12.80	3.63	1.71	3.05	3.61
P_2O_5	.06	.00	1.43	.05	.04	.04	.11
S	230	80	38500	230	218	287	215
CI	550	14	8354	665	649	1701	219
Se	15	5	29	16	10	14	19
Cr	120	45	428	126	87	112	150
Co	23	0	92	22	15	32	28
Ni	82	7	281	75	43	80	105
Cu	44	0	2603	58	30	132	24
Zn	162	22	1592	168	114	157	173
Ga	27	8	51	28	19	27	32
Ce	4	0	7	3	4	4	4
As	30	0	849	42	18	31	29
Rb	257	21	1387	288	132	270	260
Sr	63	12	321	66	51	38	100
Y	25	10	72	24	22	21	36
Zr	212	46	617	180	256	165	254
Nb	19	0	45	19	15	17	21
Sn	17	1	2670	18	17	22	13
Cs	5	0	562	8	0	16	4
Ba	1282	0	2280	1407	1040	1163	1350
La	36	16	66	32	33	35	41
Ce	123	68	206	113	112	117	133
Nd	42	0	76	41	37	40	51
Pb	51	10	1174	48	45	78	43
Th	33	10	229	32	29	27	41
U	4	0	15	7	3	5	6

* Total iron as Fe_2O_3

Table of Contents

termed Ladock Grils (Reid *et al*, 1906). Three principal lithologies are recognised in the Perran Shales and Ladock Grits, and the 72 samples are accordingly subdivided into (i) 34 slates and silty slates, (ii) 16 chert-banded slates, and (iii) 22 greywackes and siltstones (though best developed around Ladock, these last lithologies are found throughout the area: similarly the slatey rocks can be found throughout the area).

Ten major elements have been determined by rapid chemical methods, and twenty live trace elements by X-ray fluorescence, using resin-bonded powder pellets (Leake *et al,* 1969). Detection limits and an indication of analytical error for the trace elements are given in Table 3.

Medians, maxima, and minima for all 96 samples are shown in Table 1, together with medians for the 4 lithological groups. Where the distribution law is complex or skewed, the median is a better estimator of the mode value than either the arithmetic or geometric means.

2. Variations among the lithological groups

For a number of related elements, the ratios of the medians of each group to the median of all 96 samples were computed. Results are shown in Table 2.

Of the lithophile trivalent elements there is a clear distinction between the Meadfoot slates of the Penhale point - Ligger Head area (abbreviated to MSL, for convenience) and the three 'Gramscatho' groups (abbreviated to GSL for the slates and silty slates, GCH for the chert-banded slates, and GGK for the arenaceous rocks). MSL are appreciably richer in all the elements (Al,Ga,Sc,Y,Nd,Ce,La), but particularly in yttrium and scandium. Of the lithophile bivalent elements (Mg,Ca,Sr,Ra), there is a similar distinction, with MSL being rich in all the elements but particularly in calcium and strontium.

MSL, are consistently rich in siderophile bivalent elements compared with the GGK and GSL groups, but GCH contain anomalously high amounts of manganese and cobalt.

Table of Contents

TABLE 2. Median ratios: the median of each group divided by the grand median (of all 96 samples) for selected elements.

Element	Ion	Ionic Radius (Angstroms)	MSL	GSL	GGK	GCH
Al	+3	.51	1.20	1.04	.68	.90
Ga	+3	.62	1.19	1.04	.70	1.00
Sc	+3	.81	1.27	1.07	.67	.93
Y	+3	.92	1.44	.96	.88	.84
Nd	+3	1.00	1.21	.98	.88	.95
Ce	+3	1.03	1.08	.92	.91	.95
La	+3	1.14	1.14	.89	.92	.97
Mg	+2	.66	1.24	1.00	.60	1.12
Ca	+2	.99	1.67	.67	1.00	1.00
Sr	+2	1.12	1.59	1.05	.81	.60
Ba	+2	1.34	1.05	1.10	.81	.91
Ni	+2	.69	1.28	.91	.52	.98
Co	+2	.72	1.22	.96	.65	1.39
Fe	+2	.74	1.22	.97	.76	1.10
Mn	+2	.80	1.13	1.00	.38	2.50
Na	+1	.97	2.68	1.06	.65	.74
K	+1	1.33	1.08	1.09	.51	.92
Rb	+1	1.47	1.01	1.12	.51	1.05
Cs	+1	1.67	.80	1.60	.00	3.20
As	+5	.46	.97	1,40	.60	1.03
P	+5	.35	1.83	.83	.67	.67

The alkalis present a different picture. MSL have the highest sodium content but are relatively poor in other alkali elements. GGK are poorest in all four alkali elements (Na,K,Rb,Cs); GCH and GSL have a very high caesium content (in a few samples from these two groups caesium is enriched by metasomatism around the Cligga granite, by up to 560 ppm at the contact). In a traverse along the cliffs from Cligga Head towards Perranporth the enrichment is detectable for at least 800 m. away from the granite. Rubidium is also involved in this metasomatism, but the potassium content appears not to be different near the granite.

Table of Contents

TABLE 3. Detection limits and analytical precision for trace elements: precision expressed as coefficient of variation of replicate amlyses.

Element	Detection limit (ppm)	Coefficient of variation
S	22	.024
Cl	13	.021
Sc	0.7	.19
Cr	1.7	.006
Co	8.5	.005
Ni	5.7	.011
Cu	2.5	.11
Zn	2.3	.044
Ga	1.8	.16
Ge	2.2	.10
As	1.2	.065
Rb	2.0	.18
Sr	1.7	.004
Y	1.3	.012
Zr	5.6	.008
Nb	6.3	.006
Sn	1.0	.09
Cs	0.7	.27
Ba	22	.004
La	4.2	.002
Ce	13	.006
Nd	11	.018
Pb	3.6	.029
Th	3.5	.077
U	0.4	.01

The tin content is interesting, because the median for the whole Perranporth area is 17 ppm, which is 28 times the world average shale value (0.6 ppm) computed by Turekian and Wedepohl (1961). There is some local enrichment of tin around the Cligga granite, as there is of caesium and rubidium; a few other isolated samples are anomalously rich in tin (probably derived from a hydrothermal source). As even the MSL group has a median tin content of 13 ppm, there seems to be some regional enrichment of this element pre-dating the Variscan mineralisation phase. Zinc and lead are enriched to a lesser extent than tin, however, and copper is perhaps a little low here compared with world average shale values.

Table of Contents

MSL are rich in phosphorus compared with the other three lithological groups - repeating the pattern shown by the trivalent and the lithophile bivalent elements. Arsenic is enriched in GSL and GCH relative to the other two groups, and probably participated in the metasomatic activity which caused enrichments of caesium, rubidium, and tin around the granite.

3. Discussion

Regional geological considerations indicate that at least 12 factors should be taken into account in discussing Devonian sediment geochemistry.

(i) Composition of source rocks of the sediments. This effect is most clearly seen in the coarser GGK rocks, which contain fragments of basic, acid, and metamorphic rocks, as well as large clasts of shale which may be of local derivation.

(ii) Rate and degree of weathering and erosion of source rocks. The influence of this factor is difficult to appreciate fully since it affects the finer grained components of the sediments, which are those most readily altered by later events, including recent weathering.

(iii) Mechanisms and distance of sediment transport. The gross effect on lithology is shown by comparison of the Ladock greywackes and the slatey rocks of Perranporth. The most obvious chemical difference is in the silica content, however zirconium is more abundant (median 256 ppm) in the GGK group than in. the GSL group (median 180 ppm). This reflects the higher proportion of detrital constituents in the GGK group.

(iv) Contributions from contemporaneous volcanism. A few tuffaceous horizons are present in the MSL rocks (though not included in the samples analysed) and it is possible that small amounts of volcanic material may be found throughout much of the sequence. The ehert bands in the GCH group resemble those found in certain places on the south coast (notably Mullion) in close association with pillow lavas. It is probable that the manganese and cobalt enrichment in this group is related to volcanic activity,

Table of Contents

although no direct evidence of such activity has yet been found in association with GCH rocks.

(v) Environment of deposition. The MSL rocks contain a rich fauna at Newyuay and farther east, and apparently were deposited in a shallow-water, low-energy regime. The ‘Grarnscatho’ groups consist of sediments which are less mature, and which were deposited in a 'flysch' trough lying to the north of north-west of a rapidly rising landmass. This important difference in sedimentary environment is reflected in major geochemical differences. The MSL rocks are rich in (probably biogenic) phosphates, with a corresponding enrichment in calcium, strontium, and scandium, relative to the other groups. They are also relatively rich in gallium, yttrium, and the lanthanides (which tend to concentrate in clay minerals) and also in elements associated with oxidate phases: iron, nickel, and the other siderophile elements.

(vi) Diagenesis. The geochemical effects of diagenetic alteration are still little understood. However, Curtis (1969), after studying British Carboniferous sediments, suggested that diagenetic processes are important in delermining the distribution of manganese, a conclusion supported by studies of Recent sediments (Bostrom, 1967).

(vii) Regional metamorphism. The rocks of this area are metamorphosed to low greenschist facies. However, beyond controlling the present mineralogical sites of the elements, it is thought that regional metamorphism has had little effect on the geochemistry.

(viii) Thermal metamorphism. This has affected rocks within 1 to 2 km of the granite contact, the highest metamorphic facies seen in the Cligga aureole being the hornblende-hornfels facies. Possible chemical effects are obscured by the effects of severe metasomatism around the granite.

(ix) Contact metasomatism. The extent to which the metasomatic effects can be separated from metamorphism is difficult to assess. However, the effects themselves are obvious, with extreme enrichment (560 ppm) of caesium (and also enrichment of rubidium and tin) adjacent to the granite contact.

Table of Contents

(x) Hydrotherrnal alteration. Though samples from hydrothermal veins were not collected, for analysis, it was unavoidable that some hydrothermally altered material should be included. Thus there are a few samples containing anomalously high amounts of tin, copper, arsenic, zinc, or lead; one or two exceptional thorium contents are also noted, as well as a single sample in the MSL which appears to have undergone potash metasomatism, with 12.8% K_2O and corresponding enrichment in barium, rubidium, and caesium.

(xi) More recent groundwater composition and movement. Sabine (1968) pointed out the drastic effects of mineralised goundwaters on slates around the Perran Iron Lode at Treamble, the slates locally being converted to fuller's earth. Though this is an extreme case, it serves as a reminder that groundwaters influence the geochemistry.

(xii) Weathering. Although the freshest possible samples were collected, all had suffered some degree of weathering. An indication of the depth to which the rocks of this area are weathered is given by the Perran Iron Lode, in which oxidation of the primary siderite to hematite occurs to depths of 75 m. from the surface. Intense weathering of this sort throws doubt on the value of uranium analyses in particular, and in the meaning of local variations in element distribution (e.g. manganese, which is readily redistributed during weathering processes).

However, despite the confusing influences of weathering and other types of alteration, there is sufficient geochemical evidence, on a broad scale, to assist in the interpretation of sedimentary facies variations, and possibly to speculate on the geochemistry of the source area from which the Devonian sediments were derived.

ACKNOWLEDGEMENTS. Much of the work was carried out at the University of Nottingham during the tenure of a NERC Research Studentship, under (fie supervision of Dr. R. J. Firman and Professor Lord Energlyn.

BOSTROM, K. 1967. The problem of excess manganese in pelagic sediments. *Researches in Geochemistry,* **2,** 421-452, New York.

Table of Contents

CURTIS, C. U. 1969. Trace element distribution in some British Carboniferous sediments. *Geochim. Cosmochim. Acta.* **33**, 519-522.

LEAKE, B. E. ct al. 1969. The chemical analysis of rock powdcrs by automatic X-ray fluoresccnce. *Chemical Geology* **5**, 7-86.

REID, C. *et al.* 1906. The geology of the country around Newquay. *Mem. Geol. Surv,. Gt Br.*

SABINE, P. A. 1968. Origin and age of solutions causing the wallrock alteration of the Perran Iron Lode, Cornwall. *Trans. Inst. Min. Metall.,* 77, RI -135.

TUREKIAN, K. K. and WEDEPOHL., K. H 1961. Distribution of the elements in some major units of the earth's crust. *Geol. Soc. Amer Bull.*, **72**, 175-192.

This paper is published with the permission of the Director, Institute of Geological Sciences.

Institute of Geological Sciences
Exhibition Road
London SW7

GEOCHEMISTRY AND PETROGENESIS OF ELVAN DYKES IN THE PERRANPORTH AREA, CORNWALL

by S. Henley

Abstract. Major and trace element data from 20 samples of elvan dykes are used to re-examine problems of elvan petrogenesis. It is suggested that elvan dykes were emplaced by fluidisalion of a gas/crystal mixture created by attack on solidifying granite by potassium-rich aqueous fluids. These fluids could have been derived at depth in the pluton from assimilation of foundered pelitic zenoliths. There is a strong possibility that elvan petrogenesis and the main phase of hydrothermal activity are closely related.

1. Introduction

Elvans are generally quartz-feldspar porphyry dyke intrusions which traverse both granite and country-rock in Cornwall and Devon. They post-date the St. Austell granite (Rb/Sr age of the

Table of Contents

granite is 288±13 m.y. Harding and Hawkes, 1971; Rb/Sr age of the elvans is 269±8 m.y. Hawkes, Harding and Darbyshire, in press). However, field evidence indicates that they are earlier than the principal phase of hydrothermal mineralisation. The dykes trend generally ENE-WSW, though locally there are trends of E-W, N-S, and NW-SE. In the Perranporth area, most dykes trend between ENE-WSW and ESE-WNW, an exception being the Watergate Bay elvan, which strikes a little W of N. Normally the dykes have fairly steep dips, though some fill shallow-dipping fissures (Goode, 1973).

The chemistry of elvans was studied by Phillips (1875), Ghosh (1934), Stone (1968), and Hall (1970). All these workers found that elvans are acid rocks with granitic composition, showing a trend to enrichment in potassium (to 9% K_2O) and impoverishment in sodium.

2. Petrography

Typically, elvans contain 5 to 30 percent phenocrysts and 70 to 95 percent matrix. Potash feldspar is the most abundant phenocryst mineral, followed by quartz; tourmaline, biotite, zircon, apatite, and cassiterite are present as accessories. The matrix consists mainly of quartz and feldspar which commonly display graphic intergrowths. The marginal zones of many dykes are quite different, being devoid or almost devoid of phenocrysts. They display a variety of flow structures (Goode 1973), and flow lamination in particular is common.

At Gravelhill (G.R. SW765576) two parallel ENE-trending dykes occur. They display good flow-laminated margins and a porphyritic central part in the wider dyke. A narrow irregular zone crowded with megacrysts also occurs in the centre of this dyke. Most common among the megacrysts are intensely clouded broken fragments of feldspar, though biotite and embayed quartz grains also occur.

At Hanover Cove (G.R. SW738531) a southerly-dipping dyke is cut by another which dips north. The earlier elvan contains not only feldspar and quartz phenocrysts but also small xenoliths of greisen, similar to granite and greisen xenoliths in elvan dykes described by

Table of Contents

Reid *et al* (1906) and by Goode (1973). Eastward along the strike of this dyke, at Deerpark (G.R. SW80655515) an elvan dyke terminates upwards. Goode (1973) noted that curved flow-laminations are well developed here and that the marginal zone is particularly thick.

The Watergate Bay dyke (G.R. SW849558 and northwards) uncharacteristically trends N-S. The quartz phenocrysts in this elvan are rounded and embayed, and surrounded by a graphic zone; in places quartz grains are partially enclosed by large eulredral feldspar crystals.

At Wheat Budnick (G.R. SW76954G) there is an elvan dyke which has a granitic texture and a composition close to that of granite. There is much cassiterite in this elvan (Dines 1956); this cassiterite was probably derived from an adjacent tin lode. Possibly the dyke is an eastward extension of a greisen dyke exposed at Cathedral Caverns (G.R. SW741542). It may thus be connected with an eastward subsurface extension of the Cligga granite (Henley, in press).

3. Chemistry

Twenty new analyses of elvans from the Perranporth area confirm the results of earlier workers and show that elvans are silica-rich, commonly potassium-rich and extremely deficient in sodium, and contain very little calcium and magnesium. All are alumina oversaturated, with up to 12 percent corundum in the CIPW norm. Trace element data were obtained for 22 elements; an indication of analytical error and the probable detection limits for each trace element are shown in Henley, 1974, Table 3.

Apart from the Hanover Cove dykes, the elvans all contain little tin (even the Budnick dyke contains only 16 and 31 ppm in the two analysed samples); the Hanover Cove samples range up to 1396 ppm tin. Rubidium and caesium are high (median values 839 ppm and 23 ppm respectively), and K/Rb values, between 45 and 100, are low compared with unaltered granites (the St. Piran's Chapel elvan is anomalously rich in Rb with 2261 ppm - the K/Rb ratio is 20). However, greisens at Cligga Head (Hall, 1971) and altered St. Austell granites (Exley, 1958) have lower K/Rb ratios than elvans, because of lower potassium contents and higher rubidium.

Table of Contents

Thorium and uranium (medians 41 ppm and 17 ppm) are more abundant than in a world average granite (Taylor 1965; 17 ppm Th, 4 ppm U).

Sulphur correlates significantly with the modal content of opaque minerals; correlations with other elements, however, are weak, and thus sulphur is probably present in pyrite. The potential S-Fe correlation is obscured by the much higher iron content due to other minerals. In fact, there is a general statistical association of Fe, Mg, Ti, Ce, and Th, possibly indicating joint occurrence of these elements in biotite.

4. Petrogenesis

As elvan geochemistry is dominated by Si, Al, K, and Na, most of the variation can be represented on the ‘granite triangle’ (Henley 1972 Fig. 1). There is a trend from granitic compositions close to the ternary minimum toward the quartz-orthoclase join, and then a spread of compositions both ways along this join.

Stone (1968), as an explanation for the trend to high-K - low Na compositions, invoked alkali ion-exchange during emplacement as a fluidised system, with potassium from the fluid replacing sodium in the feldspar. However, this hypothesis does not account in full for the trend observed by Henley (1972, Fig. 2). Stone further suggested that resorption of quartz crystals took place during emplacement, due to a reduction of the quartz stability-field with decreasing pressure. However, in the Watergate Bay dyke (and possibly in others), there are a few partially resorbed, rounded and embayed quartz crystals partly enclosed by large potash feldspars. Such growth of the feldspar could not have occurred during the turbulence of emplacement; post-intrusive growth is represented by surrounding zones of graphic intergrowth. It seems most probable that both resorption of quartz and growth of the feldspar occurred before intrusion.

Thus a new model of elvan petrogenesis is required, one which must account for the observations noted above, and which must also be consistent with the following points.

(i) Elvan dykes are genetically related to the granites and were

Table of Contents

emplaced probably 15 to 20 m.y. later.

(ii) The dykes occupy the same fracture system as the main phase of hydrothermal mineralisation, but appear in general to have preceded the mineralisation.

(ii) Little contact alteration of the host rocks occurs. This may be because the intrusive phase was very short, or because the fluids were cool, or simply because the host rocks had already been upgraded to the greenschist facies (sec Goode 1973).

(iv) The abundance of bipyramidal quartz plienocrysts indicates that their crystallisation occurred at temperatures above the quartz inversion point (570°C).

(v) The fluidisation hypothesis (see Stone 1968) gives a reasonable emplicement mechanism; many of the structures shown by elvans (e.g. narrow offshoots from dykes) require low-viscosity emplacing fluids. The association of intrusive breccia dykes (Goode 1973) with elvans lends strong support to an emplacement hypothesis involving high gas pressures.

The granites of south-west England were probably emplaced in a fluid condition, principally by stoping. In this process, it is likely that large volumes of country rock descended to quite deep levels in the batholith, suffering varying degrees of assimilation (as indicated by xenoliths in the Dartmoor granite). During crystallisation of upper levels of the granite, potassium was largely excluded from the silicate phases and concentrated in aqueous fluids. Trapped below impermeable roof rocks these caused autometasomatism, as well as metasomatism of the inner aureole rocks (Bowler 1958 and Henley 1974). Potash feldspar megacrysts developed in the sites of original plagioclase phenocrysts to give the 'big-feldspar' granite.

In recent geophysical studies, Bott *et al.* (1970) have shown that rocks less rich in silica probably occur at deeper levels in the batholith. However, two factors indicate high concentrations of potassium in aqueous fluids generated at these depths.

(i) Foundered pelitic xenoliths would generate potassium-rich solutions after sinking to depths at which micas are dehydrated.

Table of Contents

TABLE 1. summary of geochemical data from elvans in the Perranporth area (4 samples frdm the Cravelhill dyke, 5 from the Hanover Cove dykes, 5 from the Watergate Bay dyke, 3 from the Wheal Maty dyke, 2 from the Budnick dyke, and 1 front the St. Piran's Chapel dyke.)

Oxide (percent) or Element (ppm)	Median	Maximum	Minimum
SiO_2	73.33	77.07	61.62
TiO_2	.19	.32	.03
Al_2O_3	15.11	24.98	14.26
Fe_2O_3*	1.87	4.36	.71
MnO	.02	.11	.00
MgO	.00	.37	.00
CaO	.21	.54	.09
Na_2O	.30	4.10	.16
K_2O	6.34	9.22	4.10
P_2O_5	.21	.35	.03
S	101	963	18
Cl	92	2185	41
Sc	2	6	nd
Cr	17	40	nd
Co	nd	15	nd
Ni	8	26	nd
Cu	16	439	nd
Zn	74	335	52
Ca	35	58	25
Ge	3	5	nd
As	14	1301	nd
Rb	839	2261	613
Sr	104	330	22
Y	31	58	20
Zr	84	159	15
Sn	16	1396	5
Cs	23	58	6
Ba	446	2207	212
Ce	68	125	15
Pb	75	1680	8
Th	41	97	nd
U	17	34	9

Analyses by X-ray fluorescence on fusion beads (Norrish method) for major elements and on resin-bonded powder pellets (Leake method) for trace elements.

*Total iron expressed as Fe_2O_3.

nd - not detected.

Table of Contents

(ii) Assimilation of pelilic sediments rich in potassium relative to silicon and sodium would lead to a potassium-rich but silica-poor melt, which on cooling and crystallisation would thus expel potassium-rich aqueous fluids.

Upward migration of these solutions into partially solidified granite would result in a net solution of sodium from the solid phase (Orville 1963) and solution of silica. Thus the mineralogical changes to be expected would be resorption of quartz and transformation of plagioclase to potash feldspar, and a possible net solution of the solid phases. Locally one could then envisage a situation where much of the already crystallised granite had redissolved into an aqueous-silicate fluid and had become disaggregated; this would leave corroded quartz grains, potash feldspar megacrysts (which may have continued growing) and any muscovite and other accessory minerals which happened to be stable in the new medium. These minerals are precisely those found as phenocrysts in elvans.

Following emplacement of the granites (see Dangerfield and Hawkes 1969), erosion was rapid. The Dartmoor granite was probably unroofed by 280 m.y.; in the rest of the region stress release allowed the regional fracture systems to open. A fracture, extending downward, and encountering a reservoir of the type suggested above, would allow an explosive release of pressure leading firstly to the type of breccia dyke described by Goode (1973), and secondly to an influx of a rapidly crystallising mixture of steam (now supersaturated with silica(es) and entrained phenocrysts. Hall (1974) has suggested a similar crystallisation mechanism producing porphyritic textures in granite areas characterised by locally intense fracture systems.

Final compositions of elvans would probably be controlled partly by local factors such as dyke permeability in late stages of crystallisation and the relative activities of K^+, H^+, and Na^+. A high residual H^+ activity would move the composition towards the quartz corner of the 'granite triangle' by altering feldspar to kaolin or muscovite; a high K^+ activity would have the reverse effect.

Under this hypothesis, what are apparently multiple intrusions would simply reflect significant events during a single intrusive phase. The commonly observed feature of a rhyolitic margin giving way to a porphyritic centre could be explained by prior crystal

Table of Contents

settling in the reservoir. The first fraction to flow through the dyke fissure would contain few or no phenocrysts, and depending on the amount of settling that occurred, a sharp or gradational transition to the porphyritic phase would be observed. Possibly in the Gravelhill elvan the narrow phenocryst-rich central zone represents the last 'dregs' to be intruded from the lowest part of the reservoir.

Another feature is the change from flow-laminated to massive elvan. This could probably be due to a change in either viscosity or velocity leading to a switch from larninar flow to turbulent flow. The flow-folding and flow-brecciation structures (Goode 1973) possibly represent instability of the laminar flow before complete turbulence would set in. In many cases the changes of texture and structure are coincident and are clearly the result of a viscosity contrast between the fluids from which crystallise the rhyolitic and porphyritic textured elvan.

Fissure blocking, in which upward or lateral motion of the fluid would cease, is another mechanism which could produce a marked change in elvan textures. It is tentatively suggested that a matrix change from fine-grained texture to one of large, interlocking zones of graphic intergrowths (present near the centres of many dykes) may be due to fissure blocking.

If an elvan reservoir should remain untapped for any considerable time, it seems unlikely that it would remain in the same state. Intuitively it is much more likely that the silicate constituents would tend to crystallise, leaving a reservoir of superheated steam with only silica and metal halides in solution. Is it possible that these reservoirs could be the source of the hypothermal mineralising fluids?

ACKNOWLEDGEMENTS. Thanks are due to Dr. Hawkes and Mr. Goode for enlightening discussions. Much of the work was carried out at the University of Nottingham during the tenure of a NERC Research Studentship.

BOTT, M. H. P. HOLDER, A. P. LONG, R. E. and LUCAS, A. L. 1970. Crustal structure beneath the granites of southwest England. *In Mechanism of Igneous Intrusion:* 93-102. Liverpool.

BOWLER, C. M. L. 1958. The distribution of alkalis and fluorine across some granite-killas and granite-greenstone contacts. *Abstr. Proc. Conf. Geol. Geomorph. South-west England,* **7.**

Table of Contents

DANGERFIELD, J. and HAWKES, J. R. 1969. Unroofing of the Dartmoor Granite and Possible Consequences with regard to Mineralisation. *Proc Ussher Society*, 2, 122-131.

DINES, H. G. 1956. The metalliferons Mining Region of South-West England. *Mem. Geol. Surv. Gt. Br.*

EXLEY, C. S. 1958. Magnuilic différentiation and alteration in the St. Austell granite. *Q. Jl geol. Soc. Lond.,* **114,** 117-230.

GHOSH, P. K. 1934. The Carnmenellis Granite: Its Petrology, Metamarphism, and Tectonics. *Q. Jl geol. Soc. Lond.,* **90,** 240-276.

GOODE, A. J. J. 1973. The mode of intrusion of Cornish elvans. *I.G.S. Report No. 73/7.*

HALL, A. 1970. The composition of Cornish Quartz-Porphyry ('Elvan') Dykes. *Proc. Ussher Soc.,* **2,** 205-208,

_____ 1974. Granite porphyries in Cornwall. *Proc. Ussher,Soc.,* **3.**

HARDING, R. R, and HAWKES, J. R. 1971. The Rb/Sr age and K/Rb ratios of samples from St. Austell Granite, Cornwall, *I.G.S. Report no. 71/6.*

HAWKES, J. R. 1973. Volcanism and mefallogenesis: the tin province of South-west England. *International Symp. Volcanism and Associated Metallogenesis.* Bucharest.

_____ HARDING, R. R. and DARBYSHIRE, D. P. F. (in press) The Rb:Sr ages and K:Rb ratios of the Brannel, South Crofty and Wherry elvan dykes. Cornwall. *I.G.S. Report*

HENLEY, S. 1972. Petrogenesis of Quartz Porphyry Dykes in South-West England. *Nature.* **235,** 95-97.

_____ 1974. Geochemistry of Devonian sediments in the Perranporth area. Cornwall. *Proc. Ussher Soc.,* **3.**

_____ in press. Rediscovery of a granite dyke at Perranporth, Cornwall. *Trans. Royal Geol Soc. Cornwall.*

ORVILLE, P. M. 1903. Alkali ion exchange between vapor and feldspar phase. *Amer. Jl .Sci.,* **261,** 201-237.

PHILLIPS, J. A. 1875. The rocks of the mining districts of Cornwall, and their relation to metalliferous deposits. *Q. Jl. Geol. Soc. Lond,* **31**, 319-345.

REID, C. and SCRIVENOR, J. B. 1906. The Geology of the Country near Newquay. *Mem. Geol. Surv. Gt. Br.*

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

Table of Contents

TAYLOR, S. R. 1965. The application of trace element data to problems in petrology. *Physics and Chemistry of the Earth.* **6**, 133-213.

This paper is published with the permission of the Director, Institute of Geological Sciences.

Institute of Geological Sciences
Exhibition Road
London SW7

GRANITE PORPHYRIES IN CORNWALL

by A. Hall

The porphyry dykes which occur in Cornwall are a well known feature of the region, but it is not generally realised that several of the more substantial intrusions described as "granites", for example those of St. Michael's Mount and Cligga Head, are actually composed of a very similar type of rock, i.e. granite porphyry. The difference between the plutonic and hypabyssal porphyries is that whereas the latter contain proportions of phenocrysts and groundmass that enable the groundmass to be seen easily in hand specimen, the former contain such a high proportion of phenocrysts to groundmass that they have the megascopic appearance of ordinary granites.

In order to make a clear distinction, and in the absence of a generally agreed nomenclature, The author will follow Stringhani (1966) in using the term granite porphyry for rocks containing more than 50% of megascopic crystals and less than 50% of aphanitic groundmass, and rhyolite porphyry for rocks containing more than

Table of Contents

50% of aphanitic groundmass. In Cornwall, granite porphyry occurs in plutonic intrusions (stocks), whereas rhyolite porphyry occurs in hypabyssal intrusions (dykes).

The texture of a typical rock from one of the granite porphyry intrusions (Cligga Head) is shown in fig. 1A. The rock contains crystals in three distinct and discontinuous grain size ranges. The largest crystals are approximately 1-2 cm across, consist only of potassium feldspar and make up about 20% of the rock; the intermediate-size crystals are approximately 1-5 mm across, consist of all the rock-forming minerals (orthoclase, plagioclase, quartz, micas, tourmaline) and make up 50% of the rock; the smallest crystals are 0.1-0.3 mm across, also consist of all the rock-forming minerals, and make up 30% of the rock.

This type of rock has affinities on the one hand with the coarse porphyritic granites which are common in south-west England (fig. 1B), and on the other hand with the rhyolite porphyry dyke rocks (fig. 1C). In the former, the main phenocryst mineral is potassium feldspar, whereas in the latter the phenocrysts include quartz, K-feldspar, plagioclase, and ferromagnesian minerals. It is suggested that of the three grain size categories in the granite porphyry intrusions, the largest corresponds to the phenocrysts (megacrysts) in the coarse porphyritic granites, the intermediate category corresponds to the groundmass of the coarse porphyritic granites but to the phenocrysts in the rltyolite porphyry dykes, and the smallest category corresponds to the groundmass of the rhyolite

FIGURE 1. Tracings from photomicrographs showing grain boundaries and distribution of groundmass in three granitic rocks from Cornwall.

A. Granite porphyry from the northern cliff of Cligga Head (x3). The groundmass constitutes 32% of this rock, the normal ("plutonio-size") crystals 50%, and the large phenocrysts a further 18%.

B. Porphyritic granite from the summit of Carn Brea (x 3%).

C. Rhyolite porphyry dyke from Hingston Down quarry, near Gunnislake (x3%) The groundmass constitutes 64% of the rock and the phenocrysts 36%.

Table of Contents

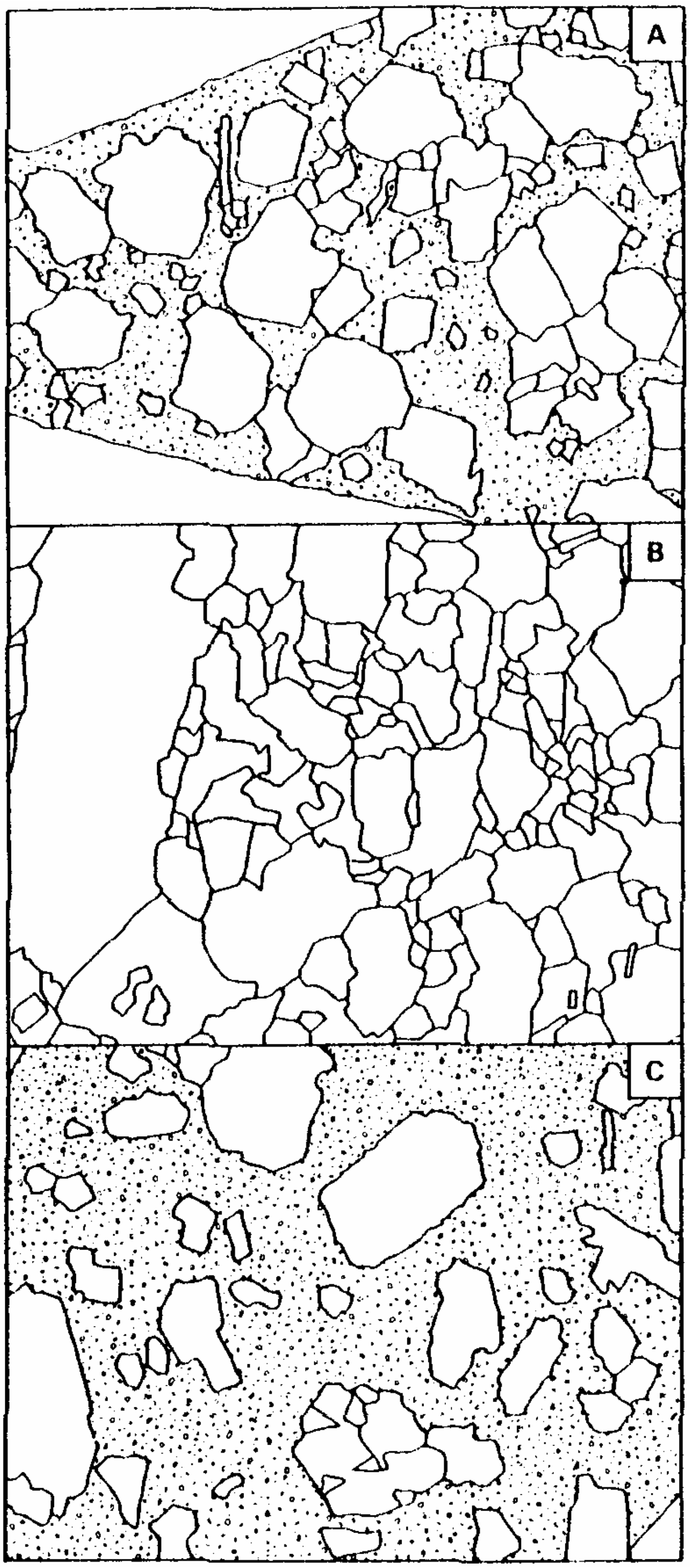


Table of Contents

potphyry dyke rocks. The inference which can be drawn from the trimodal grain size distribution is that crystallisation initially followed a course similar to that of a normal coarse porphyritic granile, but a sudden change in physical conditions at in advanced stage of crystallisation resulted in the formation of a chilled groundmass similar to that of the rhyolile porphyry dykes.

The switch during crystallisation from coarse crystals to chilled groundmass in both granite porphyry intrusions and rhyolite porphyry dykes must presumably be attributed to elevation of the liquidus by pressure release. Only a water pressure reduction could account for the sudden and sharp change to more rapid crystallisation; temperature changes and magma movements would he too slow and gradational.

Most of the granitic rocks in the plutonic intrusions of S.W. England are true granites, but granite porphyries of the type shown in fig. 1A constitute the small intrusions of Cligga Head and St. Michael's Mount, both of which are cupolas containing stockworks of greisen-hordered veins. In the Godolphin granite the texture has been found by the author in samples from Wheat Reeth, and in the Land's End granite in samples from Rosewall Hill near St. Ives. Similar granite porphyries, forming stocks rather than dykes, occur elsewhere among the Variscan granites of western Europe. In the Massif Central of France, there are granite porphyries containing slackwork tin deposits similar to those in Cornwall (Aunert 1969), but farther south, in soulhern Portugal, they are associated with copper mineralisation (Carvalho 1971). In all these examples, as in the porphyry copper deposits of North America, the occurrence of granite porphyry is associated with the presence of hydrothermal fissure systems, perhaps implying a genetic relationship. The connection can not be a simple one, however, since the opening of veins which cut granite porphyry (for example at Cligga Head) must obviously post-date the pressure changes responsible for the formation of the texture.

AUBERT, G. 1969. Les coupoles granitiques de Montebras et d'Echassières (Massif Central français) et la genèse de leurs minéralisations en étain, lithium, tungstène et béryllium. *Mem. Bur. Rech. Geol. Min.*, **46,** 345 pp.

Table of Contents

CARVALHO, D. De. 1971. The metallogenetic consequences of plate tectonics and the Upper Palaeozoic evolution of southern Portugal. *Estud. Not. Trab. Serv. Fomento Min.*, **20**, 297-320.

STRINGHAM, B. 1966. Igneous rock types and host rocks associated with porphyry copper deposits. *In: Geology of the Porphyry Copper Deposits. Southwestern North America* (ed. S. R.Titley & C. L. Hicks), Univ. Arizona Press, Tucson, pp. 35-40.

Dept. of Geology
King's College
London W.C.2

PETROCHEMISTRY OF THE MICA-LAMPROPHYRES (MINETTES) OF JERSEY (C.I.)

by G. J. Lees

Abstract. Chemical analysis of samples from 14 late Hercynian mica lamprophyre (minnette) dykes, from the Precambrian Complex of the Channel Islands in Jersey, show very high levels for potassium and the other 'incompatible' elements. A possible petrogenetic model involving partial melting of mantle material beneath a stable continental area is outlined.

1. Introduction

A characteristic feature of the Precambrian Pentevrian-Cadomian massif, constituting the Channel Islands and the north-western tip of the adjacent Cotentin Peninsula, is the relative abundance of minor intrusions of mica lamprophyre. About 60 have been reported from the northern Channel Islands, 6 or so from the Cap de la Hague complex and about 20 more from the Palaeozoic rocks elsewhere in the N. Cotentin. In Jersey, however, 83 mica lamprophyre intrusions have been reported to date.

The purpose of this paper is to present a summary of the geochemical data obtained from analysis of mica lamprophyres from Jersey with some tentative ideas as to the genesis of such rocks. A more detailed treatment of the petrochemistry will be given elsewhere.

Table of Contents

2. **Field occurrence and age**

The lamhrophyres occur in Jersey as thin (less than 3m) vertical sheets of irregular thickness. They intrude all the rock units of the island but are especially abundant in the North-West Granite. The trend of the dykes has a strong maximum in a NW-SE direction with a smaller one just F of N. These directions seem to be related rather to a regional stress or jointing system than to local patterns in individual rock units.

The mica lamprophyres are the youngest igneous rocks found in the Channel Islands with the possible exceptions of the albitedolerite suite of minor intrusions in Guernsey (Dr. R. A. Roach pers. comm.) and the late hornblende lamprophyres in Jersey. Only one radiometric date has been obtained from the Channel Islands mica lamprophyres. This was a K/Ar biotite date of 296±8 m.y. obtained from a dyke in Guernsey (Adams 1967); a late Hercynian (late which compares with those obtained from kersantite dykes in West Finistére (Leuhvein *et al.* 1972). It also compares well with the dates obtained on the late Hercynian high level granites, of 300±5 m.y. (W.R. isochron) for Ploumanac'h-Trégastel (Côtes-du-Nord), 316 m.y. (Rb-Sr biotite) for Flamanville (Manche) and 292 m.y. (Rb-Sr biotite) for Barfleur (Manche) (Adams 1967). The dykes in the Channel Islands appear to be slightly older than the Exeter Traps of S.W. England (279±6 m.y. K/Ar Biotite date on Killerton Park Minette - Miller *et al.* 1962). This echoes the relationship between the late Hercynian granites of the two regions, i.e. 300 m.y. for the Massif Armoricain granites as compared with 282 m.y. for those of S. W. England (Miller & Mohr, 1964).

3. **Petrography**

All the Jersey mica lamprophyres so far recorded are minettes, that is, essentially dark mica + potassic feldspar rocks. Many of them are very fresh. The colour index is generally over 35, reflecting their melanocratic and basic nature. Detailed petrographic descriptions have been given by Smith (1933, 1936a, 1936b, 1939) but may be summarised as follows. The rocks are usually porphyritic with the phenocrysts always of mafic minerals. Phlogopite is ubiquitous (Mélais *et al.* 1962, Velde 1969a) and is nearly always

Table of Contents

zoned.These phenocrysts have a characteristic dark, more iron-rich margin but foxy red centres occur in those from some dykes e.g. South Hill. Occasional relict phenocrysts of olivine (always completely altered) and diopside (fresh or altered) also occur. Apatite is present both as early stumpy crystals and as late acicular ones. The groundmass is made up of small euhedral phlogopite plates and interstitial potassic feldspar.

4. Petrochemistry

Chemical analyses for major and trace elements have been made on 18 samples from 14 dykes. Analyses were made by X.R.F.S. using fused discs for major elements and pressed powder discs for trace elements. The unusual mineralogy of minettes necessitated the production of a series of addition spikes using one of the minettes as the matrix. The Southampton University standard lamprophyric lava KYL is used for comparison (Table 2).

Table 1 shows the summarised results for major elements, with the average of 64 minettes as given by Métais and Chayes (1963) for comparison. Characteristic features of minettes are the low values of Al_2O_3, Na_2O and total iron; high MgO and CO_2 values and the very high K_2O and P_2O_5 contents. The Jersey minettes are slightly richer in MgO and K_2O than Métais and Chayes' average.

TABLE 1. Major element contents (WT.%) of Minettes, Jersey (C.I.)

	Arithmetic Mean (of 18)	Standard eviation	Range	Average Minette*
SiO_2	52.84	6.35	41.6 -66.5	51.17
TiO_2	1.10	0.18	0.77- 1.46	1.36
Al_2O_3	12.30	1.38	10.06-15.13	13.87
Fe_2O_3	3.01	0.92	1.39-4.26	3.27
FeO	3.80	1.17	1.70- 6.40	4.16
MnO	0.14	0.085	0.02-0.34	-
MgO	8.20	2.66	4.07-13.46	6.91
CaO	7.08	3.62	1.91--14.75	6.58
Na_2O	1.61	0.64	0.09- 2.71	2.12
K_2O	6.82	1.44	4.13-9.08	5.49
H_2O^+	1.64	0.63	0.74- 2.96	-
P_2O_5	1.47	0.48	0.63-2.24	-
CO_2	3.91	4.85	0.09-13.30	-

Mean of 64 Minettes: Métais & Chayes (1963)

Table of Contents

Table 2 gives the summarised results for trace elements. Ni and Cr are high for the MgO content of the rocks (cf. Cox *et al.* 1967), but the most striking feature is the high content of the "incompatible" elements, i.e. K, Rb, Ba, Th, U, Pb, Y, Nd, Sr, P, F, La and Cs. This feature is characteristic of potash-rich basaltic rocks and also of kimberlites and carbonatites. Compared with ocean-floor basalts (various sources but cF. Cann & Simkin 1971) and with alkali-basalts (Prinz 1968), the minettes are highly enriched in the 'incompatible' elements, concentration factors varying between x 1000 (Cs) and x 2 (Y) in the case of ocean floor basalts, and x 15 (Ba) and x 3 (P) in the case of alkali-basalts. For K the factors are x 50 and x 5 respectively.

TABLE 2: Trace Element contents (p.p.m.) of Minettes, Jersey (C.I.)

	Arithmetic Mean	Standard Deviation	Range	KPL (Keele)	KPL (Southampton)
Ba	6027	1419	438 - 9129	3620	3240
Ce	45		- 45		
Co*	37	8	26 - 47		
Cr	574	161	405 - 1027	143	
Cs**	16	14	7 - 41		
Cu*	50	6	43 - 58		
F**	0.44%	0.16%	0.29% - 0.66%		
Ca	24.5	5	16.8 - 34	29	17
K	56606	11989	34200 - 75400		
La**	316	177	153 - 475(48)		
Li**	66	19.5	36 - 88		
Mg	49457	16055	24560 - 81187		
Nb	21	9	8 - 42	12	9
Nd	196	108	59 - 429	177	69
Ni	414	161	(41)226 - 644	292	150
P	6417	2086	2700 - 9800	4059	3760
Pb	213	101	71 - 441	78	70
Rb	287	105	131 - 577	94	110
Sc*	19.3	4.7	12.5 - 26.5		
Sn	3.4	1.0	1.3 - 4		
Sr	2034	843	274 - 3521	2816	2550
Th	56	22	21 - 105	16	23
Ti	6622	1082	4600 - 8800	6954	7194
U	7	3.5	(0.0)2.0 - 13.7	<2	N.F.
V*	140	25	107 - 170		
Y	93	54	33 - 247	25	22
Zr	647	252	274 - 1127	434	460

*Emission Spectrography - 7 results **Emission Spectrography - 5 results.
All others are by X.R.F.S. ('- X.R.F.S. result).

Table of Contents

5. Petrogenesis

The classical theories for the genesis of lamprophyres have been summarised by Wimmenauer and Hahn-Weinheimer (1966). However, the advent of trace element and experimental studies has shown that most of these theories are no longer tenable. Velde (1969b) suggested that minettes could be derived from the partial melting of pyroxenites containing phlogopite. Recent experimental work (Kushiro *et al.* 1967, Kushiro 1969, Modreski and Boettcher 1972, 1973) has shown that phlogopite can exist under upper mantle conditions and may in fact be the main potash-bearing phase down to about 100 km. Phlogopite would be one of the first phases to melt, so this process, particularly if only small amounts of melting took place, could result in a powerful enrichment in the liquid phase (and hence in the resultant magma) of K and the other 'incompatible' elements which are often highly concentrated in phlogopite.

In recent years, several plate tectonic models of varying degrees of feasibility have been put forward for the Hercynian orogeny in Western Europe. Rocks in S.W. England that show similar chemical and petrological characteristics to the Jersey minettes, the Exeter Traps, have been explained as shoshonites derived from the partial melting of an underthrust Hercynian lithospheric plate in an Andean type plate collision (Cosgrove 1972). Comparison with the only well documented shoshonitic occurrence in an island arc assembly, that of Viti Levu (Fiji) (Gill 1970), shows that the Jersey mica-lamprophyres (and the F_2 & F_4 groups of Cosgrove 1972) are very much enriched in both the 'incompatible' elements and in Ni and Cr, concentration factors ranging from x 2 (K and Sr) to x 47 (Th). A large difference thus exists chemically between the rock types formed in a Cenozoic subduction zone environment like Fiji and rock types such as minettes which are always found in continental environments.

In view of the obvious similarities in chemistry between mica-lamprophyres and rocks of the potash basalt and kimberlite-carbanatite suites, it may be more profitable to look to models involving magma generation beneath stable continental areas. Melting of a small amount of mantle material followed by magma ascent involving a zone-refining process, as first proposed by Harris (1957), could result in enrichment in 'incompatible' elements to the levels found in minettes. Gast (1968) has estimated that overall

Table of Contents

partial melting of circa 1% of possible mantle material could cause enrichment of potash in the liquid phase by a factor of 40. Such enrichment would he more than enough to account for the concentration levels of incompatible elements found in the mica-lantprophyres.

ACKNOWLEDGEMENTS. I am indebted to A. C. Bishop for introclucing me to the study of Jersey rocks. A. C. Bishop, P. A. Floyd, R. A. Roach and R. C. Standley are to be thanked for helpful discussion and for critically reading the manuscrirl.

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*

CANN, J. R. and SIMKIN, T. 1971. A bibliography of ocean-floor rocks. Phil. *Trans. R. Soc. A.* **268,** 737-741.

COSGROVE, M. E. 1972. The Geochemistry of the Potassium-Rich Permian Volcanic Rocks of Devonshire. England. *Contr. Miner. Petrol.,* **36**, 155-170.

COX, K. G., MACDONALD R, and HORNING, G. 1967. Geochemical and Petrographic Provinces in the Karroo Basalts of Southern Africa. *Am. Miner.,* **52**, 1451-1474.

GAST, P. W. 1968. Trace element fractionation and the origin of tholeiitic and alkaline magma types. *Geochim. Cosmochim. Acta.,* **32**, 1057-1086.

GILL, J. R. 1970. Geochemistry of Viti Levu. Fiji, and Its Evolution as an Island Arc. *Contr.. Miner. Petrol.,* **27**, 179-203.

HARRIS, P. C. 1957. Zone refining and the origin of potassic basalts. *Geochim. Cosmochim. Acta,* **12**, 195-208.

KUSHIRO, I. 1969. Stability of Amphibole and Phlogopite in the Upper Mantle. *Carnegie Inst. Wash. Yearbook,* **68**, 245-247.

KUSHIRO, I., SYONO, Y. and AKIMOTO, S. 1967**,** Stabitity of Phlogopite at High Pressures and possible presence of Phlogopile in the Earth's Upper Mantle. *Earth Planrt. Sci. Lett.,* **3**, 197-203.

LEUTWEIN, F., SONET, J., and ZIMMERMANN, J. L. 1972. Dykes basiques du Massif Armoricain septentrional. Contribution à leur étude géochronologique. *C.R. Acad. .Sci. Par̄is,* **273**, 1327-1330.

METAIS, D. and CHAXES, F. 1963. Varieties of Lamprophyre. *Carnegie Inst. Wash. Yearbook,* **62**, 156-157.

Table of Contents

METAIS, D. RAVIER, J. and DUONG, P. K. 1962. Nature et composition chimique des micas de deux lamoprophyres. *Bull Soc. Fr. Miner. Cristallogr.,* **85**, 321-328.

MODRESKI, P. J. and BOETTCHER, A. L. 1972. The stability of Phlogopite + Enstatite at high pressures: a model for micas in the interior of the Earth. *Am. J. Sci.,* **272**, 852-869.

_____ 1973. Phase relationships of Plilogopite in the System K_2O-MgO-CaO-Al_2O_3-SiO_2-H_2O to 35 Kilobars: a better model for micas in the interior of the Earth. *Am. J. Sci.,* **273**, 385-414.

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

MILLER, J. A. SHIBATA, K. and MUNRO, M. 1962. The Potassium-Argon Age of the Lava of Killerton Park. Near Exeter. *Grophys. J. R. Astr. Soc.,* **6**, 394-39G.

PRINZ, M. 1968. Geochemistry of Basaltic Rocks: Trace Elements. *Basalts: The Poldervaart Treatise on Rocks of Basaltic Composition* (eds. Hess, H. H. and Poldervaàrt. A.), **1**, 271-323, New York: Interscience.

SMITH, H. G. 1933. Some Lamprophyres of the Channel Islands. *Proc. Geol. Ass.*, 44,121-130.

_____ 1936a. New Lamprophyres and Monchiquites from Jersey. *Q. Jl. geol. Soc. Lond.,* **42,** 365-383.

_____1936b: The South Hill Lamprophyre, Jersey. *Geol. Mag.,* 73,87-91.

_____1939. New Lamprophyres at Grève de Lecq. Jersey. *Geol. Mag.,* **76**, 165-170.

VELDE, D. 1969a. Les micas des lamprophyres: kersantites, minettes et lamproites. *Bull. Soc. Fr. Miner. Cristallogr.,* **92,** 203-223.

_____ 1969b. Les lamprophyres à felspath alcalin et biotite: minettes et roches voisines. *Contr. Miner. Petrol.,* **30**, 216-239.

WIMMENAUER, W. and HAHN-WEINHEIMER, P. 1966. Geochemische und petrographische Kriterien für die Herkunft von Kersantiten und Minetten. *N. Jb. Miner. Mh.,* 7, 201-220.

Dept. Of Geology
The University
Keele
Staffs.

Table of Contents

TIIE DISTRIBUTION OF ZINC AND COPPER IN THE GRANITES OF S.W. ENGLAND AND ITS RELATIONSHIP TO THE GEOCHEMISTRY OF THE HALOGENS

by R. Fuge

Abstract. 54 samples of S.W. England granitic rocks, comprising unaltered (31), kaolinised (13), reddened (4), and greisens (2), have been analysed for Cu, Zn, F and Cl. While the unaltered granites are rich in Cl and F, mean values for Cu, 9.7 ppm, and Zn, 39 ppm, are lower than those of average granites. In kaolinised granites Zn and Cl are depleted while Cu is enriched. There is a strong positive correlation between Zn and F, and Zn is markedly enriched in greisens.

Previous work has shown that the granites of S.W. England are richer in chlorine and fluorine than are average granites. Fuge and Power (1969) found that the mean values for samples of granite front the area were 507 ppm chlorine and 1,395 ppm fluorine; the world averages are approximately 200 ppm chlorine (Fuge, 1974) and 800 ppm fluorine (Koritnig, 1972).

Several workers have suggested that chlorine is important in the transport of metals in ore-forming fluids, and Helgeson (1964) suggested that many metals may be transported as chloride compiexes. It has been demonstrated experimentally by Kilinc and Burnham (1972) that chlorine in silicate melts is partitioned towards the aqueous phase, while Holland (1972) has shown that zinc and other metals are partitioned in a similar manner.

It is possible also that fluorine may act as an agent in the transport of some metals in hydrothermal solution (Koritnig, 1972).

In view of the potential, role of the halogens in ore transport, and the association of the S.W. England granites with mineralisation, it appeared worthwhile to study the distribution of some metals in these rocks. Zinc and copper were chosen for analysis, the determinations being performed by atomic absorption spectophotometry following hydrofluoric/perchloric acid attack of the samples.

Fuge and Power (1969) found that the distribution of fluorine and chlorine in the granites is markedly affected by hydrothermal alteration. Following kaolinisation or reddening of the granitic rock the chlorine contents are greatly depleted, as much as 60% of the

Table of Contents

TABLE 1. Copper, zinc, chlorine and fluorine in granitic rocks in S.W. England

Rock Type	Number of Samples	Copper (ppm)		Zinc (ppm)		Chlorine (ppm)		Fluorine (ppm)	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
Granites	31	2-25	9.7	12.5-62	39	76-1168	441	368- 5102	1835
Kaolinised granites	13	2-50	15.0	17.5-42	29	93- 413	205	800- 4147	1753
Reddened granites	4	4-25	9.4	10-70	37.5	202- 291	249	623- 2099	1267
Greisenized granites	4	6-18	12.5	25-63	45	89- 148	118.5	655- 4089	2507
Greisens	2	12.5-12.5	12.5	110-183	146.5	12- 15	13.5	10400-23100	16750

original chlorine being lost, while the fluorine values are only 5 to 10% lower than in the unaltered rocks. In the greisens, however, the chlorine contents are generally less than 20 ppm, while fluorine values in excess of 1% are recorded. In order to ascertain the effect of these alteration processes on the distribution of copper and zinc. samples of kaolinised, reddened and greisenized graniles were also analyzed.

The results are listed in Table 1. From the mean values for the unaltered granites it appears that the copper and zinc contents are slightly lower than those of average granites. (The world average for copper in low calcium granites was listed as 10 ppm by Turekian and Wedepohl (1961) while the zinc value for granites was estimated to he 48 ppm by Wedepohl (1972).) The values obtained for the altered rock types appear to indicate that during kaolinisation the copper content increases while the zinc content decreases. However, the mean values for the reddened granites are similar to those of the unaltered granites, bearing in mind that only four reddened granites have been analysed.

The behaviour of zinc and copper during hydrothermal alteration of granites has been studied by several workers. Zlobin and Pevtsova (1964) and Gavrilin *et al* (1967) claim that generally, during the reddening of granites, little or no zinc is lost, but that in strongly propylilized rocks there is a strong depletion of zinc. Parry and Nackowsky (1963) found that the biotites of hydrothermally altered stocks contained much more copper but much less zinc than nnaltered stocks in the same area.

The increase of copper in kaolinised granites does not correlate with the behaviour of the halogens. However, the depletion of zinc in the kaolinised rocks is similar to that of the halogens, particularly chlorine. In this latter context, it may be of significance that Dangerfield and Hawkes (1969) have suggested that some of the mineralisation of S.W. England may be due to the action of circulating thermal waters which could also be the agency for kaolinisation of the granites. It is tempting to speculate whether zinc and possibly other metals may have been leached front the granites along with chlorine, and subsequently re-deposited in veins, etc. Dangerfield and Hawkes have also suggested that copper may be derived, by circulating thermal waters from the greenstones of the

Table of Contents

area. This could explain the influx of copper into the kaolinised granites.

The most striking feature of the data summarized in Table 1 is the large increase of zinc in greisens. Only two greisens have been analysed, but each of these samples contains over 100 ppm zinc. The greisenized granites are also higher in zinc than are the unaltered granites. The distribution of zinc in these rocks parallels that of fluorine which is greatly enriched in the greisens.

Simple linear product-moment correlations were computed for all the variable pairs of elements in the study. At the 95% confidence level only one pair, fluorine and zinc, was significantly correlated, the correlation coefficient being 0.77. (N.B. The correlations were computed using untransformed data. However, the distributions of zinc and fluorine values are both very peaked and are skewed towards higher values.) No correlation between these two elements has, to the author's knowledge, been previously noted.

It is difficult to give a satisfactory explanation in terms of mineralogy, of the variation in the four elements studied. Both of the halogens are likely to occur in the hydroxy minerals, while a variable amount of the chlorine probably occurs in fluid inclusions. It is probable that the large decrease of chlorine in kaolinised rocks is due partly to the leaching out of soluble chlorine and partly due to the alteration of biotite (Stollery *et al.*, 1971, found that the chlorine content of biotites was lowered by chloritisation). The drop in fluorine content is also probably due to the alteration of biotite. The zinc and copper content of the granites is likely to be confined to the biolite. Alteration of biotite during kaolinisation is, therefore, a likely possibility for the reduction of the zinc content. However, the parallel increase in the copper content of kaolinised granites is less easily explained, it is possibly taken up by the secondary micas and/or the clay minerals formed.

The increase of fluorine during greisenization is linked probably with the formation of fluorite and white micas. The zinc content of greisens may possibly be housed in the micas, but in the author's opinion probably occurs in ore minerals.

Table of Contents

ACKNOWLEDGEMENTS. The author wishes to thank Drs. B. Booth, J. Hawkes (with the permission of the Director of the Institute of Geological Sciences) and G. M. Power for providing several of the samples analysed in this study. Thanks are also due to Mr. H. Edwards for his help with the laboratory work.

DANGERFIELD, J. and HAWKES, J. R. 1969. Unroofing of the Dartmoor granite and possible consequences with regard to mineralization. *Proc. Ussher Soc.*, **2,** 122-31.

FUGE, R. 1974. Chlorine (17) B-O. *In:* Wedepohl, K. H. (Ed.) *Handbook of Geochemistry* **II/4.** Springer-Verlag; Berlin.

FUGE, R. and POWER, G. M. 1969. Chlorine and fluorine in granitic rocks from S. W. England. *Geochim. Cosmochim. Acta.*, **33**, 888-93.

GAVRILIN, R.D., PEVTSOVA, L. A. and KLASSOVA, N. S. 1967. Behavior of lead and zinc in the hydrothermal alteration of intrusive rocks. *Geochem. International*.790-9.

HELGESON, H. C. 1964. *Complexing and Hydrothermal Ore Deposition*. Pergamon Press, London.

HOLLAND, H. D. 1972. Granites, solutions, and base metal deposits. *Econ. Geol.*, **67**, 281-301.

KILINC, I, A. and BURNHAM, C. W. 1972. Partitioning of chloride between a silicate melt and co-existing aqueous phase from 2 to 8 kilobars. *Econ. Geol.,* **67**, 231 35.

KORITNIG, S. 1972. Fluorine (9) B-O. *In:* Wedepohl, K. H. (Ed.) *Handbook of Geochemistry.* **II/3**. Springer-Verlag; Berlin.

PARRY, W. T. and NACKOWSKI, M. P. 1963. Copper, lead and zinc in biotites from basin and range quartz monzonites. *Econ. Geol.*, **58,** 1126-44.

STOLLERY, G., BORCSIK, M. and HOLLAND, H. D. 1971. Chlorine in intrusives: a possible prospecting tool. *Econ. Geol.*, **66,** 361-67.

TUREKIAN, K. K. and WEDEPOHL, K. H. 1961. Distribution of the elements in some major units of the Earth's crust. *Bull. Geol. Soc. Am.,* **72**, 175-91.

WEDEPOHL, K.. H. (Ed.). *Handbook of Geochemistry*, **II/3.** Springer-Verlag; Berlin.

ZLOBIN, B. I. and PEVTSOVA, L. A. 1964. Behavior of lead and zinc in some processes of hydrothermal alteration of granitoids. *Geochem. International* 413-20.

Dept. of Geology
University College of Wales
Aberystwyth.

Table of Contents

BIBLIOGRAPHY OF ROCK ANALYSES FROM THE GREENSTONE BELT OF S.W. ENGLAND. PART 1: MAJOR ELEMENTS.

by P. A. Floyd

Abstract. A compilation of rock analyses from the greenstone belt of S.W. England has been nnade and is available to research workers on request. A list of references from which the data have been extracted is given at the end of this paper. It is hoped that new analyses will be deposited in the "greenstone bank" so that the list can be continuously up-dated. A table of average greenstone analyses in the regional and contact metamorphic environments is presented.

1. Introduction

As a result of the development of rapid automatic methods of silicate analysis, the volume of geochemical data has increased enormously in the last five years or so. The data required for comparative geochemical studies may be scattered throughout numerous journals and unpublished research papers and is often very time-consuming to extract. Some publications contain only averages for the different rock types analysed, as the raw data take up too much costly journal space. Bearing these points in mind and the plan for a geochemical data bank to be organised by the I.G.S. it is considered that a compilation of analyses of greenstones from S.W. England would prove useful to workers in this region and elsewhere.

As the number of analyses is still relatively small it would seem an appropriate time to start such a project; it could be added to each year with the collaboration of Ussher Society members and others who are interested in greenstone belts.

2. Input and output of data

Research workers who analyse rocks from the S.W. England greenstone belt could deposit their results in the "greenstone bank" together with details of sample number, rock name, locality and any relevant publication (journal reference). Researchers wishing to use the bank would receive a printed list: of all the current data, although they would be required to check with the original depositor if wanting to use unpublished material.

Table of Contents

New data and requests for a print-out should be sent to Dr. P. A. Floyd. Department of Geology, University of Keele, Keele, Staffordshire, England. ST5 5BG.

At the present time a compilation of major elements (list A) only is available, although it is hoped to produce a similar list for trace elements (list B). It will be possible to cross- reference list B with list A

3. Type of geochemical data in the greenstone bank

The bank will hold any analyses of rocks from the greenstone belt of S.W. England. This includes both intrusive and extrusive greenstones in the regional and contact metamorphic environments, as well as keratophyres and pyroclastics. The bank does not include data obtained from post-orogenic rocks such as the Permian Exeter volcanic series of basaltic lavas and lamprophyrvids, nor rocks from the Lizard complex.

At the present time there are 219 analyses listed and they include the following main groups (with number of analyses):

Regional metamorphic environment

1. Intrusives - dolerites, diabases, spilites, proterobases (86)
2. Extrusives- basic and acid lavas, pillow lavas (15)
3. Ultrabasics - picrites (l 3)
4. All pyroclastics (4)

Contact metamorphic environment

1. Basic hornfelses (45)
2. Intermediate hornfelses (25)
3. Metasomatic hornfelses (31)

These analyses have been compiled from the literature as well as from unpublished material donated by Drs. Chesher, Cosgrove and Floyd. A list of references from which the analyses have been extracted is given at the end of this paper and must be used in conjunction with the analytical data print-out.

Table of Contents

Table 1 shows a number of greenstone averages obtained from the present list of analyses in the greenstone bank. The large Standard Deviation displayed by most of the major elements in the regional greenstones reflects varying degrees of (a) alteration under low-grade conditions (spilitizalion) and (b) magniatic differentiation. Some of the variation is probably also due to different analytical techniques and the experimental errors involved, although this is difficult to evaluate when the data have come from numerous sources.

TABLE 1. Average chemical analyses of basic intrusive greenstones in the regional and contact metamorphic environments, S.W. England.

	1		2		3		4	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
SiO_2	46.67	3.93	45.43	1.43	48.03	2.28	43.27	3.75
TiO_2	2.38	0.70	1.07	0.47	2.60	0.98	2.40	0.90
Al_2O_3	16.72	1.93	16.69	1.84	14.13	2.20	15.22	2.57
Fe_2O_3	2.00	1.34	2.38	0.80	1.10	0.56	2.30	1.69
FeO	10.03	2.55	7.32	2.02	10.63	1.41	10.15	2.46
MnO	0.25	0.21	0.19	0.04	0.20	0.09	0.26	0.16
MgO	5.71	2.84	9.98	1.85	8.37	3.02	8.98	2.08
CaO	7.83	2.87	9.28	3.14	7.93	1.94	12.01	4.10
Na_2O	3.66	1.12	2.81	1.26	2.67	1.43	1.95	0.99
K_2O	1.46	1.08	0.43	0.8	1.96	0.68	2.08	1.63
P_2O_5	0.91	0.76	0.08	0.03	0.38	0.17	0.57	0.31
H_2O^+	2.25	1.61	3.39	0.94	2.00	0.76	1.62	0.83

$\bar{x}$ = mean, s = standard deviation

1. Alkali basalt greenstones (65 samples, except TiO_2, MnO - 50; Fe oxides - 41; P_2O_5- 38; H_2O^+ - 26).

2. Tholeiitic greenstones (21 samples).

3. Actinolite-bearing basic hornfelses (8 samples).

4. Hornblende-bearing basic hornfelses (26 samples).

Table of Contents

4. **Conclusion**

It is possible that some data sources have been missed in the initial literature survey; the writer would be grateful if omissions could be brought to his attention.

It is hoped that research workers will make available all their analytical data on rocks from the greenstone belt of S.W. England so that the data can be deposited in the bank.

Greenstone bank reference list

AGRELL, S. O. 1939. Adinoles of Dinas Head. Cornwall. *Mineralog.Mag.* **25**, 305--337.

BOOTH, B. 1966. Petrogenesis of the Land's End granites. *Ph.D. Thesis, University of Keele.*

COLLINS, J. H., 1876. Note on the serpentine of Duporth in St. Austell Bay. Cornwall. *Mineralog. Mag.,* **1**, 222-225.

FLOYD, P. A. 1965. Argillization of basic hornfelses from the Land's End granite aureole, Cornwall. *Clay Minerals,* **6**, 45-58.

_____ 1965. Metasomatic hornfelses of the Land's End aureole at Tater-du, Cornwall. *Petrology,* **6,** 223-245.

HOWELLS, M. F. 1958. The petrology and structure of an area south of the Bodmin Moor granite. *Ph.D. Thesis. University of Nottingham.*

PARKER, A. 1970. Chemical and mineralogical analyses of some basic and ultrabasic rocks and their initial weathering products. *Reading University Geological Rep.* **4,** 1-44.

PHILLIPS, J. A. 1871. On the chemical composition and microscopic constitution of certain Cornish rocks. *Phil. Mag.,* **41,** 87-107.

_____ 1875. The rocks of the mining district of Cornwall and their relation to metalliferous deposits. *Q. Jl. Geol. Soc. Lond.,* **31,** 319-345.

_____ 1876. On the so-called greenstones of west Cornwall. *Q. JI Geol Soc. Lond.,* **32**, 155-179.

_____ 1878. On the so-called greenstones of central and east Cornwall. *Q. Jl Geol. Soc. Lond.,* **34**, 471-497.

Table of Contents

REID, C. 1905. Report of chemical analysis section. *Summ. Prog. Geol. Surv. Gt Br.* **55**.

_____ 1907 Geology of the country around Mevagissce. *Mem. Geol. Surv. Gt Br.*

_____ **and FLETT, J. S.** 1907, The geology of the Land's End District *Mem. Geol. Surv. Gt Br.*

BARROW, G. and DEWEY, H. 1910. Geology of the country around Padstow and Camelford. *Mem. Geol .Surv. Gt Br.*

SIDDIQUI, S. F. A. 1964. The geology and mineralization of the area between Newlyn and Mousehole, Cornwall. *Ph.D. Thesis. University of London..*

SUTCLIFFE, R. 1928. Report of chemical analysis section. *Summ. Prog. Geol. Surv. Gt. Br.* **79.**

TILLEY, C. E. and FLETT, J. S. 1930. Hornfelses from Kenidjack Castle. *Summ. Prog. Geol. Surv. Gt. Br.* Part II: 24-41.

_____ 1935. Metasomatism associated with the greenstone-hornfelses of Kenidjack and Botallack, Cornwall. *Mineralog. Mag.,* **24**, 181-202.

USSHER, W. A. E. 1913. Geology of the country around Newton Abbot. *Mem. Geol. Surv. Gt Br.*

VALLANCE, T. G. 1965. On the chemistry of pillow lavas and the origin of spirites. *Mineralog. Mag.,* **34**, 471-481.

Other references that use greenstone analytical data

FLOYD, P. A. 1967. The role of hydration in the spacial distribution of metasomatic cations in the Land's End aureole, Cornwall. *Chem. Geol.* **2,** 147-1 56.

1972. Geochemistry, origin and tectonic environment of the basic and acid rocks of Curnubia, England. *Proc. Geol. Ass.*, **83**, 385-404.

1972. Geochemical characteristics of spilitic greenstones from S.W. England. *Nature. Phys. Science,* **239**, 75-77.

and LEES, G. J. 1972. Preliminary petrological and geochemical data on the Cudden Point greenstone. *Proc. Ussher Soc.*, **2**, 421-423.

1973. Ti-Zr characterisation of some Cornish pillow lavas. *Proc. Ussher Soc.*, **2**, 489-94.

FRANCIS, E. H. 1970. Review of Carboniferous volcanism in England and Wales. *Leeds University J. Earth Science,* **8**, 41-5b.

Table of Contents

ROBSON, J. 1953. The Cornish "greenstones". *Trans. Roy. Geol. Soc. Cornwall.* **18**, 489-494.

_____ 1964. The Cornish "greenstones". *Trans. Roy. Geol. Soc. Cornwall.* 150th. Ann. volume. 115-130.

Dept. of Geology
The University
Keele
Staff's.

DISTRIBUTION OF URANIUM IN THE LAND'S END GRANITE AND AUREOLE, AND VARIOUS GREENSTONES FROM CORNWALL

by I. R. Wilson and P. A. Floyd

Abstract. A preliminary study of the U content of the Land's End granites shows that they are extremely high compared with average granites. U, depleted in altered granitic wall-rocks adjacent to mineralized zones, was probably redeposited as ore in lodes and joints. Contact metamorphosed greenstones in the aureole are variably enriched in U depending on their distance from the granite. In the regional environment pillow lavas were probably enriched during submarine weathering, whereas intrusive greenstones, with very low U contents, may have been depleted during low-grade alteration (spilitization).

1. Introduction

The occurrence of uranium minerals in the Land's End area has been known for a long time (Carne 1822; Pearce 1878) and their distribution has been summarized by Dines (1930, 1956). Pitchblende (uranium oxide) is found associated with both tin and copper mineralization as lode infillings, while the secondary minerals such as torbernite (copper uraninite) and autunite (calcium uraninite) occur in joints and cross-courses along with Fe, Co, Ni and Bi minerals. Only Wheal Owles, Trenwith and Providence have a history of uranium mining (Dines 1930); these and some other localities for uranium are shown in Fig. 1. Production from these mines and others in Cornwall is not known in detail, but is unlikely to have exceeded 2000 tons (Dines 1956).

As little precise information is available in published form, this preliminary report presents some basic data on U distribution in

Table of Contents

different magmatic rocks from Cornwall. It is also hoped that this work may throw some light on the behaviour of U resulting from various types of secondary alteration. For comparative purposes the average content of U in igneous rocks is shown in Table 1.

TABLE 1. Distribution of uranium in magmatic rocks

Rock type	Uranium (ppm)	Reference
Basic	1.0	Turekian & Wedepohl (1961)
Intermediate	1.8	Vinogradov (1962)
Intermediate	3.0	Turekian & Wedepohl (1961)
Acidic	3.0	Turekian & Wedepohl (1961)
Granites	3.5	Vinogradov (1962)

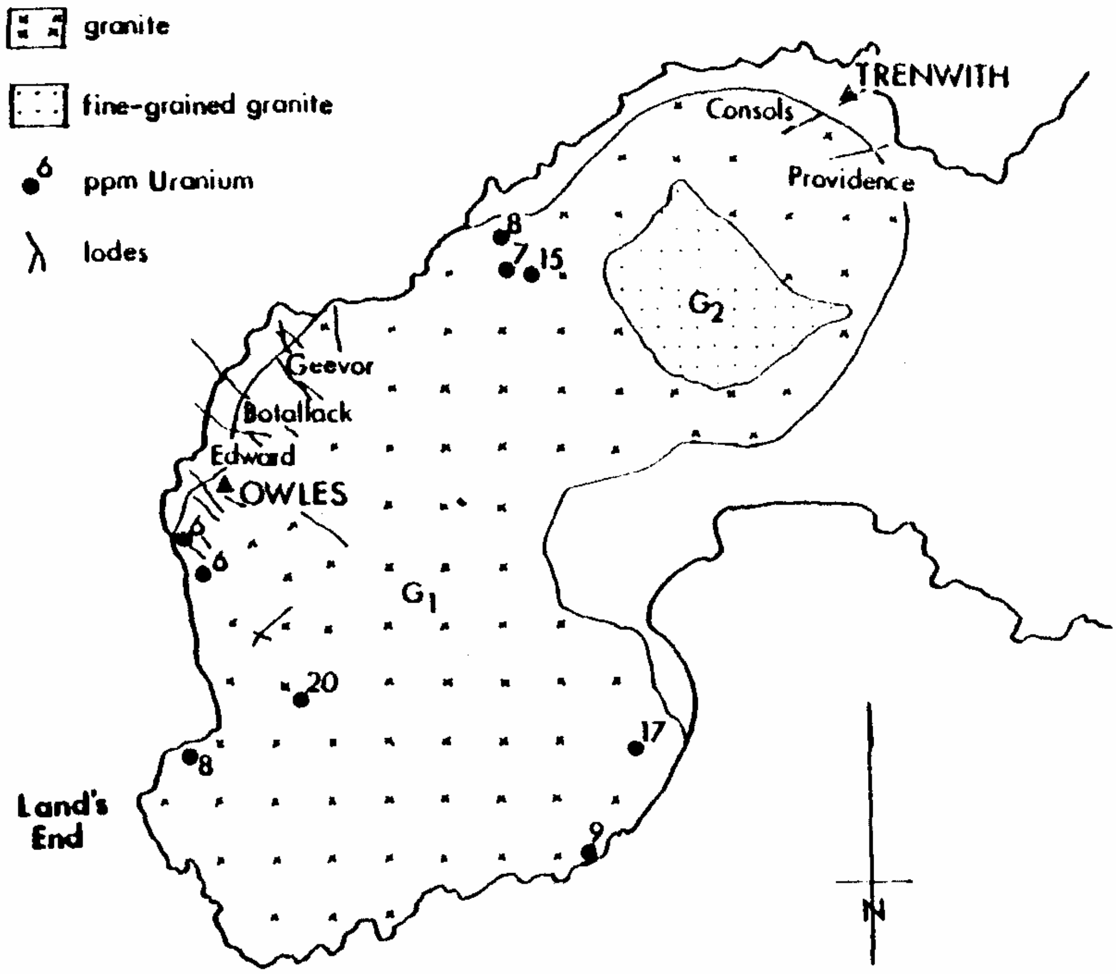


FIGURE 1 Localities of uranium-bearing mines and distribution of uranium in the Land's End granites (after T.K. Ball; personal communication).

Table of Contents

The neutron activation/delayed neutron method of analysis for uranium utilised in this study has been developed by A. W. R. E. Aldermaston in conjunction with the Institute of Geological Sciences. Precision is high (1% relative standard deviation at the 15 ppm level), and matrix effects are minimal (Ostle *et al.*. 1972).

2. **Distribution of uranium in unaltered granites**

Levels of uranium in the various granites from Land's End are presented in Table 2. Complete major and trace element analyses of the unaltered granites from Geevor are presented elsewhere (Wilson 1972). The precise location of the uranium in the granites has not as yet been studied in detail. In certain cases uranium is present as small uraninite grains and may occur along grain boundaries, or be disseminated among accessory minerals and the various major constituents. Unpublished work (Cameron 1959; Ford - personal communication) suggests that grains of uraninite may be present in inclusions and along grain boundaries and cleavage in the granite at Lamorna.

Previous work in this area of Cornwall using material from surface and quarry exposures indicated a range of uranium from 620 ppm (T.K. Ball - personal communication); these values are plotted on Fig. 1. However, it is likely that due to the high mobility of the uranyl ion $(UO_2)^-$, formed by oxidation, uraninite, or any other uranium-bearing mineral may be dissolved out relatively easily by surface weathering processes. Because values from surface exposures are difficult to interpret, most of the data presented for granites are from underground sites at Geevor mine. The two samples from the Isles of Scilly (4 and 6 ppm) are also from surface exposures and have probably been depleted.

TABLE 2. Uranium content of Land’s End (1-4) & Isles of Scilly (5,6) granites

	Granite types	U ppm
1.	Coarse-grained Boscaswell granite, 9 level (mean of 7 samples)	17.7
2.	Coarse-grained Boscaswell granite, 13 level (mean of 8 samples)	17.8
3.	Coarse-grained Geevor granite	15.8
4.	Fine-grained Boscaswell granite, 13 level	15.6
5.	Coarse-grained Isles of Scilly granite (surface exposure)	4.0
6.	Medium-grained Isles of Scilly granite (surface exposure)	6.0

Table of Contents

The coarse-grained Geevor granite and the Boscaswell coarse and fine-grained granites contain similar amounts of uranium (Table 2). These levels are from four to five times the average of 3.5 ppm for granites (Vinogradov 1962) and represent a substantial enrichment in the crust. The high uranium concentrations are also associated with high values of K, B, Li, Rb, Zr and Zn. K/U ratios in the area are between 2800 and 3700, compared with about 10^4 in all crustal materials (Heier and Rogers, 1961), though data are insufficient at present to suggest whether the ratio will be of use in determining an igneous differentiation series within the granites. Further work is being carried out to obtain results from other and different types of granite in the area, especially those marginal to the killas contact.

3. Behaviour of uranium in granitic wall-rocks

There is little available information on dispersion of uranium in wall-rocks as most of the work has been done by Russian workers (see Rogers and Adams, 1969).

In this study samples frorn levels 9E5 and 13E3 crosscuts, Simms lode, Geevor mine, were analysed for uranium and the results are shown in Fig. 2. A decrease of uranium in both wall-rock and around minor fissures is associated with zones of hematisation and tourmalinisation, 2m wide on 9 level and lm wide on 13 level. Geochemical and mineralogical variations from the two crosscuts have been outlined elsewhere (Wilson 1972) and show that Fe^{2+}, Na, Li, Mn and Sr are depleted along with U from the altered zones. Like the former elements, the depletion of uranium is confined to zones of visible mineralogical alteration.

It is too early to comment on the true significance of these results until further work is carried out, as the limited sampling along two traverse lines represents a very small proportion of the mine. Nevertheless, if the loss of uranium from wall-rock is found to be a common feature of the area then it is possible that one need look no further for the source of the uranium than the granite itself. Uranium, in uraninite, being relatively mobile, is removed from the wall-rocks by the action of thermal solutions during phases of mineralisation and if not lost from the system is redeposited as uranium minerals in lodes, cross-courses and joints.

Table of Contents

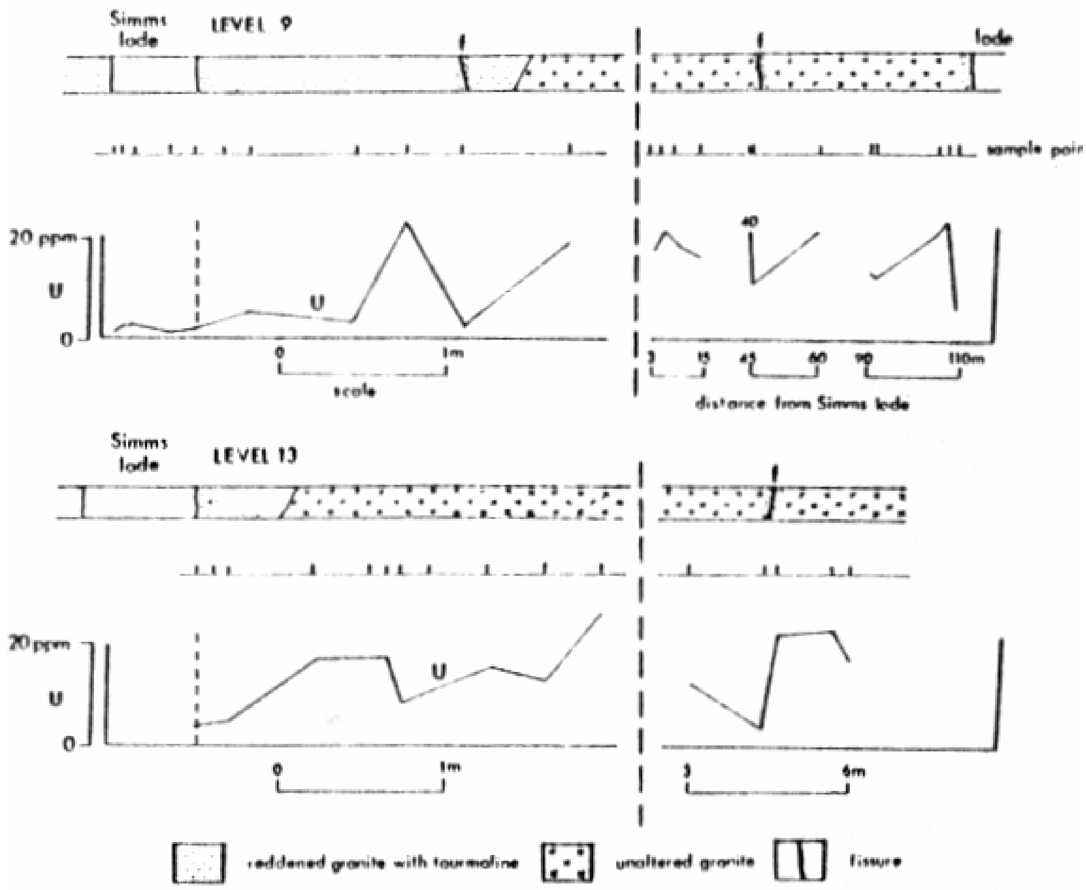


FIGURE 2. Variation of uranium in wall-rock. Simms lode. 9 level, E5 crosscut and 13 level, F3 crosscut, Geevor Mine, Land's End.

It has been demonstrated by determination of ages from the Geevor mine (Darnley *et al*, 1965), that there have been successive phases of mineralisation. Uraninite ages ($^{206}Pb/^{238}U$ age) associated with tin at Geevor are 290±7 and 223±5 m.y., while a chemical age for a late cofflnite-pitchblende infilling, associated with Fe, Cu and Bi, is 45 m.y. It was concluded that there were at least three periods of uranium mineralisation at 290. 225 and 50 m.y. in south west England. Pockley (1964), in considering four uranium-lead ages from Cornwall (including one from the Wheal Owles mine with a pitchblende-coffinite age of 38±3 m.y.) suggested that there inlay have been two periods of mineralisation at 290 and 225 m.y. with a final event at about 60 m.y. Whether this final event involved the remobilisation of older uranium with loss of lead, or the introduction of uranium, or a combination of both effects cannot be established. It is not known whether these later events are the result of rejuvenation, reworking or remobilisation by ground-water, but

Table of Contents

Sawkins (1966) has suggested that the younger ages are the result of the redistribution of radioactive material by late hot springs. K-Ar determinations of altered and unaltered granite from Geevor mine are currently being carried out and it is hoped that they might throw some light on the relative age, or ages, of metasomatism, and perhaps determine whether correlation with phases of mineralisation and U/Pb ages is possible.

On the basis of the present work the practicality of using uranium as a guide to new lodes in Geevor mine is limited, as the dispersion patterns in granitic wall-rock are very restricted and do not extend farther than the visible mineralogical alteration. What does emerge is that tin increases towards Simms lode while uranium decreases and this pattern is repeated around minor fractures though on a smaller scale.

Though the study of the distribution of uranium in wall rocks was largely confined to the granite, one short traverse was made in the vicinity of a tin-bearing sulphide lode From No. 6 level, Levant mine, which is in a contact metamorphosed hornfels (Table 3). The source of the uranium and boron is to be found in the granite and has been introduced during one of the phases of mineralisation. It is worth noting that most of the uranium localities in the area (Fig. 1) are near and adjacent to the granite-killas contact. According to Sokolova and Acheyev (1972) uranium hydrothermal mineralisation is more likely to occur in the aureoles of major granitic bodies only in areas where the intrusives are in contact with greatly altered sediments and basic volcanics. They point out that contact metamorphism is important to the localisation of hydrothermal uranium mineralisation in that its main role is extensive geochemical preparation of the country rock.

TABLE 3. Distribution of U and H in hornfelses adjacent to tin-bearing lode, Levant Mine, Land's End.

Sample position	Distance from lode (m)	U ppm	B ppm
Hanging wall	At contact	4.4	1500
Hanging wall	0.65	1.6	275
Hanging wall	0.80	2.7	135
Footwall	0.05	3.4	2600
Footwall	0.20	2.0	160

Table of Contents

4. Distribution of uranium in Hornfelses and greenstones

Two main groups of basic rocks were analysed for U: (a) intrusive and extrusive (pillow lavas) greenstones in the regional environment and (b) basic metamorphic hornfelses and metasomatic hornfelses from the contact environment of the Land's End aureole. In view of the relatively U-rich nature of the Land's End granite, the basic hornfelses might be expected to show an increase with grade within the aureole. Also, the effect on the distribution of U during Ca and Mg-Fe metasomatism could then be evaluated in different metasomatic hornfelses of similar grade.

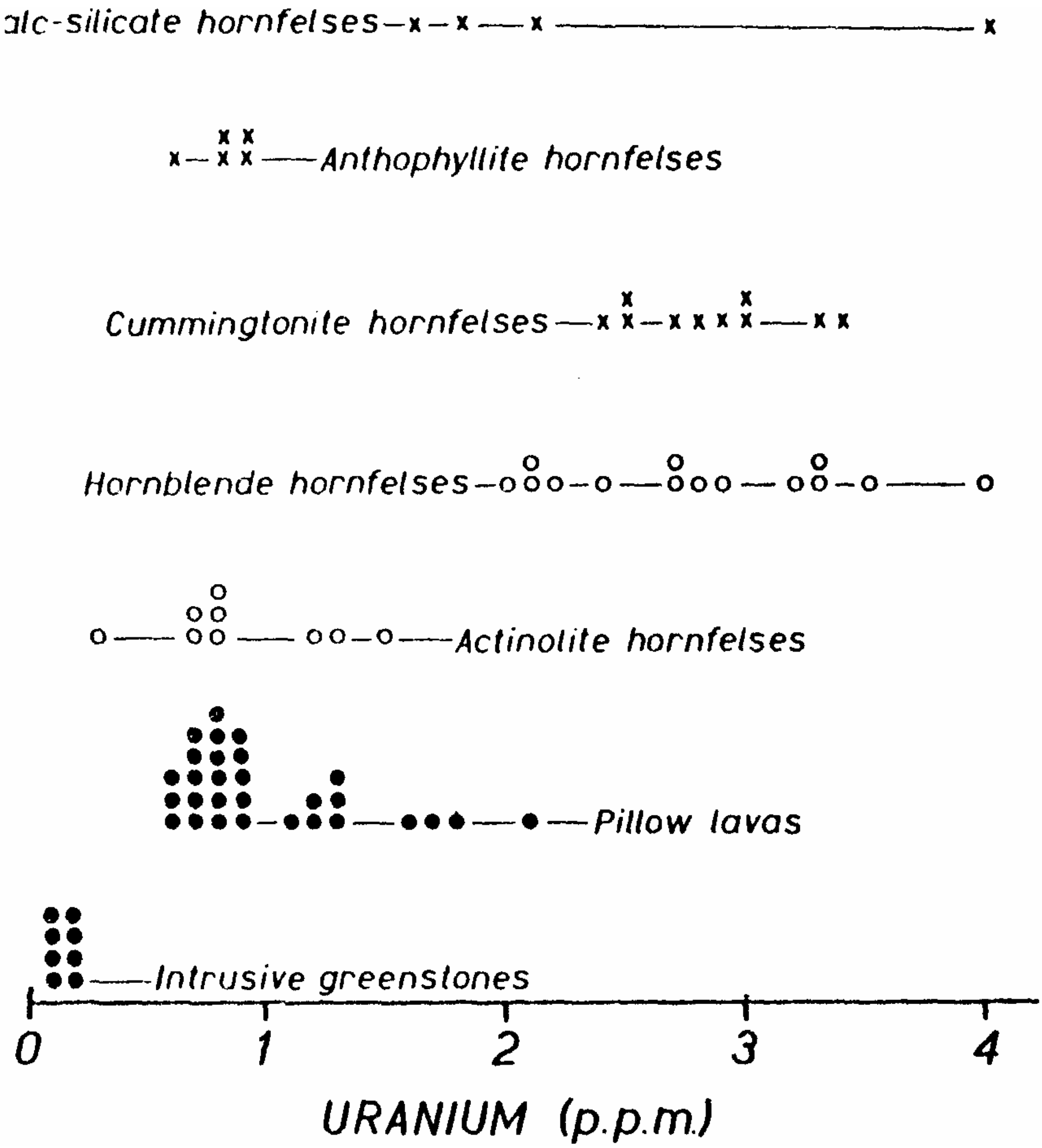


FIGURE 3. Distribution of uranium in regional greenstones (dots) from Cornwall, contact basic hornfelses (circles) and contact metasomatic hornfelses (crosses) from the Land's End aureole.

Table of Contents

The distribution of U in the different basites is shown in Fig. 3.

(a) *Contact hornfelses*

The actinolite- and hornblende-bearing basic hornfelses are the contact metamorphosed equivalents of the regional greenstones. As seen from Fig. 3 both of these hornfelsic groups have a wide range of U values, with the actinolite hornfelses overlapping that of the pillow lavas. Ou average, the higher-grade hornblende hornfelses (2.8 ppm U) have higher U contents than the lower-grade actinolite hornfelses (0.9 ppm U) and they clearly indicate the metasomatic addition of U to the aureole by the granite. One hornblende hornfels adjacent to the contact gave the highest value recorded of 11.2 pprn U (excluded from the above average and Fig. 3).

The metasomatic hornfelses were all developed in the hornblende hornfels facies and might be expected to show a similar range of U values to their parental hornblende hornfelses, unless tile U distribution was effected by the later metasomatic event. From Fig. 3 it can be seen that the cummingtonite hornfelses have a similar range and average (2.9 ppm U) U content to the hornblende hornfelses, whereas the anthophyllite hornfelses (average 0.8 ppm U) and calc-silicate hornfelses (average 2.4 ppm U) are lower. It seems unlikely that the rocks which were eventually metasomatized to the anthophyllite hornfelses would have retained an originally low U content when subjected to U metasomatism by the granite. As the adjacent hornfelses at the same grade of metamorphism as the anthophyllite hornfelses have high values, the later hornfelses must have been depleted in U during Mg-Fe metasomatism. The calc-silicate hornfelses also show a small depletion, although one sample with a high diopside content has 4 ppm. The wide range of U content in this particular group of metasomatic hornfelses may be partly mineralogically controlled and not reflect the pervading U metasomatism suffered by the hornblende and cummingtonite hornfelses of similar grade.

(b) *Regional greenstones*

The intrusive greenstones are all from Cudden Point. South

Table of Contents

Cornwall and are variably altered (spilitized) dolerites with tholeiitic affinities (Floyd and Lees. 1972). The pillow lavas were collected from Pentire Point. Kellan Head (north Cornish coast) and Mullion Island (off the Lizard) and show the development of a typical low-grade spililic assemblage. On the basis of their Ti-Zr contents they are considered to belong to an alkali basalt lineage (Floyd and Lees, 1973).

From Fig. 3 it can be seen that there is a distinct difference between the intrusive greenstones (average 0.15 ppm U) and the pillow lavas (average 1.0 ppm U). This variation could be due to either differences in the U content of the two basaltic magma types (tholeiitic versus alkali basalt) or to the effects of post-consolidation alteration. For example, data on the Hawaiian basalts (Heier et al., 1964) show that the tholeiites have 0.18 ppm U and the alkali basalts 0.99 ppm U - values that correspond to the averages for the greenstones given above. However, in view of the variably altered nature of the Cornish rocks it seems more likely that the U distribution could primarily be due to alteration processes.

Aumento (1971) has demonstrated that there is a positive correlation between Fe_2O_3/FeO ratios and H_2O contents of mid-oceanic basalts and their U values. Altered basalts with high F_2O_3/FeO and H_2O also have high U contents due to the uptake of U during deep-sea weathering. It is likely that the Cornish pillow lavas have been enriched to some degree by this process, as the rims of a number of pillows have about twice as much U as the corresponding cores. Also, the most altered pillows from Kellan Head have consistently high U contents compared with the rest.

The very low U concentrations in the tholeiitic intrusive greenstones are similar to oceanic tholeiitic basalts in general (0.10 ppm U; Tatsumoto *et al.*, 1965), but are lower than island arc tholeiites (0.30 ppm U; Jakes and White 1971). However, as the Cornish rocks have suffered variable element redistribution and loss during low-grade hydrous alteration (Floyd, in press) it seems unlikely that the U concentrations observed are primary. Aumento and Hyndman (1971) have shown that secondary calc-silicate and chlorite patches in the groundmass of mafic and ultramafic rocks have very low U (0.03 ppm U) values and probably reflect the removal of this element by "metasomatizing fluids". If, as seems

Table of Contents

likely, the tholeiitic greenstones were invaded by hydrothermal solutions during regional metamorphism, then U has been removed during the random development of secondary hydrous assemblages.

(c) Conclusions

None of the regional greenstones or contact hornfelses has retained its original U contents. In the regional environment the pillow lavas were enriched due to submarine weathering and the intrusives were depleted during low-grade hydrous metamorphism (spilitization). In the contact environment the hornfelses were enriched depending ou their grade or distance from the granite contact. During contact metasomatism the anthophyllile hornfelses were depleted relative to hornfelses of similar grade.

ACKNOWLEDGEMENTS. I.R.W. wishes to thank the Direclur of the Institute of Geological Sciences for permission to publish this paper, and P.A.F. is grateful to the University of Keele Research Fund for financial assistance during field work.

AUMENTO, F. 1971. Uranium content of mid-oceanic basalts. *Earth Planet. Sci. Letters,* **11**, 90-94.

AUMENTO, F. and HYNDMAN, R. D. 1971. Uranium content of the oceanic upper mantle. *Earth Planet. Sci. Letters.* **12**, 373-384.

CARNE, J. 1822. On the mineral productions and the geology of the Parish of St. Just. *Trans. Roy. Geol Soc. Cornwall* **2**, 290-358.

CAMERON, E. 1959. Zircons of the Canimenellis granite. *Ph.D. Thesis.University of Bristol.*

DARNLEY, A. G. ENGLISH, T. H., SPRAKE, O., PREECE, E. R. and AVERY, D. 1965. Ages of uraninite and coffinite from south-west England. *Mineralog. Mag.,* **34**, 159-176.

DINES, H. G. 1930. Uranium in Cornwall. *Mining Mag.,* **42**, 213-216.

_____ 1956. The metalliferous mining regions of south-west England. *Mem. Geol. Surv. Gt Br.*

FLOYD, P. A. and LEES, G. J. 1972. Preliminary petrological and geochemical data on the Cudden Point greenstone, Cornwall. *Proc. UssherSoc.,* **2**, 421-423.

Table of Contents

_____ 1973. Ti-Zr characterization of some Cornish pillow lavas. *Proc Ussher Soc.*, **2**, 489-494.

HEIER, K. S., McDOUGAL, I. and ADAMS, J. A. S. 1964. Th, U and K concentrations in Hawaiian lavas. *Nature*, **201**, 254.

JAKES, P. and WHITE, A. J. R. 1971. Composition of island arcs and continental growth. *Earth Planet. Sci. Letters.* **12**, 224-230.

OSTLE, D., COLEMAN, R. F. and BALL, T. K. 1972, Neutron activation analysis as an aid to geochemical prospecting for uranium. In: *Uranium Prospecting Handbook,* I.M.M., London. 95-109.

PEARCE, R. 1878. Notes on pitchblende in Cornwall. *Trans. R. Geol. Soc. Cornwall.*, **9**, 10.1-4,

POCKLEY, R. F. C. 1964. Four new uranium - lead ages from Cornwall. *Mineralog. Mag.,* **33**, 1081-1092.

ROGERS, J. J. W. and ADAMS, J. A. S. 1969. Uranium. In: *Handbook of Geochemistry* (Ed. K. H. Wedepohl), Springer-Verlag, Berlin.

SAWKINS, F. J. 1966. Preliminary fluid inclusion studies of mineralization associated with the Hercynian granites of south-west England. *Trans. Inst. Min. Metall.,* **75**, B109-B112.

SOKOLOVA, N. T. and ACHEYEV, R. N. 1972. Causes of localization of uranium mineralization in contact metamorphic aureoles and granitoids. *Geochem. Internat.,* **9**, 1067-1079.

TATSUMOTO, M., HEDGE, C. E. and ENGEL, A. E. J. 1965. K, Rb, Sr, Th, U and the ratio of Sr^{87} to Sr^{86} in oceanic tholeiitic basalt. *Science.* **150**, 886-888.

TURKENIAN, K. K. and WEDEPOHL, K. H 1961. Distribution of the elements in some major units of the earth's crust, *Bull. Geol. Soc. Am.,* **72**, 175-192.

VINOGRADOV, A. P. 1962. Average contents of chemical elements in the principal types of igneous rocks of the carth's crust. *Geochemistry.* **7**, 641-664.

WILSON, I. R. 1972. Wall-rock alteration at Geevor tin mine. *Proc. Ussher Soc.,* **2**, 425-434.

I.R.W.
Institute of Geological Sciences
Gtay's Inn Pond
London

P.A.F.
Dept. of Geology
The University
Keele
Staffs

Table of Contents

Mineral deposits from the Okehampton, Mendip and Exmoor areas (Abstract):

by R. F. Youell

Okehampton Area. The mines here were abandoned in the general depression of the 1880's, and have received relatively little attention compared with Cornish copper mines. The mineral deposits were disposed around the northern periphery of the Dartmoor granite and about half a mile from it. Copper pyrites, bornite, malachite and other minerals have been identified by X-ray and chemical methods, though owing to the rough conditions of the visible workings it is unreliable to estimate the richness of the deposits without relying on the mining records of 1880.

Mendip Area. In the past, copper minerals were not commonly found in the Mendips. However, samples have been obtained and copper content confirmed from four sites on the south western part of the Mendips. A copper occurrence not hitherto reported has been noted at Moon Hill roadstone quarry, where copper pyrites and malachite have been detected in fissures and in association with stone extracted for road metal.

Exmoor Area. Substantial quantities of almost pure haematite have been identified in two parallel east-west-trending outcrops at Beggearn Huish and Torr, with confirmatory lodes in the railway cuttings at the latter place. Similar deposits have been identified at Stream and near Watchet; all of them are in Triassic deposits but very near the boundary with the Devonian. None of these has been reported before even though the ore is of better quality than the Brendon Hill Devonian ironstones. The ironstone appears to be of the same type and age as that at Luccombe and Wooton Courtney, both of which have received scant attention in the past. There are indications of haematite exposures at Alcombe near Minehead forming deposits in Triassic rocks parallel to and a few miles north of the Brendon Hill-Simonsbath ironstones. According to Groves (1952) there were less than a dozen chemical analyses available from the Brendon Hill mineral series. In view of this, a detailed examination has been carried out. Large white crystals from Gupworthy mine are virtually pure iron manganese carbonates

Table of Contents

occurring as isomorphous siderite/rhodocrosite and weathering to Haematite as a dark brown outer shell retaining the crystal appearance of the siderite.

Dept. of Physics
The University
Leeds

NEW EVIDENCE ON MINERAL DEPOSITS FROM CENTRAL EXMOOR

by R. F. Youell

Historical

Some of the mining activity on Extmoor, such as that at Combe Martin, is of considerable antiquity. Sir Coppleston Bamfylde's copper mines at Heasley Mill were well established by 1700. In contrast, the Brendon Hill and Eisen Hill workings of the Ebbw Vale Iron Company, and the Simonsbath workings of the Dowlais, Ulverston and Plymouth Companies date from the middle part of the 19th Century. Geographical isolation, the cause of transport and access difficulties, restricted the exploitation of the lodes; by 1882 mining interests had collapsed in spite of the good quality of the iron ores.

The ironstone workings of Exmoor have not been well documented, for in many cases abandonment plans were not deposited, or have been lost or destroyed. However, the author can record the recent discovery of valuable evidence; a tithe map of Staddon Hill suggests the existence of deposits in the area between Eisen Hill and the Exford Mines. Furthermore, a map in the Somerset County archives indicates all the known mineral lodes of the 1855 era as well as the exact route of the mineral railway from Porlock to the Simonsbath Mines. The latter had eluded Orwin (1929) in his authoritative history of Exmoor. Bad cartography on such old maps and plans that are available can lead to considerable confusion, particularly with regard to deviations from the fixed cardinal points of the compass.

Table of Contents

The deposits

A great number of the workings fall into groups along lines running from about l5°-20° north of west to south of east. Such a pattern is followed by the Brendon Hill - Eisen Hill mines which worked three parallel fissure systems. Parallel to and proceeding south from this line are the Exford workings, then the mines between Blackland and Wheal Eliza and, most southerly of all, the Cornham Ford - Deer Park - Horsen system. Lleweflin (1855) regarded the trend of the deposits as being almost due east-west; this led to some confusion as it was inferred that mines such as Cornham Ford and Wheal Eliza are part of the same fissure system, when this is not the case.

Throughout Exmoor the ores tend to consist of siderite at depth, with an upper weathered zone of haematite. Manganese and copper minerals are impurities in some deposits.

The Woolcombe Farm area

Cantrell and others (1919), apparently misled by the names Great and Little Woolcombe, referred to the Woolcombe lode as occurring probably near Woolcombe Farm. The farm is about 2 miles south of the Great Woolcombe Lode as it appears at the surface and 2½ miles south of the Little Woolcombe Lode. This error, of itself, would not be serious were it not for the fact that there is evidence at Woolcombe Farm of mineral workings having no relation to either of the Woolcombe lodes.

Three open workings in the vicinity of Woolcombe Farm, each between 10 and 20 feet wide and trending E15°-20°S, have been examined by the author. Two of the trenches are in line with each other on opposite sides of the Withypool Cross -Exford road at SS 806 354 and SS 808 353, while the third is parallel to them, near the farm, at SS 808 349. These workings can be demonstrated to be unconnected with the ‘Great Woolcombe Lode’ of Groves (1952) and the ‘Little Woolcombe Lode’ of Llewellin (1855), both of which are sited well to the north of the area under consideration.

Examination of the material excavated from the trenches showed it to consist of shale and sandstone, in places bearing thin veins of specular haematite. Samples of specular haematite and small amounts of chalcopyrite, bornite, malachite and thuringite

Table of Contents

were confirmed by X-ray and chemical analyses. Malachite occurs mostly as surface films on shale, suggesting that it may be a weathering product. Specular haematite, white quartz and chalcopyrite were also found in small amounts on the exposed rock in the Sherdon Water near Sherdon Bridge and Dillicombe.

The exposure in the Woolcombe Farm trenches was too poor to allow any structural assessment of the deposit. Mineralogically, the assemblage would appear to be similar in nature to the Heasley Mill ores rather than those of the Barle Valley.

ACKNOWLEDGEMENTS. The author acknowledges the help and courtesy of Sir Bernard Waley Cohen, the North Motion and Molland Estates and other landowners for giving permission to do research work on their land; he thanks Mr. P. Claughton and Mr. R. Sellick for placing their local knowledge at his disposal, also the Somerset and Devon County Archivists and the Institute of Geological Sciences for their assistance.

CANTRELL, T. C. and others. 1919. Iron ores of Somerset, Devon and Cornwall. *Mem. Geol. Surv.*

GROVES, A. W. 1952. Wartime investigations into the haematite and manganese resources *of* Great Britain and Northern Ireland. *Min. of Supply Monograph.*

LLEWELLIN, W. 1855. *Report on the Exmoor Mineral Property, addressed to Frederic Winn Knight, M.P.* J. E. Taylor. London.

ORWIN, C. S. 1929. *Reclamation of E.xmoor Forest.* Oxford University Press.

Dept of Physics
The University
Leeds

New evidence on the mineral workings of Exmoor (Abstract):

by F. J. Rottenbury and R. F. Youell.

Gaps exist in the published records of Exmoor mineral deposits for the area between the Eisen Hill mines and the Exford workings. Although the deposits here are believed to be of Permo-Triassic age as a fissure filling in the Devonian, the ore deposits do largely follow directions parallel to the strike, so that the idea of "lodes" used by 19th Century writers, though technically wrong, does provide a reasonable basis for classifying the workings.

Table of Contents

New evidence has come to light in the form of notes by a geologist, whose name cannot be deciphered, on a tithe map of about 1850. He divides the ore workings and exposures into the Rayleighs Cross, Cutcombe Barrows, Gupworthy, Red Deer and Copper Mines groups. Only the Gupworthy group extends over the whole area. Two important occurrences of ore at Great Staddon and Ashcombe mentioned on this plan have been confirmed, and another ironstone working east of Exford does fit into this idea.

Several errors have been found in published memoirs; most of these attribute a mineral working or exposure to the wrong farm or estate. The most serious error refers to the Woolcombe Lode, which was one of the Simonsbath Deer Park group of ironstones, as being "near Woolcombe Farm". The evidence suggestes that the workings near Woolcombe Farm are not connected with the Deer Park ironstones but closely related to the Heasley Mill, North Molton deposits. Details of this will be given in a separate paper.

Evidence has come to light that mineral working on Brendon Hills took place at a time well before the published dates suggest and that a mineral railway to serve these mines was planned as early as 1845.

A number of gaps in the mining evidence near Simonsbath have been found in Orwin's work; it is clear that the mineral railway from the mines to Porlock was planned as early as 1826, and that the Pinkworthy pond and canal were built for working the inclines hydraulically.

Dept. of Physics
The University
Leeds

Table of Contents

PENDARVES MINE: SOME COMMENTS ON TIIE MAIN CROSSCOURSE, THE TRYPHENA LODE AT THE GRANITE/KILLAS CONTACT AND LODE/ELVAN RELATIONSHIPS

by J. R. Hamilton

Abstract. Development of the Pendarves Mine from June until December 1973 indicates that in the vicinity of the main crosscourse on No. 3 level some shale occurs on its eastern upthrow side as an assimilation within the Harriet lode fracture. The vertical displacement on the fault now appears to he at least 40 metres. Within the present mine confines Tryphena lode is impoverished upon passing upuard from granite to shale, except in some instances where the transition is accompanied by a lode-elvan dyke association. Lode-elvan intersections weaken lodes where the dykes are not brecciated. Intersections accompanied by brecciation of the elvan can provide enhanced tin values within both lode and elvan.

In Pendarves Mine, a normal fault on 3 level north separates granite from shale. This is the main crosscourse, west of which the country rocks appear to be downthrown in comparison with their counterparts lying to the east. The crosscourse strikes on average N.05º.W and dips east at 85°. Subsurface contouring of the buried granite ridge on either side of the fault suggests the west downthrow to be at least 40 metres. This however is no more than a general figure based on data derived from widely spaced surface diamond drilling.

Recent development of the northern crosscut on 3 level together with on-lode development of certain branches of the Harriet Lode in the vicinity of the fault have failed to indicate the true relationship between ground lying east and west of the crosscourse. Observation of one of the Harriet branches at it approaches the fault from the east is, however, worth recording. Lying between granite walls, the lode has been driven on for 35 metres from the crosscut towards the crosscourse, and at present the face is about 5 metres distant from an intersection. The lode dip has been fairly consistently south at 67°. At 32 metres from commencement of the drive at the crosscut, metamorphosed shale was seen in the face in the form of a V, with

Table of Contents

the lode occupying a position under its northern side, thus maintaining a southerly dip. Such an occurrence was unexpected, for no shale was formerly believed to lie on the eastern side of the fault at this elevation. Another 2 metres of advance altered the appearance of the lode, which currently occupies a fissure dipping south as before but now intermixed with brecciated shale and quartz, the whole carrying acceptable tin values and lying between granite walls.

Underground diamond drilling suggests that neither the Harriet lode nor branches of the same will be found in juxtaposition on the west side of the crosscourse. However, we confidently expect to locate the lode's western continuation at some future time and beyond present working confines.

Turning next to the Tryphena lode as it now appears near the granite-killas contact. The transition from granite in the east to killas or shale in the west is revealed on 2 horizons, these being 2 level (107 metres below shaft collar) and 3 level (144 metres below shaft collar). On No. 1 Level (52 metres from surface) shale lies against shale on either side of the fault.

Commencing the description at the greater depth on 3 level west, the transition occurs 460 metres south-west of Simms shaft, where an unfaulted contact passes obliquely across the drive at about N 10° E with a north-westerly dip of 75°. The contact is cleancut, with little or no assimilation of shale by granite at the contact. The metamorphic aureole within the shale is limited in extent to no more than 5 metres.

In approaching the contact from the east, the Tryphena lode, despite a nearby elvan intersection, was productive and promising. Stoping was recently begun, the western stope limit terminating in granite 9 metres east of the contact, that is, very close to killas. As a result, it has long been expected that the latter will appear at the west end of this stope, and in fact a few fragments were seen at one stage at the top of the western manway when it stood 8 metres above

Table of Contents

rail level. Workings are now 12 metres above rail level, yet no shale is present in substantial quantity and the lode persists as a strong, nearly vertical structure having a lens of elvan on its north-, or footwall. It appears probable that this occurrence of elvan is currently protecting the lode, as it were, from contact with the north-easterly dipping shale. Eventually, the lode will doubtless enter shale, at which point past experience suggests that reversal of its dip coupled with impoverishment may well ensue, resulting in foreshortening of the stope from the west.

The contact between shale and granite dips west overall, for on 2 level it lies only 155 metres from the shaft as compared with 480 metres on No. 3 level. On 2 level the contact appeared dipping 75° west in the drive, and striking due north. West of the contact, as on 3 level, Tryphena lode, as far as it was followed, proved unproductive in Killas, but it was productive in granite. Sloping above 2 was therefore commenced, terminating in granite 5 metres east of the contact. The planned stope-length along lode strike was 60 metres. After raising the west manway 10 mettes above rail level, shale was encountered within which the lode dip abruptly changed from 70°S to 45°N accompanied by structural weakening and loss of tin values. The stope was therefore foreshortened by 16 metres at its west end and the manway elevated at this point to 18 metres above rail level. At 18 metres above 2 level, shale was again entered and the lode's attitude of reversed dip accompanied by general impoverishment found to be maintained. Moreover, the remaining eastern portion of the slope entered shale at the same elevation and mining of the ore body was discontinued for this reason. Throughout the stope, reversal of dip occurred within 2 metres of upward advance. Tin values cut off equally abruptly. The adjoining stope to the east is now working at a higher elevation, since longitudinally, the formerly flat shale-granite contact again rises in the general vicinity of Simms shaft, where Tryphena lode becomes enveloped by an elvan dyke which protects the lode from adjoining shale, and prevents reversal of dip which would probably have occurred had the elvan been absent. In this way, certain branches of Tryphena lode remain marginally productive as high as No. 1 level where they lie between elvan walls, the dyke itself standing in shale and not subject to dip reversal.

Table of Contents

Perhaps the impression has been conveyed that the elvans, where they occur in conjunction with lode structures, possess some geologically maternal qualities, protecting their young lodes from the ravages of the killas jungle. This is not altogether true. In many instances, both Tryphena and Harriet lodes are drastically impoverished by the elvans where the latter are massive, compact and unaltered, and where the lodes appear to have attempted to traverse them. Yet where the lodes intersect and temporarily follow the elvan fracture pattern, and where the elvans are themselves even moderately brecciated, lode enrichment is common. One recent example of this phenomenon occurred on 4 level west, where Tryphena lode intersected, at a very flat angle, a major elvan dyke. The lode turned slightly to follow the direction of strike of the dyke, which was at this point somewhat brecciated. The lode retained its strong structure, apparently near the footwall of the elvan, which is itself south-dipping, while the main body of the brecciated elvan became strongly mineralized with respect to tin.

Note added in proof. Since the foregoing was written, an in-shale extension of Tryphena lode has been located at the western extremity of 2 level. In attitude, the lode is nearly vertical, tin rich, and over one metre in width along 100m of strike.

Athlone Regional Technical College
Dublin Road
Athlone
Eire

Table of Contents

GRYLLS BUNNY, A 'TIN FLOOR' AT BOTALLACK

by N. J. Jackson

Abstract. An area of economic tin values distributed within a sub-horizontal sheet-like horizon is known as a tin floor. The old mine workings at Bolallack, known locally as Grylls Bunny show all the morphological features of a tin floor zone. This zone is localised within a sequence of metasomatic iron and calcium rich hornfelses.

1. Introduction

The workings are located 100m north of Allen's shaft (SW 364335) within a sequence of contact metamorphosed basic rocks. The floor zone is approximately 35m thick, extends 75m along its east-west strike, and was worked for 75m on its underlie, which dips at 20° to the north. The Land's End granite contact is located about 100m to the east. At present there are four discontinuous floor horizons each between 1 and 4m thick. The morphology of the workings suggests that the ore occurred in bunches, pods and lenses within each horizon. There are several lodes in the area, Corpus Christi, Wheal Hazzard and De Narrow, but none of them are exposed or immediately related to the floor mineralizalion. However, there are several minor fissures related to the joint pattern and it is probable that these acted as channelways for the mineralizing fluids.

2. Petrography of the floor zone

The rocks immediately above and below the floor zone are banded hornblende hornfelses, consisting of alternating bands of hornblende, epidote and biotite, and granular plagioclase feldspar, sphene, calcite and opaque ores. The area occupied by the floor zone can be divided into two petrographic units. East of the path to Botallack village there is a zone of extreme iron enrichment (65% total Fe) and depletion of silica. The hornfelses in this area are composed of alternating bands, up to 2cm thick, of magnetite cordierite and chlorite. There appears to be no petrographic control over the deposition of tin in this zone. West of the path the rocks are enriched in calcium (20% CaO) and iron (30% total Fe). The introduction of these two components has led to the production of skarn assemblages in the metabasite hornfelses. Mineralogically, these rocks are composed of bands of grossular garnet, diopside, clinozoisite, calcite and sphene, alternating with bands of magnetite.

The tin mineralization in this area is associated with a tourmaline horizon. Fig 1 shows a petrographic sequence through a pillar in the workings. The metabasite skarns (A) grade into a biotite, hornblende, plagioclase hornfels (B) which, in turn, grades down into a 60cm-thick tourmaline bed (C). The tourmaline, a schorl variety, is euhedral and exhibits strong zoning. Growth

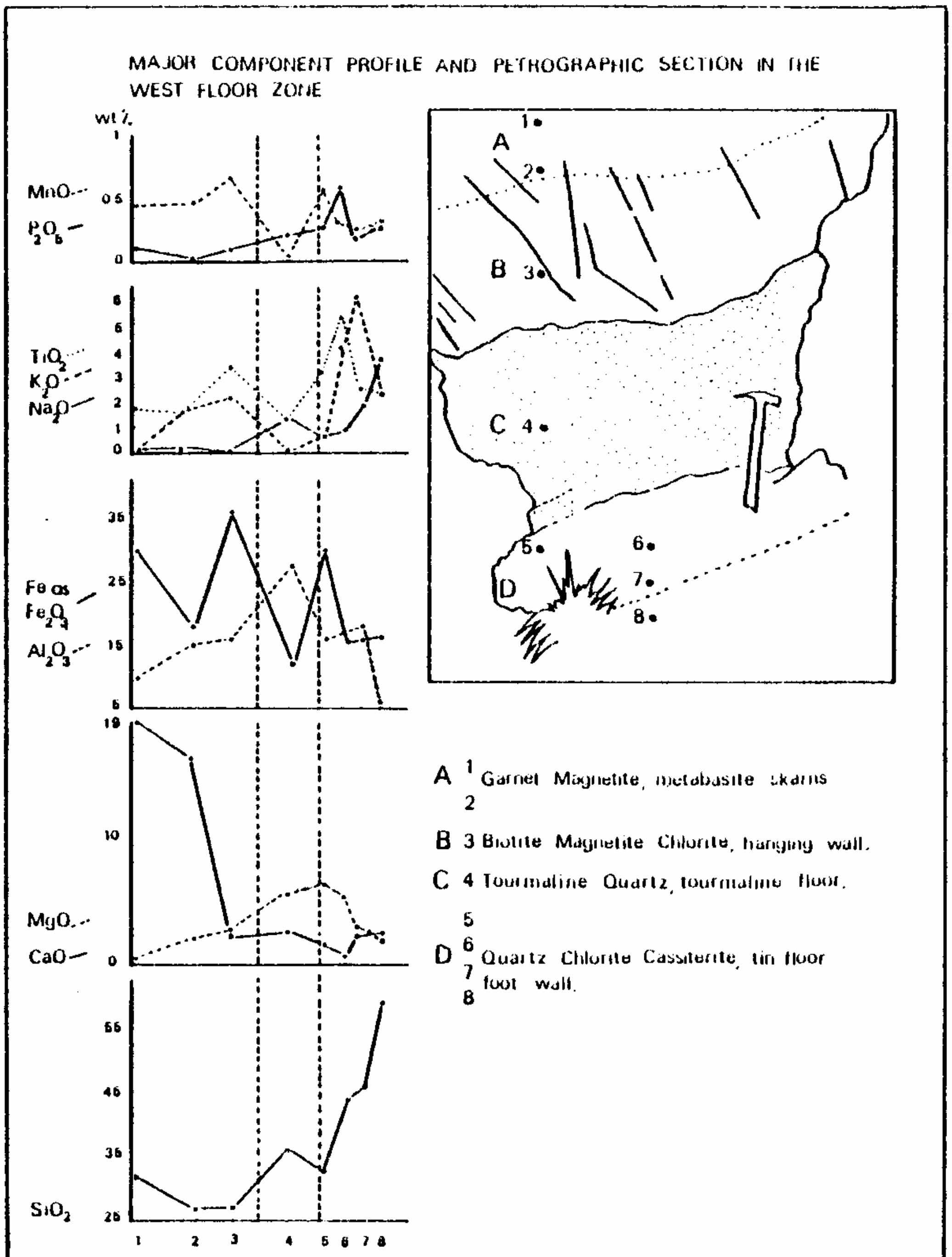


Fig 1

Table of Contents

relationships with the other hornfels types indicates that the tourmaline replaced both the calc-silicate and biotite hornblende assemblages. The tourmaline horizon ends abruptly against an assemblage of biotite, chlorite, quartz, sphene and opaque ores. Tin, in the form of cassiterite, is located in zones D, C and D and appears to replace the tourmaline in horizon C. Trace element data indicate that the tin, up to 2.5%, may be found in any of the horizons mentioned above, but it usually occurs in the foot wall.

3. Origin and formation of the floor zone

The formation of the floor zone probably took place in two stages. During the initial phases of contact metamorphism the metabasites underwent a large-scale redistribution of several major components. In the Botallack area this process produced a series of iron and calciferous hornfelses due to the fixation of these two components within a limited horizon, about 50m thick. This metabasite skarn zone dips sub-parallel to the granite contact but at a lower angle (25° to the west), and cuts earlier tectonic structures.

The second stage in the formation of the floor zone took place during an early phase of mineralization. Boron rich hydrothermal fluids, migrating through minor fractures in the metabasites, selectively replaced several hornblende-biotite hornfels horizons within the skarn sequence. The localization of boron produced the tourmaline bed which later acted as a lithological control on the localization of the tin.

ACKNOWLEDGEMENTS. The author whishes to thank Geevor Tin Mines Ltd. and King's College, London for financing this study. Particular thanks are due to Professor R. A. Howie for critically reading the manuscript.

Dept. of Geology
King's College
London

Table of Contents

W. A. E. USSHER HIS WORK IN THE SOUTH-WEST

by D. L. Dineley

British geology in the latter half of the nineteenth century owed much to the remarkable work of the Geological Survey of Great Britain. The pattern and standard of excellence for the New Series One Inch to the Mile geological maps was to no small extent established by the Survey's work in the southwest of England. H. T. De la Beche, who became the Survey's first Director, had mapped the counties of Cornwall, Devon and parts of Somerset and his report appeared as the Survey's first Memoir in 1839. When William Augustus Edmond Ussher was appointed as Assistant Geologist in the Geological Survey in April 1868 the Director General was Sir Roderick Murchison and the revision of the geology of the west of England was in hand. Ussher was to spend the greater part of his active life in carrying forward the survey of this region and his achievement has been rarely excelled even among such vigorous and intelligent geologists as have entered the Geological Survey. He also served for some time in the London area and the Midlands.

Ussher was nineteen when he took up his appointment in 1868 and was sent in 1870 to join H. B. Woodward on the survey of the Wellington (Somerset) sheet. He retired in 1909, having carried out field work for nine further New Series sheets which include the Taunton and Bridgwater sheet, and those covering the region from Sidmouth around the southern flank of Dartmoor through the South Hams to Plymouth, Bodmin and St. Austell. The descriptive memoirs followed some years after the maps, the last concerning sheet 339, the geology of the country around Newton Abbot (1913).

In addition to his work as a Survey geologist, the many papers that Ussher published in several journals between 1869 and 1914 make an impressive collection and range in content from a consideration of the origins of the Cornubian granites through the stratigraphy and structure of the Palaeozoic and Mesozoic rocks to the Pleistocene and Recent deposits and the effects of solifluction. He contributed to the *Geological Magazine*, the *Quarterly Journal of the Geological Society of London*, the *Proceedings of the Somersetshire Archaeological and Natural History Society* and to the journals of other local learned societies, and to the Reports of

Table of Contents

Section C of the British AssocitQion. He led field excursions to South Devon for the Geologists' Association (1900, 1901, 1907) and contributes to its *Proceedings.*

In recognition of his work he was awarded the Wollaston Fund of the Geological Society of London in 1890, the William Bolitho Gold Medal of the Royal Geological Society of Cornwall in 1903 and the Murchison Medal for 1914 again by the Geological Society of London.

Perhaps among the most important influences upon Ussher's work and career were his Friendship with Arthur Champernowne of Darlington Hall in South Devon, and with Professors Gosselet of Lille and Kayser of Marburg. With Champernowne he made significant discoveries in South Devon, having corresponded with him at some length before he was sent by the Geological Survey to continue the geological mapping that Champernowne had been carrying out. Unfortunately Champerowne died in that same year, 1887.

Cosselet and Kayser not only conducted Ussher over their own ground (the Franco-Belgian and Eifel outcrops of the Devonian) but also visited Devon to see the Devonian and Carboniferous there under his guidance. The result was that more than a simple stratigraphic account of the British succession was produced; the correlation with the now classical scheme of stages and "horizons" which was provided has remained remarkably intact since then.

In his scientific papers Ussher showed himself to be observant, methodical and aware of the pitfalls awaiting the stratigrapher and structural geologist in Southwest England. He was not afraid to change his mind nor to advance a provisional working hypothesis where other geologists would have remained mute. He seems to have been a very direct personality, stating his mind clearly and replying with vigour when he felt that his work was under criticism.

At the end of his life, in 1920, Ussher could have justly felt that he had made a major contribution to the geology of the west country, a contribution which has enabled others since then to enter the area with a shrewd idea of the difficulties and the attractions of Cornubian geology.

Table of Contents

Stratigraphy

From the outset Ussher was concerned with setting up usable stratigraphic successions in rocks of wide variability. His earliest paper (1869) deals with the local New Red Sandstone succession in West Somerset and in this and several later papers on rocks of this system Ussher emphasised the need to describe the critical or principal lithologies and to determine the range of lateral variations from them.

In due course when he worked upon both the Meadfoot Beds and the Culm Measures he used the word *"type"* to describe it range of associated lithologies in these formations. Thus a *type* within such a set of beds was a laterally variable association of closely related lithologies, constituting perhaps what today would be called a *facies* or perhaps, in some cases, a *lithosome*. Ussher showed the distributions of some of these types on his own maps, as for example in "The British Culm Measures" (1892) and there the word is also used where today the term “formation” might be employed.

It is another feature of these studies that the standard English stratigraphical rock terminology is rarely used. Series, stage, zone and group are words that appear infrequently and may not have the meaning they have today. On the other hand the terin "horizon" occurs frequently and may refer not to a single plane or to a single bed but to as large a body of strata as the Lower Culm. Whether or not Ussher deliberately used such ternis in a loose fashion is not clear but in the case of "horizon” he seems to have in mind the German "Horizont" which may be a bed or stratum. Ussher’s terminology was essentially pragmatic: it reflected his bent as a field geologist. Perhaps, because he felt that continuing study would reline and improve the rough stratigraphy he outlined, Ussher intentionally used rather imprecise terminology. He seems to have felt that for the purposes of mapping the Palaeozoic rocks in Devon the detailed description of stratotypes would not have been very useful, and perhaps he was right.

Ussher made frequent and seemingly appropriate use of European terminology in his descriptions of Palaeozoic strata. A few examples are given below: they are tenus which can be used today as effectively as at the beginning of the century.

Table of Contents

Knollenkalk
Krammenzelstein = a nodular limestone. These rocks are found in the red Upper Devonian strata in South Devon and are now locally thought to represent a disruption of interbeclded limestone and slate rather than the products of diagenesis in unconsolidated sediment (Riddolls, 1970).

Schalstein = a pyroclastic rock. Rietschel (1966, p.18) sets out a field distinction between *Schalstein* (rarely well-bedded, little colour variation, grain-size highly variable, particles angular) and *Kerntophyr-Tuff* (almost always well-bedded, strong parting parallel to bedding, often multicoloured, particles often of one size, frequently well rounded).

Cypridinenschiefer = slates with ostracodes. According to Rietschel (1966, p.26) the term was first used in 1846 by F. Sandberger.

Büdesheim fauna = Ussher made numerous references to this classic German occurrence of ammonoids (mid-Frasnian). But he was not always as exact in this as modern work would require (see House 1963, p.8) - i.e. references in Ussher's memoirs to the Büdesheim fauna are not in every case to be taken at their face value.

In North Devon and West Somerset Ussher's work on the Devonian rocks began early and occupied him periodically all his life. His geological map of the area appears in the Victoria County History of Devonshire (1906) and was adopted by Hamling (1910) (Goldring 1952). The Foreland-Hangman Beds argument occupied his attention and although he found some favour in Champernowne's suggestion that Foreland Beds and Hangman Beds were the same formation, he eventually rejected it for lack of sufficient positive evidence (1886, 1889, 1891). Following the visit of his European friends his correlation of the successions with those on the continent has remained virtually intact.

Table of Contents

In South Devon, too, Ussher's principal contribution has been in the ordering of the sequence of the many different Devonian formations and facies. He recognised the differencers between the rocks of a southern (or eastern) area and a western and by collecting fossils wherever possible was able to show the age equivalence of rocks of widely different lithology (see Memoirs of the Geological survey). The stratigraphic position and distribution of the "Ashprington Volcanic Series" was included in this work.

The Culm Measures were studied and mapped as part of Ussher's duties in the Geological Survey only in South Devon, but he visited and studied the outcrops widely in the north of the county and in Cornwall. In 1892 he published an account of the general stratigraphy of the Culm Measures, reviewing previous work and setting out his own classification of these rocks into Upper, Middle and Lower groups and describing the Eggesford, Morchard, Exeter and Codden Hill types. The fossils and associated volcanic rocks were considered and a useful comparison with the German Culm (Westphalia, Upper Harz, etc.) was made. Further information was included in a paper published by the Institute of Mining Engineers (1901, 1902) together with a map on the scale of one inch to four miles. Subsequent work during Ussher's lifetime added little to change his accounts of these rocks and it was not until sedimentology and the biostratigraphy of the Carboniferous had advanced substantially in the 1950's and 1960's that much serious revision could be undertaken (see Edmonds *et al*., 1969).

Ussher's descriptions of the Permo-Triassic rocks of the Southwest provide much local detail and the broad divisions that he used in his work for the Survey have largely stood the test of time. He regarded the successions in South Devon as probably of Permian age and older than the similar couglomeratic or breccia-bearing rocks in West Somerset (1889).

In 1877 Ussher spent part of his leave in Normandy to examine the Triassic rocks there: he also succumbed to the temptation to visit the local small outcrops of Devonian. He hoped to establish whether or not the Normandy Triassic formed an easterly prolongation of that system from Southwest England, and if the Palaeozoic of N. France had contributed fragments that were incorporated into the Triassic strata of Devonshire.

Table of Contents

A close acquaintance with the "Post-Tertiary" geology of Cornwall seems to have been Ussher's early in his career. In 1879 he published privately an account of this topic with a long preface describing how the failure of the Geological Society of London to accept his two papers on the Cornish Pleistocene left him no alternative but to print the work himself. There is a candour in this preface that suggests that Ussher had a command of purposeful prose equal to that of any geologist of his day. The paper itself seems today not extraordinary in its findings and one is left feeling that the Geological Society's referees may have had cause for second thoughts as time went by.

Ussher's grasp of the geology and genesis of recent deposits was good and in a paper on "terminal curvature" (1878) he recognised the eflcets of solifluction of the 'head' over fissile strata.

Structure

The determination of a detailed stratigraphic succession in the Palaeozoic rocks of Devon and Cornwall and its correlation with the European standard remains a nuajor concern in local geology, the recognition of the major structural features and tectonic style or fabric of the country are no less matters of lively debate today. Following the pioneer work of De la Beche and others in the first half of the nineteenth century, little real advance was made until Ussher's work began to appear. Most of his contribution is displayed on the One-Inch Geological Maps, and the Memoirs add both necessary detail and an outline of the structure present. Although the writing may lack modern terminology Ussher's work conveys the ‘feel’ of the geology and the maps provide outcrop patterns that are accurate even if views on the boundaries may have changed. Palaeontological and other evidence now directs us to interpret some of the latter as involving inverted strata and this evidence was not known to Ussher.

Ussher's palaeontological and stratigraphical work led him in

Table of Contents

South Devon and Cornwall to suspect structures which have since been proved. He correctly delineated the Watergate Bay and South flants anticlines in the Dartmouth Beds and he postulated both strike-faults and wrench-faults of considerable magnitude. Thrusting, the NW-SE large dextral faults and later wrench-fatilting he regarded as essential components of the later phases of deformation of the Palaeozoic rocks.

The emplacement of the granites and especially the intrusion of the Dartmoor mass together with the resulting deflection of strike in the beds on the eastern flank of the moor were discussed in 1892 and again in 1912 and 1913. He regarded the Dartmoor granite as remelted pre-Devonian basement.

Ussher's mapping of the contact between the schisis of the Start-Bolt area and the Meadroot Beds was more detailed and accurate than previous attempts and he favoured (1904) the view that the metamorphosed rocks south of the contact were allered equivalents to those to the north. He gave no ultimate opinion as to whether the contact was a thrust, fault or a sharp non-diastrophic metamorphic boundary.

Another topic investigated by Ussher (1891) is of interest here. It concerns the evaluation of the Palaeozoic rocks south of the Mendips in the search for coal, and it led him to examine the Canningtou Park Palaeozoic inlier. He recommended that a boring be put down to test the ground within the area Otterham-Pulsham-Wedpiore-Brean, the site of a possible coal basin. The Mesozoic cover was suggested as less than 1,000 feet and probably no more than 400 feet. Sixty years later Wills (1956) suggested that coal-bearing rocks may underlie the nappes of the Mendip hills, and perhaps extend even farther south, but he has no more evidence than had Ussher. At Cannington Park Ussher recognised that the inlier consists of Carboniferous Limestone, much deformed, and that an important fault cuts out part of the local Devonian succession between it and the other (Devonian) inliers. Ussher thought this dislocation might be a thrust. In recent years other geologists have returned to the idea of a thrust here and underlying Exmoor (Falcon *in* Cook, Hospers and Parasnis, 1952: Bott *et al.,* 1958: Webby 1965: Wills 1973). On the grounds of geophysics and structural geology the idea is appealing, but the existence of such a thrust has yet to be proved.

Table of Contents

Ussher's work remains a model of its kind and the rapid progress made in the geology of Southwest England in the last decade or so would have pleased him greatly. In many cases where his work has been superseded (by new studies) later authors acknowledged the accuracy, acumen and insight of the man after whom this Society is named; which is as it should be.

I am indebted to Dr. S. C. Matthews for information about the German terms referred to above, and to Mr. G. Disson for information about Ussher's work with the Geological Survey and to them both for kindly suggesting improvements to the manuscript.

USSHER'S PUBLICATIONS EXCLUSIVE OF THOSE FOR THE GEOLOGICAL SURVEY OF GREAT BRITAIN.

1875 On the subdivisions of the Triassic rocks, between the coast of west Somerset and the south of Devon. GEOL. MAG., Dec. II. **2**, 163-168.

1876 On some old gravels of the River Dart, between Totnes and Holne Bridge. TRANS. DEV. ASSOC., **8**, 427-433.

1876 On the Triassic rocks of Somerset and Devon. JL. GEOL. SOC., **32,** 367--394.

1877 On the age and origin of the Watcombe Clay. TRANS. DEVON. ASSOC., **9**, 296-300.

1877 A chapter on the Budleigh pebbles. TRANS. DEVON. ASSOC., **9**, 222-226.

1877 A classification of the Triassic rocks of Devon and West Somerset, with some gencral observations on the variability of strata. TRANS. DEVON. ASS., **9**, 392-399.

1878 The chronological value of the Pleistocene deposits of Devon. Q. JL. GEOL. SOC., **34**, 449-458.

1878 On the chronological value of the Triassic strata of the southwestern countics. Q. JL. GEOL. SOC., **34**, 459-469.

1878 On the geology of Paignton. TRANS. DEVON. ASSOC., **10**, 203-208.

1878 On the mouth of the river Exe. TRANS. DEVON. ASSOC., **10,** 377-383.

1878 On terminal curvature in the South-Western counties. Q. JL GEOL. SOC., **34,**49-55.

1879 The post-Tertiary geology of Cornwall. Printed for private circulation by Stephen Austin & Sons, Hertford. Plate, 'iv'. 59p.

1879 Post-tertiary geology of Cornwall GEOL. MAG., Dec. II, 6, 102-110, I66-172, 203-211.

1879 On the Recent geology of the Cornish coast near Padstow. Abst. from "The post-tertiary geology of Cornwall' printed for private circulation and appearing in TRANS. R. GEOL. SOC. CORNWALL

1879 On the Triassic rocks of Normandy and their environments. JL GEOL. SOC., **35**, 245-267.

1879 **CHAMPERNOWNE, A. and_________**Notes on the structure of the Palaeozoic districts of West Somerset. Q. JL GEOL. SOC., 35, 532-548.

1880 On the geology of parts of Devon and West Somerset, North of South Moltun and Dulverton. PROC. SOM. ARCH. NAT. HIST. SOC., 1879, **25**, 1-20.

1880 Physical features of Devonshire. TRANS. DEVON. ASSOC., **12**, 251-273.

1881 On the geology of Dawlish.TRANS. DEVON. ASSOC., **13**, 150 -158.

1881 "Prehistoric Europe" - Submerged Forests and Forest Beds, Cornwall. GEOL. MAG., Dec. II, **8**, 131-13-1.

1882 On the Palaeozoic rocks of north Devon and west Somerset. REP. BRIT. ASSOC. for 1881, pp.629-631 [Abstract] *and* GEOL. MAG., Dec. II, **8**, 441-447, 1881.

1884 On the geology of South Devon, with special reference to the long excursion. PROC. GEOL. ASSOC., **8**, 442.-452.

1886 The Relations of the Middle and Lower Devonian in west Somerset [Abstract] REP. BRIT. ASSOC. for 1886, 649.

1887 The Culm Measures or Devonshire. GEOL. MAG., Dec. III, **4**, 10-17.

1887 TheDevonian rocks between Plywouth and East Looe. TRANS. R. GEOL. SOC. CORN., **10**, 70-81.

1887 Pleistocene notes on the Cornish coast, between Plymouth and Looe. TRANS. R. GEOL. SOC. CORN., **10**, 63-69.

1887 On the recent geology of the Cornish coast near Padstow [Abstract] TRANS. R. GEOL. SOC. CORN., **10**, 58-62.

1888 The Devonian rocks of west Somerset on the borders of the Trias [Abstract] REP. BRIT. ASSOC. FOR 1887,720.

Table of Contents

1888 The granite of Dartmoor. Part I. TRANS. DEVON. ASSOC.. **20**, 141.149.

1888 The granite of Dartmoor Part II. TRANS. DEVON. ASSOC. **20**, 148-157.

1988 The Triassic rocks of West Somerset [Abstract] REP. BRIT. ASSOC. FOR 1887. 719-720.

1989 The Triassic rocks of West Somerset and the Devonian rocks on their borders. PROC. SOM. ARCH. NAT. HIST. SOC. **35**, Pt. 11. 1-36.

1889 The Devonian of the Western region and geology of Tavistock. TRANS. DEVON. ASSOC., **21**, 437-451.

1889 Some points of interest in the geology of Somerset. [Abstract] REP. BRIT. ASSOC. FOR 1888.659-660.

1889 The Watcombe terra-cotta clay [Abstract] REP. BRIT. ASSOC. FOR 1898. 672.

1890 The Devonian rocks of South Devon. Q. JL GEOL. SOC., **46.** 487-517 and GEOL. MAG., Dec. III.7, 284-5.

1890 The Devonian rocks of Great Britain [Abstract] REP. BRIT. ASSOC., FOR 1884. 578-590,

1840 The geological formation at Blue Anchor. PROC. SOM. ARCH. NAT. HIST. SOC., **35,** 43-46.

1840 [The geological features of Porlock valley] PROC. SOM. ARCH. NAT. HIST . SOC., **35**, 17.-35.

1891 The Devonian rocks. as described by De La Beche interpreted in accordance with recent researches. [Abstract] REP. BRIT. ASSOC. FOR 1890. 801-802 *and* TRANS. GEOL. SOC. LOND. **11**, 273-326. 1891.

1891 On the probable nature and distribution of the Palaeozoic strata beneath the Secondary etc. rocks of the southern counties; with special reference to the prospects of obtaining coal by boring south of the Mendips. PROC. SOM. ARCH. NAT. HIST. SOC., **36,** 88-1.16.

1891 Vulcanicity in the lower Devonian rocks. The Prawle problem, GEOL.

1892 MAG., Dec. III, **8**, 511-512 and REP. BRIT. ASSOC. 1891, 642-3. [Abstract]

1892 The Briitish Culm Measures. PROC. SOM. ARCH. NAT. HIST. SOC., **38,** 111-219.

1892 Devon and Cornish granites, [Abstract of paper read before the British
1893 Association. Edinburgh, August. 1892] GEOL. MAG.. Dec. III, **9**, 467.8 *and* REP. BRIT. ASSOC. for 1892, 709.

1892 Permian in Devonshire. GEOL. MAG., Dec. III. **9**, 247-2511.

1894 **(Baron A.) VON REINACH and _**_________ On the occurence of fossils in the Magnesian Limestone of Bulwell, near Nottingham. [Abstract] REP. BRIT. ASSOC. for 1893,768-9.

1898 The geological structure of Devon. REP. TRANS. PLYMOUTH INST., **12**, 292-302.

1899 **WOODWARD, H. B. and_**__________)Excursion to Seaton,
1900 Sidmouth, Budleigh Salterton and Exeter. PROC. GEOL. ASSOC., **16**, 133-153.

1900 The Devonian. Carboniferous and New Red rocks of West Somerset. Devon and Cornwall. PROC SOM. ARCH. NAT. HIST. SOC., **16**, 1-64.

1900 **(WOODWARD, H. B., HUNT, A. R. and**____________Excursion to Newton Abbot, Chudleigh. Dartmoor and Torquay, Easter, 1900. PROC. GEOL. ASSOC., **16,** 425-442.

1901 **HUNT. A. R. and**__________________Excursion to the Start, Prawle, and Bolt districts. PROC. GEOL ASSOC., **17**, 119-135.

1901 The Culm-Measure types of Great Britain. TRANS. INST. MINING ENG., **20**, 360-391,

1902 Geological map of the British Culm-Measures, 1 inch =4 miles. (To illustrate his paper published in 1901). TRANS. INST. MINING ENG., 20, pl.xvi.

1902 Radiularian chert in the Culm. GEOL. MAG., Dec. 4, **9**, 576.

1903 Geological mapping. REP. TRANS. PLYMOUTH INST., **13**, 39-40.

1904 The Devonian rocks of Cornwall GEOL. MAG., Dec. 5, **1**, 587-591.

1905 Geology of the Kingsbridge and Salcombe district. GEOL. MAG., Dec. 5, **2**, 91-92.

1905 Notes on the Upper Devonian rocks in St. Minver parish. TRANS. R. GEOL. SOC. CORN., **13,** 85-87.

1905 The Geology of Devonshire. *Victoria History of the Counties of England*. Devonshire, I, 1-48 and 2 geol. maps. London, Constable.

1907 Excursion to Plymouth, Easier, 1907. PROC. GEOL. ASSOC., **20,** 78-93.

1908 Radiolarian rocks of the Culm Measures, Devonshire. GEOL. MAG., Dec. V, **5**, 138.

Table of Contents

1910 Cornwall- Devon and West Somerset *in* GEOLOGY IN THE FIELD: the jubilee volume of the Geologists' Association (1858-1908): edited by H. W. Monckton and R. S. Harries, London. E. Stanford, 1910; 859-896.

1911 **RICHARDSON, L. S., ------ ___________WHITAKER, W. and WINWOOD, H. H.** Excursion to Dunball, Burlescombe, Ilminsler, Chard, Ham Hill and Bradford Abbas. PROC GEOL. ASSOC., **22**, 246-263.

1914 A geological sketch of Brean Down and its environs. PROC SOM. ARCH. NAT. HIST. SOC., **60**, 17-40.

REFERENCES

BOTT, M. H. P., DAY, A. A. and **MASSON-SMITH, D.** 1958. The Geological Interpretation of Gravity and Magnetic Surveys in Devon and Cornwall. Phil. Trans. Ser. A., **251**, 161-141.

COOK, A. R., HOSPERS, J. and PARASNIS, D. S. 1952. The Results of a Gravity Survey in the Country between the Clee Hills and Nuneaton. Qt. Jl. Geol. Soc., **107,** 287-.106.

EDMONDS, E. A., McKEOWN, **M. C. and WILLIAMS, M.** 1969. British Regional Geology: South-West England. (3rd ed.). London: H.M.S.O.

GOLDRING, R. 1952. Geological Maps of North Devon and West Somerset. Proc. Bristol Nat. Soc., **28**, 351-353.

HAMLING, J. G. *in* _________________ and **INKERMANN ROGERS,** 1910. Excursion to North Devon, Easter, 1910. Proc. Geol. Assoc.. **21**, pl.33.

HOUSE, M. K. 1963. Devonian ammonoid successions and facies in Devon and Cornwall. Qt. Jl. Geol. Soc., **119**, 1-27.

RIDDOLLS, B. W. 1970. The origin of calcareous nodules in Upper Devonian slate near Newton Abbot (Abstract). Proc. Ussher Soc., **2**, 158.

RIETSCHEL, S. 1906. Die Geologie des mittleren Lahntroges. *Abh. Senckenb. Nat. Ges . H.* **509**, 1 -58.

Table of Contents

WEBBY, B. D. 1965. The Stratigraphy and Structure of the Devonian Rocks in the Quantock Hills, west Somerset. *Proc. Geol. Assoc.*, **76,** 321-344.

WILLS, L. J. 1956. *Concealed coalfields.* Blackie & Son, pp.208.

_____ 1973. A palaeogeological map of the Palaeozoic floor below the Permian and Mesozoic Formations in England and Wales. *Geol. Soc. London, Mem. No.* **7**.

Dept. of Geology
The University
Bristol

Table of Contents

THE USSHER SOCIETY

Objects

To promote research into the geology and geomorphology of South West England and the surrounding marine areas; to hold Annual Conferences at various places in South West England where those engaged in this research can meet both formally to hear original contributions and progress reports and informally to effect personal contacts; to publish proceedings of such Conferences or any other work which the officers of the Society may deem suitable.

Constitution

Membership. A person shall become a member on written application to the Secretary and payment of the annual subscription.

Subscription. The annual subscription shall be one pound fifty pence for ordinary members and one pound for students and retired members, due on January 1st each year.

Conference Fee. All those who attend a Conference shall pay a fee at the time of registering, the amount of which will be determined from year to year by the Organizing Committee.

Annual Business Meeting. A business meeting shall be held during each Annual Conference and shall elect the Organizing Committee and two auditors for the next Conference.

The Organizing Committee shall consist of a Chairman who shall hold office for not more than two consecutive years and shall not be eligible for re-election to the office for a further two years, a Vice-Chairman who shall be the retiring Chairman, a Secretary, a Treasurer, an Editor and five others, any of whom may be eligible for re-election. The Committee shall have powers to co-opt.

Conference Guests. The organizing Committee shall be empowered to invite a distinguished scientist to attend the Annual Conference and address it on a topic of interest to the Society.

Amendment of this Constitution may be effected by simple majority vote at the Annual Business Meeting.

Table of Contents