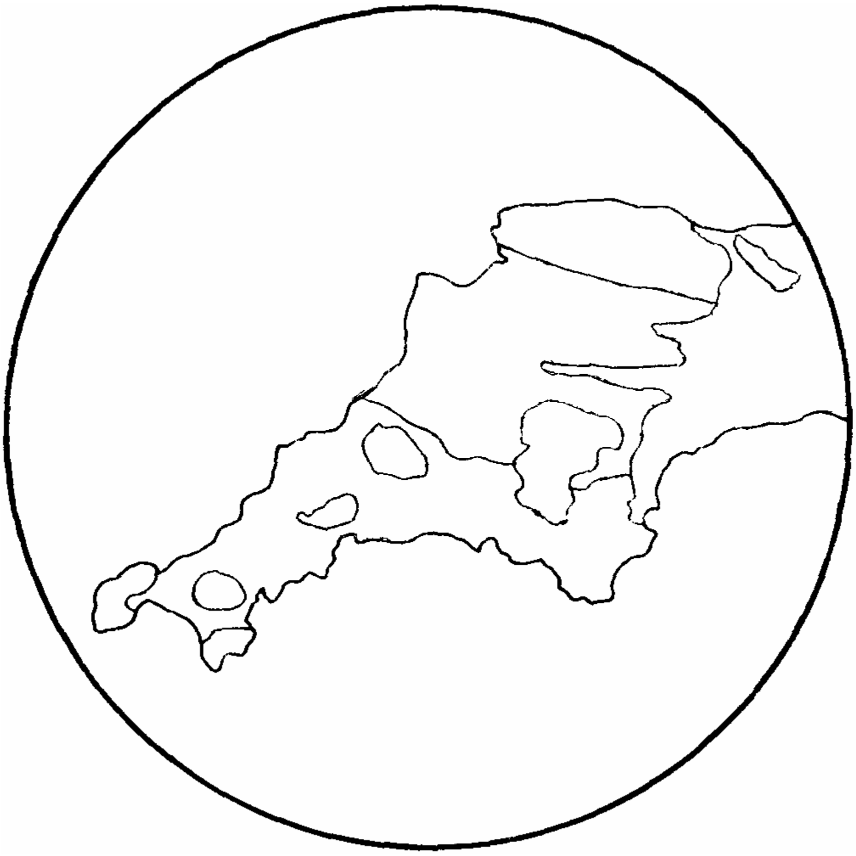
PROCEEDINGS
OF THE
USSHER SOCIETY

VOLUME THREE
PART TWO



1975

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Dr. M. B. Hart,
Department of Environmental Science,
Plymouth Polytechnic,
Plymouth, PL4 8AA,
Devon.

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USSHER SOCIETY

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PART TWO

Edited by
A. WHITTAKER

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Conference of the Ussher Society held at Plymouth
January 1975

Chairman's Report

For its thirteenth Annual Conference the Society revisited Plymouth, using, by kind invitation, the accommodation and facilities at the College of St. Mark and St. John.

The fall of the New Year public holiday on a Wednesday and the early re-opening of some teaching departments combined to dictate the timing of our Conference - unusual in being at the end of a week. It was reassuring, however, to note that this break with tradition in no way decreased the customary keen attendance. Next year's meeting, circumscribed by the same timing factors, must encroach more heavily upon the weekend and will further test the dedication of our membership.

Marking a departure from routine, the Invited Address this year opened the final half-day session of conference papers. An entertaining presentation on the subject of "Tourmaline" by Professor R. A. Howie served to remind many of us that this familiar mineral, so typical of the Hercynian magmatic zone, may well repay more detailed investigation. Saturday's field excursion to coastal sections of Lower Devonian strata at Wembury and Bovisand attracted a reduced, but eminently manageable, number of participants who enjoyed an instructive and interesting day under the guidance of Dr. D. Hobson.

The venue for the 1976 meeting provoked considerable discussion - and some confusion - at the Annual General Meeting. After considering various alternatives the membership once again showed its partiality for the Torquay area.

In recording my sincere thanks to the Committee for their unfailing support I would like to pay particular tribute to the two retiring members. Professor Kidson joined the Committee in 1970

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since when he has provided, to our mutual benefit, a valuable official link with our geographer colleagues. Dr. Crosbie Matthews, a long-standing and well-known member of the Society, was also elected in 1970 and in the following year took up the reins of Secretaryship. His energetic enthusiasm and irrepressible good humour have been a model to successive Chairmen and Committees. I am sure that we all hope to see - and hear - them at many meetings in the future. In their place may I welcome Dr. Colin Exley and Dr. Tony Hall to the Committee and Dr. Malcolm Hart to the Secretaryship.

Finally, I should like to record our indebtedness to Dr. Alf Whittaker who, with great patience and finesse, has steered Vol. 3, Part 1 of our *Proceedings,* the largest issue in our history, through the unfamiliar territory of new printers and new format to such a successful conclusion. With the inevitable "teething troubles" now resolved he hopes to achieve speedier publication of Volume 3, Part 2.

K.E. Beer
22 April 1975

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TOURMALINE

by R. A. Howie

Abstract. The chemistry of tourmaline is reviewed briefly. Fairly abundant data exist on the chemistry of magmatic iron-rich tourmalines from the Hercynian granites of South-West England and elsewhere, but a plea is made for more data on the secondary or hydrothermal tourmalines from altered granites, mineralized veins and metasomatized country rocks. Recent work on the major and trace element chemistry of schorl (and on elbaite from Meldon) is discussed.

Tourmaline is a characteristic accessory mineral of granites, granite pegmatites and pneumatolytic veins; it also occurs in some metasomatic and metamorphic rocks. The main compositional varieties of this mineral are the magnesian tourmalines or dravites, the iron tourmalines often known as schorl, and the alkali tourmalines or elbaites which are usually rich in lithium: there is a continuous series between dravite and schorl and between schorl and elbaite, but there appears to be an immiscibility gap between elbaite and dravite. Buergerite is a recently discovered variety rich in ferric iron:

Dravite	$NaMg_3Al_6B_3Si_6O_{27}(OH,F)_4$
Schorl	$NaFe_3^{2+}Al_6B_3Sl_6O_{27}(OH,F)_4$
Elbaite	$Na(Li,Al)_3Al_6B_3Si_6O_{27}(OH,F)_4$
Buergerite	$NaFe_3^{3+}Al_6B_3Si_6O_{30}(F,OH)$

Although the crystal structure of tourmaline contains six-membered rings of composition Si_sO_{18}, the symmetry is reduced to trigonal by the symmetry and three-fold nature of the BO_3 groups. This may be seen when the general formula is written in the form:

$$Na(Mg,Fe,Mn,Li,Al)_3Al_6[Si_sO_{18}J(BO_3)_3(OH,F,O)_4$$

In the granitic rocks of South-West England, schorl or black tourmaline is the main variety represented, and indeed this mineral is a typical accessory phase in most of the Hercynian granites of Western Europe. Its mode of occurrence in, for example, the Dartmoor granite has been given in detail by Brammall and

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Harwood (1925). As has been remarked by Exley and Stone (1964), there are two distinct generations of tourmaline in these granitic rocks: the earlier generation is the widespread accessory phase which occurs in most of the granites and is yellow to brown in thin section, whereas the later generation is blue-green in thin section and is found associated with somewhat altered reddened granites and associated with joints. This later generation, clearly produced during an alteration process, has been termed hydrothermal by Power (1968).

The chemistry of tourmaline is complex, and indeed John Ruskin (1890), in a delightful book full of mineralogical lore and sub-titled "Ten lectures to little housewives on the elements of crystallization", remarked that "the chemistry of it is more like a mediaeval doctor's prescription than the making of a respectable mineral". Because of the analytical difficulties associated with boron and the refractory nature of tourmaline reliable full chemical analyses are not abundant, but the advent of spectrographic, atomic absorption, XRF and electron microprobe techniques has in recent years provided numerous partial analyses enabling variation in chemical composition to be related to other properties such as cell parameters and also to the occurrence. Chemical variation in schorl from the granitic rocks of South-West England has been studied in detail by Power (1968) who has shown from partial analyses of forty-eight samples for major and trace elements that the later hydrothermal tourmalines are richer in Mg, Ca, Sr and Sn and lower in Fe, Mn and F compared with tourmalines of the earlier magmatic generation. A similar antipathetic relationship between Mg and Mu in schorl from pegmatites had been noted by Shiruoda (1956). In the work by Power, however, only six of the forty-eight samples were of so-called hydrothermal tourmaline, and although the cumulative frequency plots indicate that the hydrothermal tourmalines form a distinct population, there is an obvious need for more data. The present author would indeed make a plea that in view of the very widespread tourmalinization in mineralized veins and in metasomatized country rocks in Cornwall, here is a fruitful field of study.

An examination of eighty tourmalines from various parageneses (Němec, 1973) showed that relatively high contents of tin (Sn 0.006 per cent.) are characteristic of schorl in tin-rich associations from tin-bearing areas and from complex pegmatities. The Sn contents were found to show a positive correlation with F and were not

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controlled by the major element content of the tourmaline but by the concentrations of Sn in the mother fluids, reflecting the presence or absence of cassiterite in the rock. It has been recognised that in the hydroxyl position of the structure, part of the (OH) is often replaced by F; chlorine may also occur - from thirty-one samples of schorl from South-West England 0.024-1.102% Cl has been recorded (Fuge and Power, 1969). Recent work on the chemistry of schorl also includes that by Neiva (1974) on the major and trace element contents of schorl from Portuguese granitic rocks and for major elements of schorl from Siberian pegmatites by Shiryaeva and Shmakin (1969) and from Tien-Shan and the Pamirs by Otroshchenko and Dusmatov (1971). Although zoning is often apparent in thin sections of schorl, little modern work has been done on the chemical variation this represents. Electron microprobe analyses of a colour-zoned schorl from New Zealand are reported by Black (1971) who found an enrichment in Ti in the deep olive brown core; she also reported that the tourmalines studied appear to have inherited their composition, at least in part, from their host rock, having the highest Fe/Mg ratios in rocks with high Fe/Mg ratios (rhyolites and pegmatites) whereas those from metasediments have lower Fe/Mg ratios. A mutual antipathy between tourmaline and biotite has been noted in Bohemian granites (Čech, 1963). Dearman and El Sharkawi (1965) have reported that around the Dartmoor granite tourmaline occurs in shales and tuffs of the Culm but that it is represented in the more calcareous sediments by axinite and datolite; the coexistence of schorl with axinite has, however, been reported by Howie (1970) from a contact-altered dolerite at Carrick Dhu, St. Ives. In northern Nigeria, the formation of tourmaline-bearing veins and pegmatites was clearly related to late-stage granite emplacement, but the scarcity of tourmaline in the granites themselves and the widespread occurrence of tourmaline in or near the associated metasedimentary rocks led McCurry (1971) to suggest that the source of the boron lay in the metasediments.

Although in South-West England most of the occurrences of tourmaline are of schorl, in the Meldon aplite, near Okehampton, both green and pink varieties of elbaite occur (also the bicoloured variety). The early generation of magmatic veins and metasomatized aphtes contain green tourmaline (verdelite) whereas the later hydrothermal veins and associated aplites contain pink tourmaline (rubellite). Chemical analyses (Chaudhry and Howie, 1976) show

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that the green colour of the verdelites is due to divalent iron whereas the rubellite has a much lower iron content. This is in agreement with the earlier work of Bradley and Bradley (1953) who considered that in elbaites the pink colour is due to low iron but not necessarily high manganese, whereas the green colour is due to high iron but not necessarily low manganese. The interpretation of the optical absorption spectra of tourmalines has been considerably aided by recent observations of Mössbauer spectra and the realisation of the importance of charge-transfer processes, see for example work by Faye *et al.* (1974) who place emphasis on the $Fe^{2+} \rightarrow Fe^{3+}$ process which gives rise in the blue and black tourmalines to a prominent absorption band at around 18,500cm^{-1}.

As most tourmalines contain small but definite amounts of potassium and are highly stable minerals which are reasonably argon retentive, they are of use for K/Ar isotopic dating. Some recent results include a mean minimum apparent age of 229 m.y. for tourmaline from an adularia-tourmaline vein in Geevor tin mine, Pendeen, Cornwall (Fitch and Miller, 1972). The study of stable isotopes is also proving useful and it is hoped that determination of $^{18}O/^{16}O$ ratios for primary and secondary tourmalines from South-West England may yield important information on their temperature of crystallization.

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Department of Geology
King's College
Strand
London WC2R 2LS

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FLUID INCLUSION STUDIES IN S.W. ENGLAND

by D. H. M. Alderton

Abstract. Recent temperature and salinity determinations on fluids associated with south-western ore deposits agree with previously published data. Fluids associated with N-S veins (crosscourses), however, have distinctive salinities. It is suggested that the origin of these ores has more in common with that of the Pennine deposits than with other Pb/Zn/F deposits of South-West England.

1. Introduction

Sorby (1858) was the first person to seriously evaluate the use of fluid inclusions as geothermometers. Many of his determinations were on material from Devon and Cornwall. Since then, many temperature determinations have been made on samples from south-western ore deposits. Salinity and Na/K values are also of great value, but very little published data exist (see Sawkins 1966). The majority of the temperature determinations are lacking in precision due to there being no corrections for salinity or pressure, corrections being especially difficult to apply when the salinity of the fluid is not obtainable, or the depth of formation is unknown.

2. Present study

Several samples of quartz and fluorite were collected from ore deposits in Devon and Cornwall. Many of these were collected from mine (lumps; these are not ideal, but suffice for a general comparative study. Where possible, the homogenization temperatures and salinity of the inclusions were measured. Uncorrected temperatures agree well with those previously published. A wide range exists for all the deposits, from 150°C to 500°C. The Sn/Cu mineralization gave a maximum concentration of temperatures in the range 200-350°C, whilst the Pb/Zn mineralization indicates lower temperatures, around 150°C.

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The salinities of the fluids are mostly in the range 25 to 0 eq. wt.% NaCl. The presence of daughter minerals (e.g. halite, sylvite and gypsum) indicates that higher salinities were attained, but these are relatively rare.

When these results are combined with Sawkins' data, and plotted on a diagram of salinity against temperature, an interesting point emerges. Fluids associated with N-S Pb/Zn/F veins (crosscourses) all have salinities close to 25 eq.wt.% NaCl. Fluids associated with the (normal) ENE-WSW-trending veins have a wide range of salinities, from 18 to 0 eq.wt.% to NaCl. Of special interest is the low salinity (2.5) obtained by Sawkins for a Pb/Zn vein with a normal trend (Lambriggan, near Perranzabuloe).

Detailed work on major tin deposits in Tasmania (Groves and Solomon 1969) and Bolivia (Kelly and Turneaure 1970) has shown that the general trend is for a decrease in salinity and temperature of an ore-bearing fluid with time. No such distinct trend occurs in Devon and Cornwall, but it does seem that the low temperature mineralisation should have the lowest salinity. Normal-trending veins fit into this relationship, suggesting that the minerals in them are the product of one main mineralization sequence. Moreover, their (relatively) low salinities suggest a hydrothermal origin, presumably related to the granites. The high salinities and low temperatures of the mineralized crosscourses are suggestive of a different origin. The salinity values are similar to other Pb/Zn/F deposits in Britain of Mississippi Valley type (North Wales, Pennines, Derbyshire). For these deposits it has been suggested that the ore was transported by Carboniferous or Permo-Triassic connate waters. The mineralization in the crosscourses of South-West England could have a similar origin, and need not be genetically related to the granites.

Smith (1974) has suggested that the higher filling temperatures and the magmatic characteristics (high Y, Ce and La content) of fludrites from Cornwall and the north Pennines indicate that they are directly related to the granites. However it seems feasible to ascribe these characteristics to a higher geothermal gradient (waning igneous activity) and leaching of granitic material by these fluids. The granites in these two areas have thus acted only as modifying agents.

Galena ages from Devon and Cornwall (Moorbath 1962) are all approximately the same (280m.y.) - suggesting one episode of

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mineralization. The crosscourses are definitely later than the normal-trending veins in the area, as they often displace the latter. In fact Dearman (1963) has concluded that movement along the crosscourses could have occurred as recently as in the Tertiary. The distinct structural trend and salinity of these mineralized veins seem to set this phase of mineralization apart. The idea of one period of mineralization would thus be untenable.

Sulphur isotope evidence supports this view. Gavelin *et al.* (1960) gave $\delta^{34}S$ values for sulphide samples from Devon and Cornwall. These indicate that whilst the normal-trending veins are of 'magmatic' origin, the N-S veins are not. Although not conclusive, the Pb/Zn/F mineralization in the crosscourses could have been formed by leaching of sedimentary (biogenic) sulphides.

3. Conclusions

Fluid inclusion studies in South-West England indicate that the salinities of fluids associated with N-S Pb/Zn/F veins (crosscourses) are distinct from those associated with the main sequence of mineralization (ENE-WSW trending veins). The salinities for the crosscourses (25 eq.wt.% NaCl) are similar to those of other Pb/Zn/F deposits. From this it is suggested that the origin of these deposits is not directly linked with the presence of granite. Tentatively, it seems that the fluids could be of connate or meteoric origin, and the sulphides of biogenic origin. If the above conclusions are correct, classic ideas about the mineral zoning in Devon and Cornwall would need to be modified. Much of the low temperature mineralization would, in fact, not fit into this zonal scheme. Similarly, such statements as the following would clearly no longer be applicable. . . ."Since their (crosscourses) mineral content has every appearance of belonging to the granitic episode they probably represent the final stage of that mineralization." (Dines 1956 p. 14).

ACKNOWLEDGEMENTS are due to F. W. Smith and T. J. Shepherd for helpful discussion and use of their equipment. Professor R. A. Howie critically read the manuscript. This work was undertaken as part of a Ph.D. research project at London University, financed by N.E.R.C.

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Dept. of Geology
King's College
Strand
London WC2R 2LS

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‘CARBONAS’ - A REVIEW

by N. J. Jackson

Carbona is a local Cornish mining term applied to any irregularly-shaped, non-lode ore body, usually tin bearing and formed by a replacement process. Morphologically there are two distinct types - pipes and sheets. Pipes are cylindroidal bodies of intensely altered rock with a maximum diameter of 20m and up to 200m in length. They may be vertical, inclined or horizontal and they are usually associated with a mineralized fissure. Sheets are much more lodelike in character. They are planar bodies of intensely altered rock usually on the footwall of a fault, or below the intersection of two fissures. They are usually subvertical, with dimensions of up to 20m in width and up to 200m along the strike and dip.

Favourable sites for the development of replacement deposits occur (a) in the roof of the pluton above a vertical ore shoot (e.g. East Lovell and St. Ives Consols) (b) at the margins of the pluton near the intersection of the ore shoot with the contact (e.g. Geevor) (c) outside the pluton within the ore shoot at the intersection of a granite sheet with a mineralized vein system (e.g. Levant and the No. 12 lode South Crofty).

Geographically, most of the documented replacement deposits occur in the extreme south-west of the peninsula, the St. Ives and South Wendron districts being particularly important.

The associated wallrock alteration is usually intense and reflects the local composition of the fluids e.g. greisenization at East Lovell, tourmalinization at St. Ives Consols, chloritization at Geevor, feldspathi-ration at Levant. The ore assemblage is usually cassiterite in association with simple sulphides (pyrite, chalcopyrite and arsenopyrite). Fluorite, tourmaline, chlorite and quartz are the common gangue minerals.

The two main controls over the localization of these deposits are (a) replacement below a structural trap (e.g. a clay filled fault), (b) selective replacement of a favourable lithological horizon (e.g. replacement within a granite sheet).

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THE LEVANT MINE CARBONA

by N. J. Jackson

Abstract. Intense, disseminated and massive cassiterite-sulphide mineralization occurs at the intersection of a granite sheet complex and a minor mineralized vein system on the 180 fathom (329m) level of Levant mine. The associated wall-rock alteration includes the first recorded development of extensive albitization in South-West England.

1. Introduction

The famous old mine known as Levant is situated on the cliffs 3km north of St. Just (SW 367346). During a recent exploration programme by Geevor Tin Mines Ltd. a mineralized granite sheet (the Carbona) was intersected on the 601 level (-329m) approximately 120m south-west of Skip shaft. A drive south-east from the cross-cut, and a subsequent extensive diamond drill programme, revealed that the mineralization was extremely irregular in distribution and value. The main controls over the localization of ore are major and minor fissures, joints, the granite junction and zones of intense alkali metasomatism within and bordering parts of the granite.

2. The granite

The granite sheet is about 8m thick and dips to the south-east at 25° (Fig. 1 A and B). It cuts a sequence of fine-grained dark pelitic hornfelses with minor volcanic horizons. The granite is a white, moderately coarse (0.5cm), aphyric, leucocratic rock. It is composed of microperthitic orthoclase with well-developed patch and band exsolutions, primary quartz with undulose extinction and sutured grain boundaries, plagioclase An_{10-15} which is sericitised, biotite and muscovite. Accessory minerals include apatite, fluorite, tourmaline and opaque ores. The average mode of six unaltered granites is quartz 35.5, orthoclase 32.5, plagioclase 27.0, muscovite

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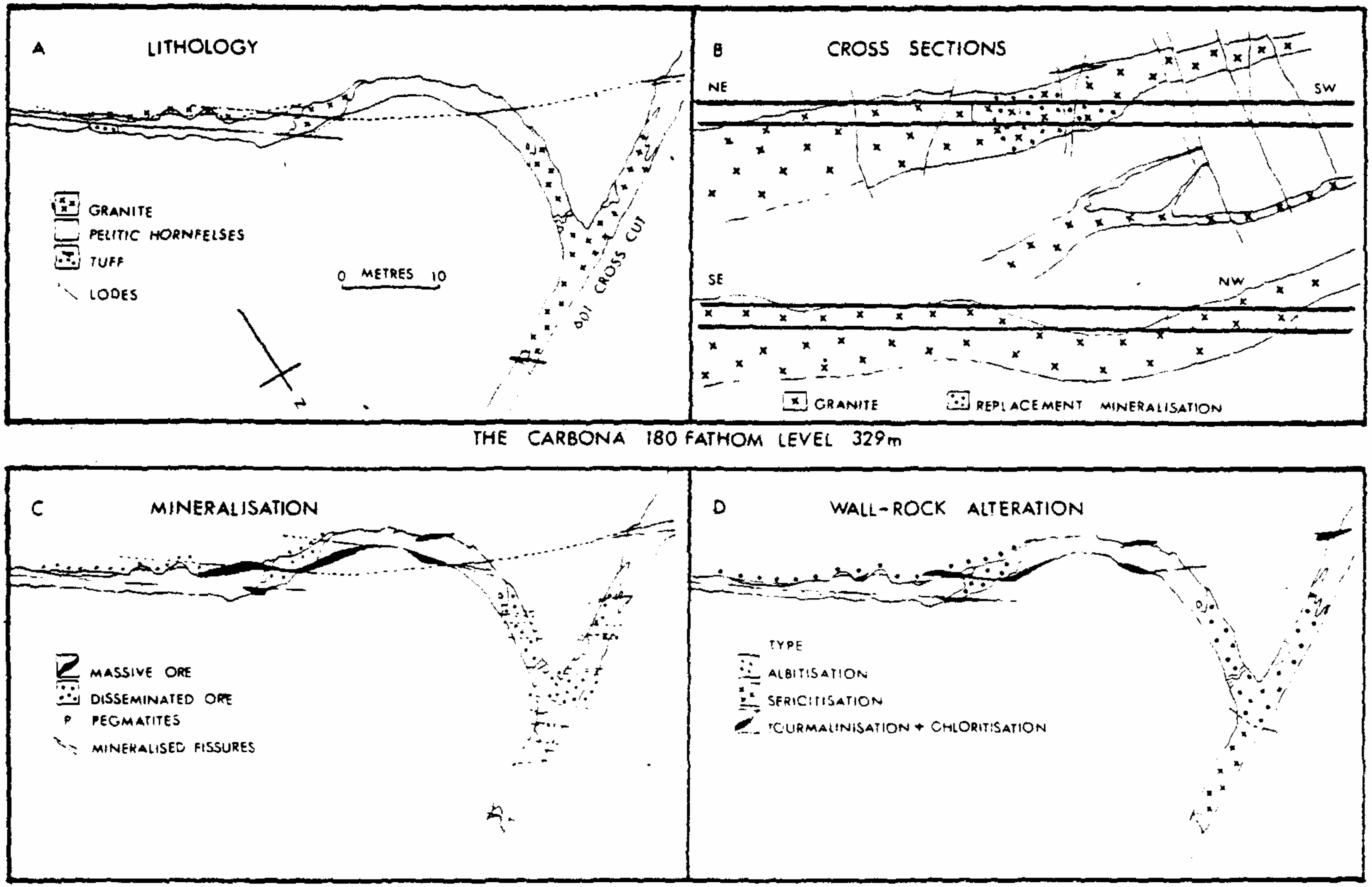

FIGURE 1. The Carbona at Levant Mine.

2.0, biotite 2.5, tourmaline 0.5. With reference to the system Q-Or-Ab-H_2O, both the unaltered granites of the main pluton (Wilson 1972), and the Levant granite, plot close to the ternary minimum at 1,000 bars. Like other granites of South-West England the Levant granite is enriched in B, Li, Rb, F, Su, As and depleted in Sr and Ba.

3. Mineralization

The mineralized rock occupies a belt up to 10m wide trending north-west through the granite sheet (Fig. lc). There are two types of deposit - disseminated cassiterite-sulphide and massive cassiterite-sulphide. Simple pegmatites composed of quartz and fluorite, bordered by chlorite and feldspar, occur within the roof zone. The massive cassiterite-sulphide deposits occur at the intersection of some of the larger fissures with the granite metapelite contact. The ore consists of cassiterite, arsenopyrite, chalcopyrite and pyrite in association with tourmaline, quartz, chlorite, fluorite and pink orthoclase. Tin and copper values are variable but locally may be as much as 2-3%. Vuggy structures containing cassiterite, sulphides, tourmaline, quartz, calcite, fluorite and pink orthoclase are also common. Disseminated cassiterite-sulphide deposits occur throughout the ore zone. These consist of fine grained intergrowths of pyrite, chalcopyrite and arsenopyrite in association with cassiterite, chlorite and often tourmaline. Average tin and copper values are between 0.2% and 0.3% respectively.

4. **Wall-rock alteration**

The mineralized granite shows a variety of mineralogical and chemical changes in response to hydrothermal metasomatism by the mineralizing fluids. The alteration includes kaolinization, chloritization, tourmialinization, hematization and silicification. However, the most widespread type of alteration is albitization.

(a) Mineralogical changes in the wall-rock

The pattern of mineralogical variation in the wall-rocks reflects the north-west trend of the ore zone (Fig. 1 d). The outer zone of the alteration envelope consists of the sericitization of plagioclase coupled with the chloritization of biotite and the growth of secondary unstrained quartz. This zone ends abruptly at the

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junction with the ore zone. In the ore zone the granite is completely recrystallized to form a rock containing up to 90% albite. The albite is usually unaltered although it may be replaced by tourmaline, chlorite, cassiterite and sulphides. At the present time the process by which the orthoclase and plagioclase is converted to albite is poorly understood. If the process is a straight cation exchange reaction involving the substitution of Na for K and Ca in the feldspar structure, examples of orthoclase and plagioclase mantled by albite might be expected. This has not been found. However, when relict orthoclase is found it is always altered to kaolinite. This suggests that the conversion might be a two-stage process.

The probable sequence of wall-rock alteration events is:

(1) Formation of albite in the ore zone and sericite in the envelope.

(2) Introduction of B, S, Mg, Fe, (Sn, Cu, As) to produce the tourmaline, chlorite, cassiterite sulphide assemblages.

(3) The late formation of K feldspar and the local sericitization of albite.

(b) Chemical changes in the wall-rock

A traverse was made in 601 cross-cut from unaltered granite into the ore zone, the results of this traverse are shown in Fig. 2. On a wt% basis the components which increase in the ore zone are Na_2O, MgO, total Fe, Al_2O_3, MnO, TiO_2, H_2O, B, S and ores. Those which decrease are SiO_2, K_2O and Rb, and those which remain constant are CaO, F, P_2O_5, Cr, Ni and Li.

Compared with a previous study of wall-rock alteration in the same area (Wilson 1972) the trends described above show considerable differences. The main differences are:

(1) The reverse relationship of the concentration of alkali cations in the wall-rock, Na>K at Levant, K>Na at Geevor.

(2) The greater mobility of Si and Al at Levant.

(3) A greater introduction of material into the wall-rocks at Levant which increases the S.G. of the rocks from an average of 2.65 to 3.5.

5. **Formation**

A model for the formation of the Carbona is now proposed. The granite sheet was intruded approximately 50m vertically above the main pluton. At a later date a major channelway developed passing through the main pluton and the granite sheet. Mineralizing fluids

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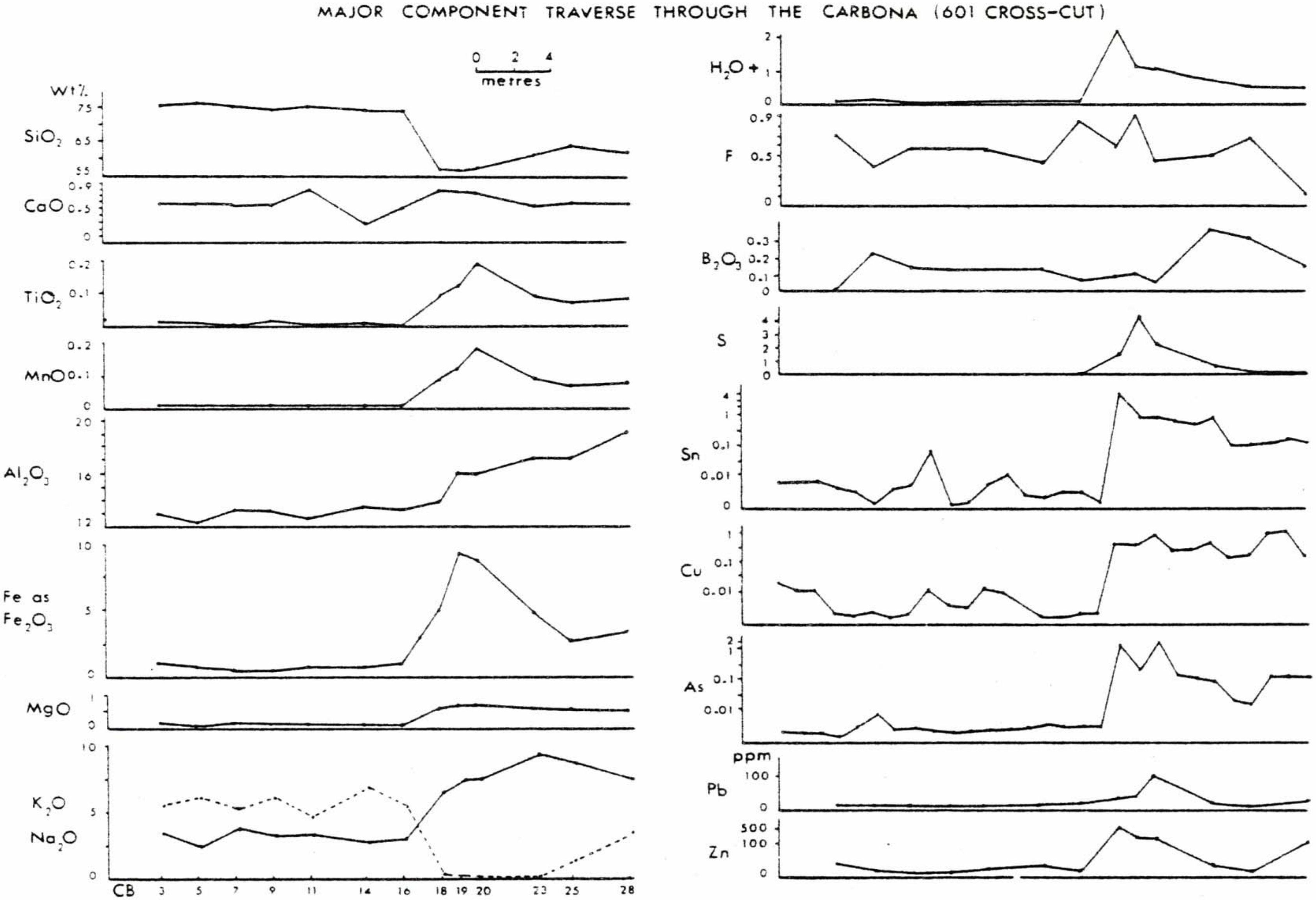

FIGURE 2. Major component traverse through the Carbona.

passing through the channelway reacted at depth with the wall-rocks of the main pluton. The main wall-rock alteration process in this zone would probably be sericitization, which involves the liberation of Na from plagioclase. The sodium-rich solutions travelled through the channelway until they reached the granite sheet. The main fissure is not very well developed in this area and the solutions were forced to migrate through small fissures in the sheet. Intense reaction took place involving cation exchange reactions between the Na in the fluids and K and Na in the orthoclase and plagioclase. Si and K were removed from the system and fixed at higher levels in quartz-chlorite-orthoclase veins. Na was fixed within the system in albite and Ca in fluorite. After the initial phase of alterations, Sn, Cu, Fe, As, Mg, B and Si were introduced to produce the oretourmaline-chlorite-quartz assemblage. The latest solutions had a low Na/K ratio allowing orthoclase to form.

WILSON, I. R., 1972. Wall-rock alteration at Geevor tin mine. *Proc. Ussher Soc.,* **2**, 425-434.

Dept. of Geology
King's College
Strand
London WC2

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Primary dispersion of rubidium at Wheal Jane at Cligga Head mines and its possible use as a pathfinder (Abstract):

by M. J. Al-Atia

Rubidium is a volatile element which is highly mobile in primary geological environments. Because of this it appeared possible that Rb might form distinctive dispersion patterns around ore bodies and thus have a potential use as a pathfinder element, a potential enhanced by the fact that the analytical chemistry of Rb is based on simple techniques. This assumption has already been tested in several different geological environments. The present paper reports on the investigation of the distribution of rubidium at Wheal Jane and Cligga Head mines, and how it correlates with the distribution of K, As, Sn, Cu and Zn.

Rubidium distribution at Wheal Jane is well developed and 61 per cent of the samples of killas collected (70 samples) contain more than the threshold value of 535 ppm Rb: this anomalous dispersion extends for up to 10m from the lode and is independent of K concentration which remains fairly uniform in both background and mine samples. The correlation coefficient between Rb and K is very high (0.95) in the background samples, while it has an insignificant value in the mine samples (0.1). Rb and Rb/K correlate well with Sn, As, Cu and Zn. With depth, Rb and Rb/K decrease and samples from the 5th level are less anomalous than those from the 3rd: this occurs in both 13 and Moor lodes. The elvan also contains high Rb (800ppm), and where the, rock has been cut by small veinlets the values are still higher.

At Qigga Head Rb is strongly dispersed in the greisen and killas, and samples collected at the surface show that Rb/K in greisen is as much as 20 times that in the granite. Rb/K also correlates positively with other elements investigated. It may be noted that although samples of killas from the surface show high Rb/K, those from the second level underground show even higher values, together with higher values for As and Sn as well.

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These results, together with other information gathered by both the writer and other workers, support the suggestion that Rb may well be an ideal pathfinder for certain types of mineralization.

Dept. of Geology & Oceanography
University College of Swansea
Swansea

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A GEOCHEMICAL DIVISION OF THE NAMURIAN SIIALES OF DEVON AND CORNWALL AND ITS SIGNIFICANCE

by Stephen McCourt

Abstract. The results of X.R.F. analysis on 88 samples of Namurian shale are presented. Statistical tests, in particular the Kolmogorov-Smirnov two sample test, indicate the presence of two distinct groups in the sample analysed. The geological implications of this distinction are discussed.

1. Introduction

Remapping of the area between Bridestowe and Launceston led the author to the conclusion that two structural levels, separated by thrusts, can be recognised on the west side of the Dartmoor granite. The Lower Carboniferous sequences of the allochthon can be distinguished lithologically and paleontologically from those of the autochthon, which were described from Meldon by Deartnan (1959). Distinctions between the Upper Carboniferous lithologies are far less obvious as "Crackington" facies shales and sandstones appear in both the allochthon and the autochthon. In poorly exposed ground therefore, the structural affinities of these beds were difficult to establish.

D. V. Hogan and T. R. Harrod, Officers of the Soil Survey, had noticed (pers. comm.) that the soil type generated on that part of the Upper Carboniferous outcrop considered to be allochlhonous differed front that supported by the Crackington shales exposed in the Feign Valley and around Exeter. A geochemical project was initiated to test the possibility that this difference was caused by variations in the chemistry of the parent material.

2. Sampling and analysis

A total of 88 samples was analysed by X-ray fluorescence, for selected major and trace elements, using a Philips P.W. 1220 at Exeter University; the shale was run against a standard

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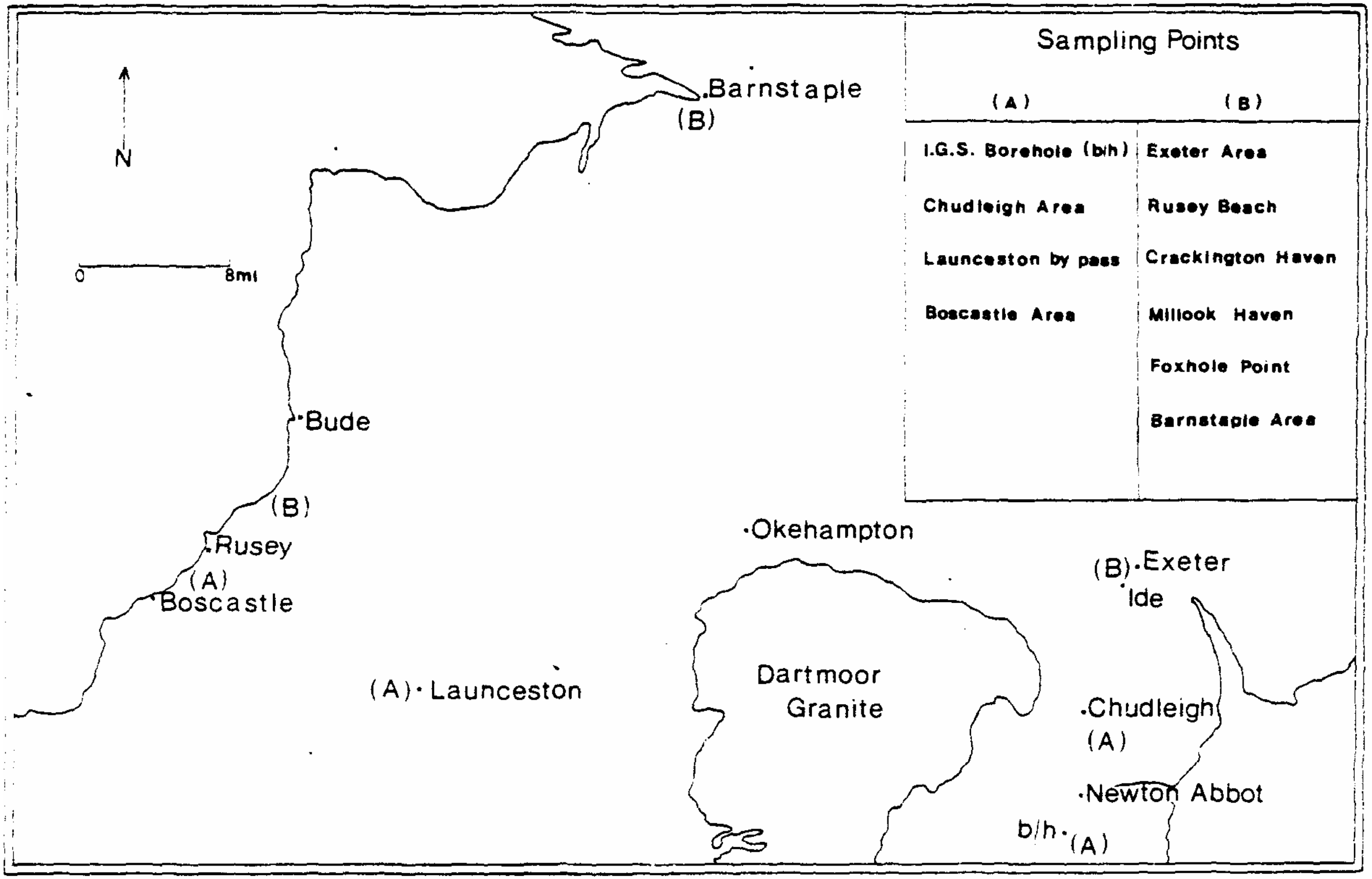

FIGURE 1 Distribution of sampling points.

K-S ONE SAMPLE TEST

Critical Values of D

Sample Size	Alpha Value For Dmax				
	0.20	0.15	0.10	0.05	0.01
88	0.1134	0.1028	0.1293	0.1442	0.1728

Computed Values of Dmax		Interpretation
SiO_2	0.0413	Accept the null
TiO_2	0.1347	Reject the null
Al_2O_3	0.0719	Accept the null
T. Fe	0.1612	Reject the null
MgO	0.0422	Accept the null
CaO	0.9387	Reject the null
Na_2O	0.1314	Reject the null
K_2O	0.1084	Accept the null

Table **1** Dmax expresses the maximum difference (D) between a normal cumulative frequency distribution and the observed distribution

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from Nottingham University (No. 1007). The analysis was for comparative purposes only as certain of the values supplied for the standard were considered speculative. The shale samples were drawn from a wide area (fig. 1), and divided into Group A, corresponding to the allochthon, and Group B, corresponding to the authochthon. Sufficient samples were collected to allow valid statistical analysis and care was taken to ensure that equal numbers were present in both groups. Because of the need for clean fresh material, the number of sampling points was restricted. Material from natural exposures was supplemented by samples obtained from an I.G.S. borehole at Rydon Ball Farm near Newton Abbot, and from a number of boreholes sunk in connection with the Chudleigh and Launceston by-passes.

After analysis, the data were subjected to a series of statistical procedures to test whether the two sample groups had been drawn from a single population (the Null *hypothesis*) or from two different populations (the Alternative *hypothesis*).

The Kolmogorov-Smirnov (K-S) one sample test was used to determine whether or not the data were normally distributed. The results (table 1), show that only $A1_2O_3$, SiO_2, K_2O and MgO are normally distributed at the chosen levels of significance.

In view of these results, it was decided to use non-distribution dependent tests only and in particular the K-S two sample test. The K-S two sample test is particularly valuable for it determines the degree of agreement between two cumulative frequency distributions, thus taking into consideration all aspects of the sample distribution.

The results of this test are shown in table 2.

3. **Conclusions**

The results of the statistical tests, and in particular the K-S two sample test, show quite clearly that the sample analysed consists of two distinct groups (A and B) which correspond exactly with the structural levels referred to earlier.

This distinction now allows characterization of Upper Carboniferous shale formations, on the south side of the "Culm Synclinorium", in their different structural settings. As such, it

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K-S TWO SAMPLE TEST

Critical Values of Dmax

Value of Dmax so large as to call for rejection of Ho at the indicated level of significance

0.260172	0.290028	0.315618	0.347607	0.368932	0.415849
0.10	0.05	0.025	0.01	0.005	0.001

Computed Value of Dmax		Interpretation	
SiO_2	0.114		Accept Ho
TiO_2	0.159		
Al_2O_3	0.159		
T. Fe	0.100		
MgO	0.159		
CaO	0.368	0.005	Reject Ho
Na_2O	0.430	0.001	
K_2O	0.260	0.10	
Sr	0.270	0.10	
Rb	0.320	0.025	
Ga	3.7778 (K_D)	0.10	
Ni	4.4444 (K_D)	0.05	
Ba	4.4444 (K_D)	0.10	

Table **2** K_D Value: the numerator of the largest difference between two observed cumulative frequency distributions i.e. of D

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provides a key to the stratigraphy and structure in this area of indifferently exposed terrain. It appears therefore that:

(i) the Upper Carboniferous shales occurring as allochthonous sheets on the east and west sides of the Dartmoor granite were deposited with a different provenance from those incorporated in the more open folds of the autochthon in these same areas.

(ii) sedimentary structures suggest that the basin in which the allochthonous shales accumulated was fed by erosion of an uplifted landmass to the south of the fold belt, whereas the autochthonous shales show E-W transport directions (Freshney *et al.* 1972).

(iii) recent field work, both east and west of the Dartmoor granite, indicates that these two areas of deposition have subsequently been brought together tectonically. The shales now seen as the allochthon have slid northwards after uplift from the deeper parts of the fold belt.

ACKNOWLEDGEMENTS. The author is indebted to the South West Road Construction Unit and in particular to Mr. N. Eathorne (Superintendent Engineer Devon Sub-Unit) without whose assistance many of the samples would not have been obtained. Thanks are also due to Mr. P. R. A. Wells who computed the statistics and to Mr. D. L. Dallow for help and advice during the analysis. A research studentship from N.E.R.C. is gratefully acknowledged.

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Dept. of Geology
The University
North Park Road
Exeter

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Mineralization of the Exmoor district (Abstract):

by F. J. Rottenbury

Exmoor has a long mining history and a hundred mineralized sites are known in the 380 square miles of the district. Mineralization is confined within narrow bands of country which trend east-west across the whole district. It appears to be related to major underlying linear structural features.

Two main paragenic mineral groups are found; Fe, Cu in eastwest trending fissures and Pb, Zn, Sb with north-west trends. K-Ar dating indicates two main age groups with peaks at 300 and 345 M.Y. Twelve previously unrecorded minerals have been found but the mineralogy is simple. Exsolution and other textures indicate relatively high formation temperatures in the south-west of the area. Vague horizontal zoning, discernible in the Heasley area, could be due to lithological control of deposition.

The hydrothermal nature of the deposits is clear, but the source of mineralization is not, although postulated northward thrusting of Exmoor would require the source to lie to the south

Similarities between Exmoor deposits and deposits in South Devon and North Cornwall suggest that a widespread early phase of mineralization took place before the main tin-tungsten phase which is thought to be associated with the Hercynian granite.

Pixeyweek
Alswear
South Motion

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Clay ironstones on Exmoor (Abstract):

by R. F. Youell

Many of the iron ores on Exmoor are secondary fissure fillings in the Devonian, though there are possibilities that some of the haematite in the Triassic rocks may be a primary ore. Despite reports of clay ironstones from Exmoor, very little accurate evidence has been presented on their occurrence.

The earliest references to clay ironstones appear in the Knight documents between 1855 and 1859, though there are conflicts of evidence as to whether the deposits were genuine.

On a map of the Dowlais Iron Company are two lines marked clay ironstone, and they fit exactly with two old workings at Orchard, on the west side of a tributary of the Exe, and to the north near the abandoned railway. The ores are fairly high in silica, but also quite rich in ferric iron. The hand specimens, although not as crumbly as typical Liassic ironstones, do appear to be different from other Exmoor ores. They are apparently oxidized oolitic mudstones, with white and red sections resembling a fully oxidized ore from the Lias. The appearance is in keeping with a clay ironstone that has been oxidized and hardened in the process of weathering. The quarries do not appear to have normal road metal or building stone in them and there is little evidence that these workings, though a considerable distance from the nearest road, had any trackway or cartroad away from them.

Two other early workings that have escaped mention in the reviews of mineral operations on Exmoor, at least as regards Geological Survey reports, are those at Stone Down and Codsend Moor. They resemble the Orchard material in being oolitic ores oxidized and hardened by weathering.

It may be significant that all of these clay ironstone workings are about a mile north of the limit of the better known Exmoor iron ore workings (i.e. from Eisen Hill to Exford and Exe Cleave).

Another small working for clay ironstone was reported at Watersweet (sic.); this has been detected on the south bank of the East Lynn about 90 metres from the confluence.

Dept. of Physics
The University
Leeds

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Iron-manganese mineralization at Merehead Quarry, Eastern Mendips (Abstract):

by C. Alabaster

Iron and manganese oxides occur in faults, joints and fracture zones as replacement deposits in the Carboniferous Limestone. Prior to mineralization, some of these structures had developed into open fissures, subsequently infilled with limestone rubble, or become underground water-courses. The latter contain large volumes of inverted aragonite and "flowstone" calcite. Two types of fissure vein may be distinguished on the evidence of primary fissure-fill: they are "high calcite" veins, in which calcite is the major infill component, and "low calcite" veins, which have lesser amounts of primary calcite.

It is suggested that solutions of iron and manganese entered the fissures and underwent chemical separation. Precipitation of iron was universal. Locally, precipitation of manganese followed. Colloidal precipitates were usually formed. Foreign ions present in the original solutions became adsorbed by the gel precipitates. Remobilization of these ions during diagenesis, led to the development of the lead carbonates cerussite and hydrocerussite. Certain rarer minerals occur in association with them: crednerite ($CuO.Mn_2O_3$) and the oxychloricfes mendipite ($Pb_3O_2C1_2$), chloroxiphite ($2PbO.Pb(OH)_2.CuCl_2$) and diaboleite ($2Pb(OH)_2. CuCl_2$) have been found.

Most of the fissures show variable amounts of discordant Jurassic infill, composed mainly of limestones and breccia. The Jurassic infillings are almost totally unaffected by the earlier Mn-Fe mineralization (which is probably of Triassic age) except for cases of local staining and small-scale replacement at places adjacent to a particularly heavily mineralized part of an iron-manganese vein. Anions from the Jurassic sea may have contributed to oxyctiloride mineral development.

Sulfide-bearing calcite-baryte veins cut the mineralized fissures. At some localities they can be seen to continue up into the overlying Inferior Oolite.

Dept. of Geology, The University, Bristol

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ALLUVIAL TIN AT COLSTON, BUCKFASTLEIGH

by R. C. Scrivener and J. H. Walbeoffe-Wilson

Abstract. Unsorted sediments at the base of the alluvium of the River Dart contain cassiterite in addition to magnetite, specular hematite and gold. The tinstone is derived from a wide area of the Dart catchment. The deposit is considered to have formed under periglacial conditions.

1. Introduction

The area lies on the west bank of the Dart, 2.5km south-east of Buckfastleigh; it occupies a N-S strip of alluvium, which reaches a maximum width of 100m. The elevation is 17m O.D, and a median grid reference is SX 7520 6450. To the west, the deposit is flanked by a terrace feature consisting of head-derived gravel.

Some years ago, the site was prospected by one of the authors (J.H.W-W) in the course of investigating alluvial tin deposits in the catchments of the rivers Dart and Teign. Test pits were excavated along an E-W line between Colston House (SX 7511 6489) and the River Dart, and from these, heavy mineral concentrates were obtained by panning. Tin content of the concentrates was found by chemical analysis. For the purposes of subsequent work, grab samples from pits and surface exposures were collected and subjected to sieve analysis and heavy liquid separation.

2. The deposit

The alluvium rests on an irregular surface of grey, Upper Devonian slates, which may be seen exposed along the west bank of the river. A buried channel, 35m wide and running N-S in the middle of the alluvial tract was located by the line of test pits. The base of this channel lies 1-2m below the present river level. A typical section of the alluvium in the deepest part of the channel is given in table 1.

At the eastern and western extremities of the test pit line, the bedrock lies a little above the present river level. The alluvium sequence is attenuated, but tin ground is present, reaching a

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Table 1. Test pit at SX 7522 6454, vertical section

Lithology	*Thickness/m*	*Depth/m*
Brown, clayey soil	0.50	0.50
Yellow-brown clay-silt, with many angular cobbles and small boulders of slate, limestone and volcanic rocks	1.80	2.30
Stiff, grey clay	0.24	2.54
Tin ground, cobbles and gravel with blue-grey clay and silt. A 0.08m band of yellow clay at 3.17m depth	0.80	3.34
Bedrock, grey slate, at		3.34

maximum thickness of 0.30m, where it is exposed in pits and at the surface along the river bank.

The tin-bearing sediment is composed of a range of particle sizes from small boulders to silt and clay. It is completely unsorted and shows no evidence of bedding. In a typical sample, the silt and clay fraction accounts for 30-35 per cent of the whole, it is yellow-brown or, more commonly, blue-grey in colour. Angular and sub-angular grains of quartz and country rock, with abundant light brown mica flakes, form the bulk of the sand fraction; the remainder consists of rounded grains of quartz with iron ores, tourmaline, cassiterite and other heavy minerals. The larger size fractions fall into two distinct populations. The bulk is composed of rather angular state, limestone and volcanic rock fragments of local derivation; the second, and lesser population, has an upper size limit at about 10cm diameter and consists of well rounded clasts of quartz and quartz-tourmaline veinstone, hornfels, tinstone, magnetite and hematite.

Table 2 gives a detailed analysis of a typical sample of tin-bearing sediment. In addition to the heavy minerals listed in the table, sulphides and wolframite have been noted in the finer size fractions, but these are of rare occurrence. Occasionally, fragments of wood, nuts and mammal bones have been found in the upper part of the tin ground.

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Table 2. Particle size and heavy mineral distribution in tin-bearing sediment,
Sample collected at SX 7524 0427

Particle size range, sieve aperture/mm	*Weight Per cent*	*Heavy minerals*
100-5	21	Common: magnetite, specular hematite, tourmaline, chloritic veinstone, red-brown hematite, limonite Minor: tinstone
5-1	20	Common: tourmaline, specular hematite, red-brown hematite Minor: cassiterite Accessory: gold
1-0.063	25	Common: tourmaline, mica, specular hematite, red-brown hematite Minor: cassiterite, zircon, rutile Accessory: garnet, gold
Finer than 0.063 (silt and clay)	34	Heavy minerals not determined

3. Origin of detrital minerals

An interesting feature of this deposit is the unusual suite of heavy minerals, which includes, in the relatively coarse fractions of the tin-bearing sediment, cassiterite, magnetite, specular hematite and gold. Cassiterite is found in rounded fragments of veinstone varying in size from 100mm to Smm across. Below 5mm the grains consist of more or less pure cassiterite, which has a colour range from pale honey-brown to deep red-brown. This fine cassiterite is persistent to the finest sieve fraction examined (0.063 mm aperture). The coarse fraction veinstone shows a wide variation in composition, typical samples having the following constitution:

(i) Euhedral, coarse, red-brown cassiterite with quartz and aggregates of blue, acicular tourmaline.

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(ii) Finely disseminated, honey-brown cassiterite in a quartz-chlorite matrix.

(iii) Veinlets of brown cassiterite in pale grey quartzite.

(iv) Coarse, red-brown cassiterite veining black, hornfelsed mudstone.

(v) Coarse, red-brown cassiterite in a granitic matrix of quartz, tourmaline and feldspar.

(vi) Red-brown cassiterite with specular hematite, quartz and tourmaline.

Hand specimens and thin sections of tinstone from the alluvial deposit have been compared with specimens from veins in the Dartmoor Granite and its metamorphic aureole, and it appears that the alluvial material is derived from a wide area of the Dart catchment. Cassiterite-bearing veins in the Nexworihy and Birch Tor areas have contributed to the deposit, and specimens collected from the Holne and Scorriton districts closely resemble the mineralized hornfels of (iii) and (iv) above. Typically the granite-derived veinstone has a smaller average particle size than the material derived from the aureole. This reflects the difference in distance of transport; the tin-bearing hornfels is normally present in large 20-100mm fragments, while the granitic veinstone seldom exceeds 25mm diameter.

Irregular, rounded masses of magnetite are common and range in size from 10-80mm across. The mineral is massive and finely crystalline with abundant small vesicular cavities, which are commonly filled with a limonitic alteration product. No source of magnetite is known within the catchment of the Dart above Côlston. It is probably derived either from a deposit such as that at Haytor Vale (SX 772 771), in Carboniferous sediments of the metamorphic aureole of the Dartmoor Granite (Dines, 1956, p. 732) or from the Devonian volcanic rocks, as at Bulkamore Mine (SX 749 632), where magnetite impregnates pyroclastic rocks (Dines, 1956, p. 740).

Specular hematite is present as irregular masses up to 200mm across, and varies from a hard, granular, massive variety to a soft, friable mixture with earthy, red hematite. It is probably derived from the thin iron ore veins found in the Devonian limestone of the Buckfastleigh area. The tin bearing deposits of central Dartmoor, particularly the Birch Tor area, contain specular hematite in association with quartz, tourmaline and cassiterite. Although these fall within the Dart catchment, it is unlikely that hematite from that

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source would have survived transport to the lower reaches of the river.

Gold occurs rarely as unrolled flakes up to 5mm across. Its derivation is problematic; detrital gold was known from the alluvial stream tin works in Cornwall (Dines, 1956) and has been recorded from streams in the Sheepstor area of Dartmoor (Cook *et al.,* 1974, p. 166). Within the Dart catchment, Brammall and Harwood (1926, p. 14) recorded gold in a pegmatitic rock found at Bittleford Down (SX 707 756), and associated with quartz and hematite at various other localities on the granite.

4. Conditions of deposition

Cornish stream tin deposits, described by Dines (1956) and De la Beche (1839), show a close resemblance to the deposit at Coiston. In every case, the tin ground forms the lowest part of the alluvium, and rests on an irregular bedrock surface. Tin values within such deposits are patchy and this is also true of the prospect under consideration. At Colston, the best values are found in the buried channel, in places reaching 20lb tin/cubic yard, and in crevices in the bedrock surface away from the channel. It would seem that this surface, scattered with locally derived boulders, acted as a natural riffle for heavy mineral fragments washed down the Dart from the high ground of the Dartmoor Granite and its aureole. Periglacial conditions, with high seasonal precipitation, were probably responsible for the type of deposit seen at Colston. Transport of heavy fragments of veinstone was effected during periods of violent flooding in the Dart channel, the finer sediment would have been deposited to form a matrix for the boulder gravel during the seasons of lower rainfall.

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Devon

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Clay mineral suites in the post-Armorican formations of S.W. England (Abstract):

by M. E. Cosgrove

Over 1,000 samples of sedimentary rocks, taken from surface exposures and boreholes, have been studied for their clay mineral suites. The rocks, ranging in age from Permian to Oligocene, have been studied in the laboratories at Southampton as part of various staff, postgraduate and undergraduate research projects.

The results show that the Permo-Triassic (including Rhaetic) sediments are dominated by illite, usually with chlorite and some mixed-layers (mainly illite-montmorillonite interstratifications), but with only rare kaolinite and montmorillonite. The White Lias marks the incoming of kaolinite, to establish an illite-kaolinite-chlorite suite, which persists from the Lias and into the Kimmeridge Clay, where chlorite disappears. Kaolinite disappears in the Portland-Purbeck strata where an illite-montmorillonile assemblage is established up to the level of the well-known Cinder Bed. Above this horizon kaolinite reappears, is well established in the Wealden, and persists into the Tertiary; the Chalk is outstandingly different as it is dominated by montmorillonite. In the Tertiary sediments of the Hampshire Basin there are two main clay mineral suites, illite-kaolinite on the western side of the basin and montmorillonite-illite with minor kaolinite and chlorite on the eastern side. Interpretation of these assemblages is complex, with apparently conflicting evidence of provenance, sedimentary environment and diagenesis.

Dept. of Geology
The University
Southampton

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THE STRUCTURE AND AGE OF THE GNEISSES OF SARK, CHANNEL ISLES

by F. A. Gibbons and G. M. Power

Abstract. Examination of field relationships on Sark has expanded a structural history oversimplified by previous workers. The island consists essentially of semi-pelitic and amphibolitic gneisses which have undergone at least two intense deformational episodes before the intrusion of, and formation of a foliation in, the early Cadomian (late Precambrian) granites. The Sark gneisses compare so closely with the 2,600 m.y. old gneisses of Guernsey and La Hague, France, that there seems a strong probability of a long time lapse between the formation of the gneisses and granitic intrusion.

1. Introduction

The island of Sark occupies a central position with respect to the other Channel Islands and the nearby French mainland. It consists of an ancient gneissic complex intruded by Late Precambrian foliated granites (Fig. 1), the whole having been affected subsequently by several phases of dyke injection and much faulting. The basement gneisses may be divided into semi-pelitic and amphibolitic varieties but both appear to haxe undergone a similar deformational history. The banded semi-pelitic gneiss crops out in almost every main bay around the central part of the island. The amphibolitic rocks form concordant horizons at a number of structural levels within the semi-pelitic gneisses, varying in size from thin, boudinaged lenses (e.g. Telegraph Bay, G.R. 459752) to massive units up to 50m. in thickness (e.g. Port du Moulin, G.R. 458766). The foliated granites occur as large masses making up both the north of the island and Little Sark in the south and also as sheets in the central part of the island. Previous papers may be referred to for a more detailed description of Sark rock-types (Sutton and Watson 1957); petrology (Woolridge 1925); general geology (e.g. Hill and Bonney 1892, Plymen 1926).

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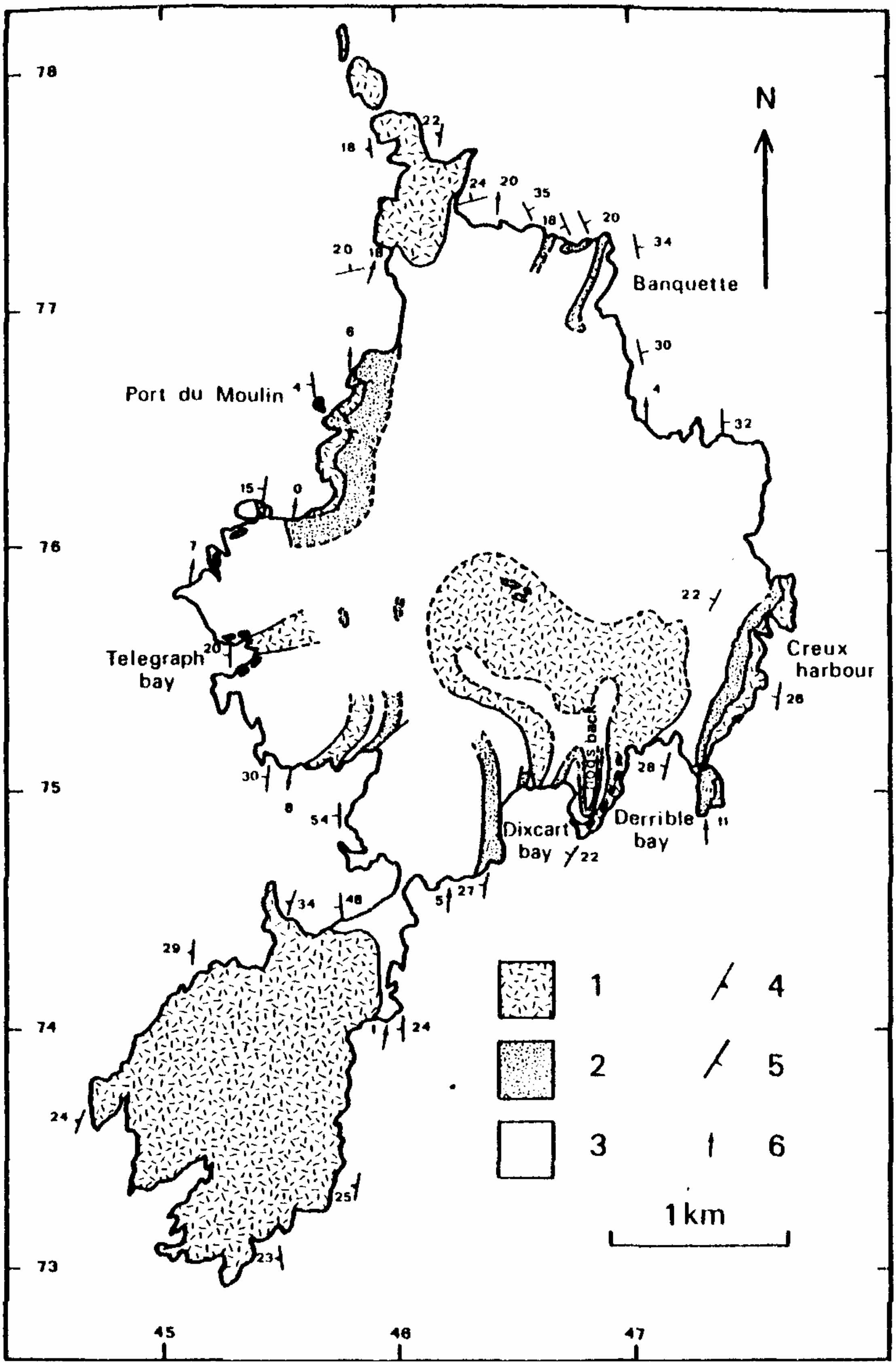

FIGURE 1. Geological sketch map of Sark (dykes and most faults omitted). Key: 1. Foliated intrusive quartz diorite and granodiorite; 2. Amphibolitic gneiss; 3. Semi-pelitic gneisses containing lenses of amphibolitic material; 4. Strike and dip of foliation in the intrusive granitic rocks; 5. Strike and dip of main foliation, S_2; 6. Trend and plunge of L_2 lineations.

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The main aim of this contribution is to define clearly the sequence of geological events that may be recognised in the Sark rocks. Then by comparison with the sequence of events seen in the Precambrian gneisses of the south of Guernsey and La Hague, Manche, on the French mainland, to suggest that it is highly likely that a long period of time separated the formation of the metamorphic and granitic rocks on Sark rather than that they both formed during the same general period as concluded by Sutton and Watson (1957).

2. **The semi-pelitic and amphiholitic gneisses**

These gneisses are structurally complex and at least two metamorphic foliations may be recognised within them, both pre-dating the intrusion of the Late Precambrian granites. The earlier surface (S_1) is a gneissose banding but the imposition of the main foliation seen in the rocks today (S_2) has tended to destroy the evidence of earlier events. In some places small-scale folds of the gneissose banding (S_1), have been preserved (see Fig. 2 c). More commonly only relict, appressed fold hinges are found within the main foliation, or sometimes a prominent lineation may be seen

FIGURE 2. Field relationships in the Sark gneisses.

Key- dots: more psammitic layers; crosses: early aplitic vein; pecks: Sark granite.

a. F_2 folds, Banquette, looking north.

Early psammitic layers (S_0) have been boudinaged and folded. Gneissose banding (S_1) is folded around the hinge of the fold and the main foliation (S_2) is only poorly developed parallel to the axial plane of the F_2 fold.

b. F_2 fold, east of Le Grand Creux, looking south.

c. F_2 folds, west side of Dixcart Bay, looking north.

The gneissose banding (S_1) is continuous around the hinges of the folds and must pre-date the D_2 deformation. Away from the hinges the S_2 foliation becomes the dominant feature with the gneissose banding (S_1) transposed parallel to it.

d. F_3 monoclinal fold, north of Banquette, looking south.

e. Granite cross cutting F_2 fold in amphibolitic gneiss, south end of flogs Back.

The Granite must post-date the D_2 formation.

a, c drawn from photographs.

b, d, e field sketches by Frances Parker.

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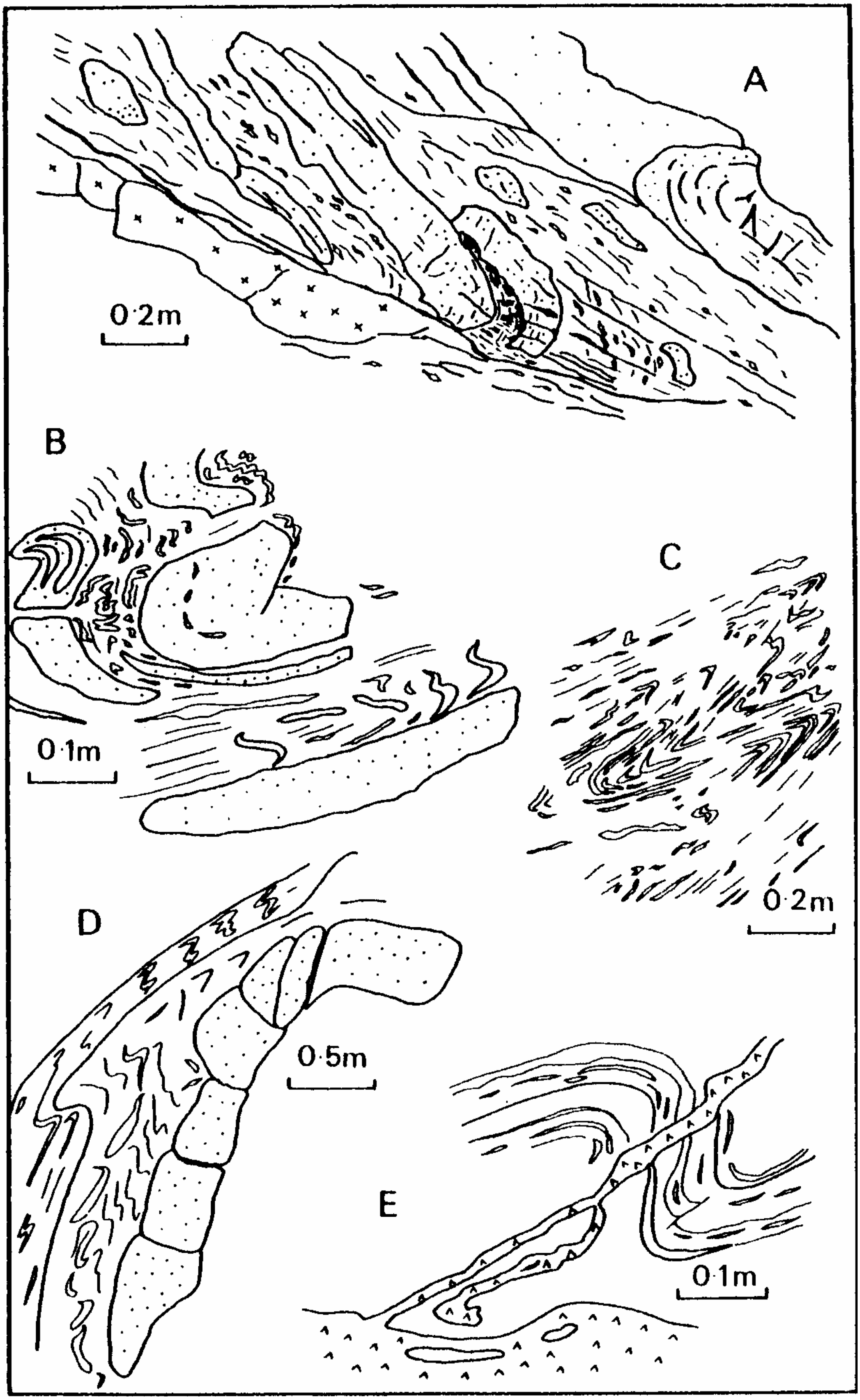

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formed by the intersection of the gneissose banding with the main foliation surface.

The early history of the gneiss is best reconstructed at Banquette (G.R. 469771) where the main foliation (S_2) has not been so pervasively developed and earlier structures are more easily recognised. It is interesting to note that the Banquette rocks are atypically rich in psammitic bands, suggesting that the effects of deformation may be related directly to the lithology of the rock being deformed. The alternating layers of semi-pelitic and psammitic material in the gneiss could reflect original compositional variation in a sedimentary rock and are termed S_0. It is suggested that this layering was subjected to deformation (D_1) the effect of which is recorded by mineral lineation, boudinage and by the metamorphic segregation of felsic minerals. The metamorphic segregation is preferentially developed in the semi-pelitic layers and forms the gneissose banding and foliation S_1 (Fig. 2). Following this, both S_0 layering and S_1 banding have been folded by a later deformation (D_2) which at Banquette produced recumbent isoclines with axial planes dipping moderately eastward and fold axes plunging very gently NNW. (Fig. 2a). The axial planar penetrative foliation (S_0 associated with these folds is only poorly developed at Banquette but is usually the dominant structure seen in the gneisses in other parts of the island.

Numerous measurements of the S_2 foliation and associated axial planes, fold axes, mineral alignments and surface intersections (S_1 on S_2) for the whole island show the D_2 deformation to have folded and deformed the rocks on axes plunging gently NNW. In addition, the main foliation (S_2) may be shown to have been gently folded on a large scale, expressed around the north of the island as a wide northerly plunging antiform. Locally, monoclinical flexures of the main foliation (S_2) may be observed (see Fig. 2d) and could be related to the larger scale antiform. These F_3 folds have steep axial planes and fold axes that plunge gently NNW., coaxial with the F2 folds. There is no doubt that the F_3 folds post-date the main deformation (D_2) as they may be observed to have folded the main foliation (S_2) and also small scale F_2 fold axes. Intersection lineations of S_1 on S_2 surfaces, normally parallel to F_2 fold axes, have been deformed around F_3 fold axes.

As shown in the next section, the intrusion of the Sark granites post-dates the development of the main foliation (S_2) in the gneisses.

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However, it has not proved possible to define the timing of the F_3 folds with respect to the intrusion of the granites. It may be that they are related to the mechanism of granitic intrusion.

3. **Intrusive granitic rocks**

The Sark granites have intruded the metamorphic gneissic complex at a number of structural levels, typically as thick sheets along the pre-formed S_2 country rock foliation. The intrusions vary in composition from the quartz diorites of Little Sark to the granodiorite of Creux Harbour (G.R. 477757) and the west coast. Adams (1967) obtained a Rb/Sr whole rock isochron defined by samples from the Sark granites which gave a Late Precambrian age of 650 ± 90m.y. and he classed the granites as early Cadomian intrusions along with others from the Armorican Massif.

Alignment of the constituent mineral grains has given a gneissose texture to the Sark granites expressed either as a foliation or as a less well defined lineation. The orientation of the foliation in the granites corresponds closely to that of the main foliation (S_2) in the country rock gneisses. In addition, linear structures in the granites, such as long axes of deformed xenoliths, have a similar orientation to that of lineations and fold axes in the gneisses. There is, however, much clear field evidence showing that the main foliation (S_2) in the gneisses was formed before the intrusion of the granites. A study of the geology across the Hogs Back (G.R. 469748), for example, demonstrates the intrusive nature of the granitic rocks. A thick sheet of quartz diorite has enveloped innumerable xenoliths of gneiss within which the main foliation (S_2) is veined and cross-cut by the intrusive granite (Fig. 2e). Reaction at the margins of many amphibolitic rafts has resulted in the growth of fresh new hornblende crystals, and partial assimilation of the xenoliths has sometimes produced ghost structures around remnants of the F_2 folds in the gneisses. The foliation in the granites at sharp contacts lies broadly concordant to that of the country rock, although it is often displaced around, or discordantly abuts against, local irregularities in the contact. It seems likely that the foliation in the granites was formed during a later regional metamorphism, but the possibility that it was produced by localized stress patterns induced during intrusion cannot be ruled out.

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4. Relative timing of events

A series of events has been recognised for the rocks of Sark.

1. An early deformation (D_1) resulting in the formation of a gneissose banding and foliation (S_1). The orientation of this deformation is not known.
2. The main deformation. (D_2) giving rise to a dominant penetrative foliation (S_2). Small scale isoclinal F_2 folds and associated linear structures plunge gently NNW.
3. Gentle monoclinal flexures of S_2 forming F_3 folds with fold axes plunging gently NNW.

Intrusion of granitic sheets. (Time relations between F_3 folds and granitic sheets not known.) Formation of foliation in the granites parallel to main foliation (S_2) and of linear structures plunging gently NNW in the granites.

The recognition of this sequence of events does not give any firm indication of the age difference between the gneisses and the granites. When considered in conjunction with the radiometric age determination of 650 ± 90 m.y. on the Sark granites (Adams, 1967) it does at least provide a minimum age limit for the gneisses. If the gneisses and granites were formed during broadly the same general period of the early Cadomian orogeny then the sequence of deformation and metamorphism suffered by the gneisses is not at all typical of the Cadomian orogeny in Northern France and special pleading is required to account for them when compared with the low grade Brioverian sediments on Jersey.

The gneisses of Southern Guernsey and parts of the La Hague peninsula, west of Cherbourg, France, have both yielded radiometric ages of around 2,600 m.y. (Adams 1967, Leutwein *et al.*, 1973) and both have been shown to have experienced a similar geological history (Power and Roach 1974). The sequence of events identified in the Sark gneisses is remarkably similar to that of the gneisses of Guernsey and La Hague. In the absence of radiometric age determinations for the Sark gneisses it would seem most reasonable to consider them as an extension of the Guernsey gneisses. Despite the coaxial nature of succeeding deformations this would indicate that a long period of time elapsed between the formation of the Sark gneisses and the intrusion of the granites.

ACKNOWLEDGEMENTS. We are grateful to Frances Parker for permission to use her field sketches and for many stimulating discussions on the geology of Sark.

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GMP
Dept. of Geology
Portsmouth Polytechnic
Burnaby Road
Portsmouth

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A new tale for the Lizard (Abstract):

by D. F. Strong, R. K. Stevens, J. Malpas *and* J. P. N. Badham

The ultramafic - amphibolite assemblage of the Lizard area has been generally taken as a type example of a mantle-derived hot ultramafic intrusion and its associated contact aureole. This assemblage, and its sedimentary and tectonic setting, can be matched in detail with rocks of well-known ophiolite complexes which display much circumstantial evidence of having been formed at oceanic ridges, and subsequently tectonically emplaced at compressive plate margins. In particular, we suggest that the Lizard harzburgites are relict upper mantle, depleted by partial melting during diapiric upwelling at a mid-ocean ridge. The gabbros are the resulting partial melt. The amphibolites are basaltic/ diabasic/gabbroic layers 2 and 3 of the oceanic crust, which may have been metamorphosed during tectonic and intrusive activity on the ridge, or more probably during tectonic emplacement (obduction of the ophiolites at a compressive plate margin). The Kennack "gneisses" are granitoid melts produced by a partial melting of the amphibolites during this metamorphism. The Mylor and Gramscatho groups are sediments deposited prior to, during, and consequent to this obduction, and the Meneage crush zone is a typical tectonic/sedimentary black shale melange produced proximally to, and beneath, the obducted ophiolite. The Man O'War gneiss may be remobilized portions of a basement now overriden by the ophiolite. Of the various generations of "Black Dykes" some are thought not to be genetically related to the ophiolite: others, however, represent the base of a sheeted dyke complex.

JPNB
Dept, of Geology
The University
Southampton

DFS, RKS, JM
Memorial University
Newfoundland

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K-Ar isotopic age determinations from mineral veins in the Lizard area (Abstract):

by A. N. Halliday

"Adularia" felspar occurs as a common vein mineral, associated with zeolite/calcite mineralization in much of the Lizard area, Cornwall. K-Ar age determinations on fifteen "adularia" samples give apparent ages ranging from 181 m.y. to 220 m.y., except for one sample giving 156m.y.

X-ray diffraction studies show that the felspars are dominantly monoclinic with a minor triclinic portion, excepting two samples which are entirely, monoclinic. The obliquity of the triclinic portion varies from zero (monoclinic) to that of intermediate microcline and (with the exception of the 156 m.y. sample which is monoclinic) is approximately inversely proportional to the apparent K-Ar age. Extrapolation of the triclinicity/apparent age plot back to zero argon loss (i.e. monoclinic state), suggests that the felspars formed at approximately 215 m.y. (possibly as two phases at 210 m.y. and 220m.y.), and indicates major alkali hydrothermal activity in the Lizard at this time. The 156 m.y. felspar sample (from Holseer Cove) may indicate a later hydrothermal event.

School of Physics
The University
Newcastle-upon-Tyne

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A study of secondary fabrics in the rocks from the Lizard peninsula (Abstract):

by J. Singh

Magnetic anisotropy technique was applied to samples taken from selected areas of the Lizard peninsula. The object of the magnetic fabric study was to observe secondary magnetic fabrics imposed on the local areas due to (i) the intrusion of granite into the Devonian sediments, (ii) the intrusion of serpentine into the hornblend schists, and (iii) the movement of the Lizard thrust boundary. Samples taken in the neighbourhood of the Carnmenellis and Godolphin granite masses showed a strong compressional fabric, possibly suggesting that the Devonian sediments were compressed and overturned as the granite was emplaced. The distinct change in the fabric parameters at the north end of Church Cove - Landewednack and the southern end of Cadgwith Cove are possibly the remanent secondary fabric resulting from the intrusion of the serpentine into the hornblend schists. In sites taken at increasing distances from the Lizard thrust boundary, the degree of anisotropy falls from comparatively high values down to the low values recorded from the Devonian sediments. There is also a small degree of rotation of the ellipsoid causing alignment of the strike of the maximum-intermediate foliation plane sub-parallel to the boundary fault.

School of Physics
The University
Newcastle- upon-Tyne

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NOTES ON SOME IGNEOUS ROCKS OF WEST CORNWALL

by R. T. Taylor and A. C. Wilson

Abstract. Four types of greenstone occur within the Mylor Slates: fine-grained pillow lavas; a medium- to coarse-grained, intrusive intra-volcanic suite intruded concurrently with volcanism and sedimentation; agglomerates and tuffs of restricted occurrence; and medium- to coarse-grained intrusive sills which post-date the extrusive rocks but which have been deformed during the later phases of folding.

The Tregonning-Godolphin Granite consists of two main components: an inner megacrystic biotite granite which is largely surrounded by an even-grained lithium-mica granite. Extensive rafts of hornfelsed state occur along the southern margin of the granite, and the contact-metamorphic aureole to the north and west is found to be much wider than indicated by earlier mapping.

1. Extrusive and intrusive greenstones

(i) The two greenstone types of the St. Ives area

There are several greenstone outcrops within the presumed Devonian marine Mylor Slates of the Penzance (351/8) Sheet. The most extensive of these runs from near Longrock (SW 500 314) to north-east of Gwinear (SW 598 374). Although there are few exposures in this belt of greenstones, it is evident that the rock types are similar to those which crop out along the northern margin of the Land's End Granite from Porthmeor Cove (SW 425 375) to St. Ives (SW 516 405). The greenstones from the latter area (Fig. 1) are described below but it is believed that conclusions drawn from the field relationships are valid in the former area and also around Penzance, where similar igneous rocks.occur.

Two distinct greenstone types can be mapped but although separable on a local scale (Fig. 1), regionally they show a strong tendency to occur in association with each other. The first type is represented by fine-grained occasionally vesicular pillow lava in which the lengths of individual pillows may range up to three

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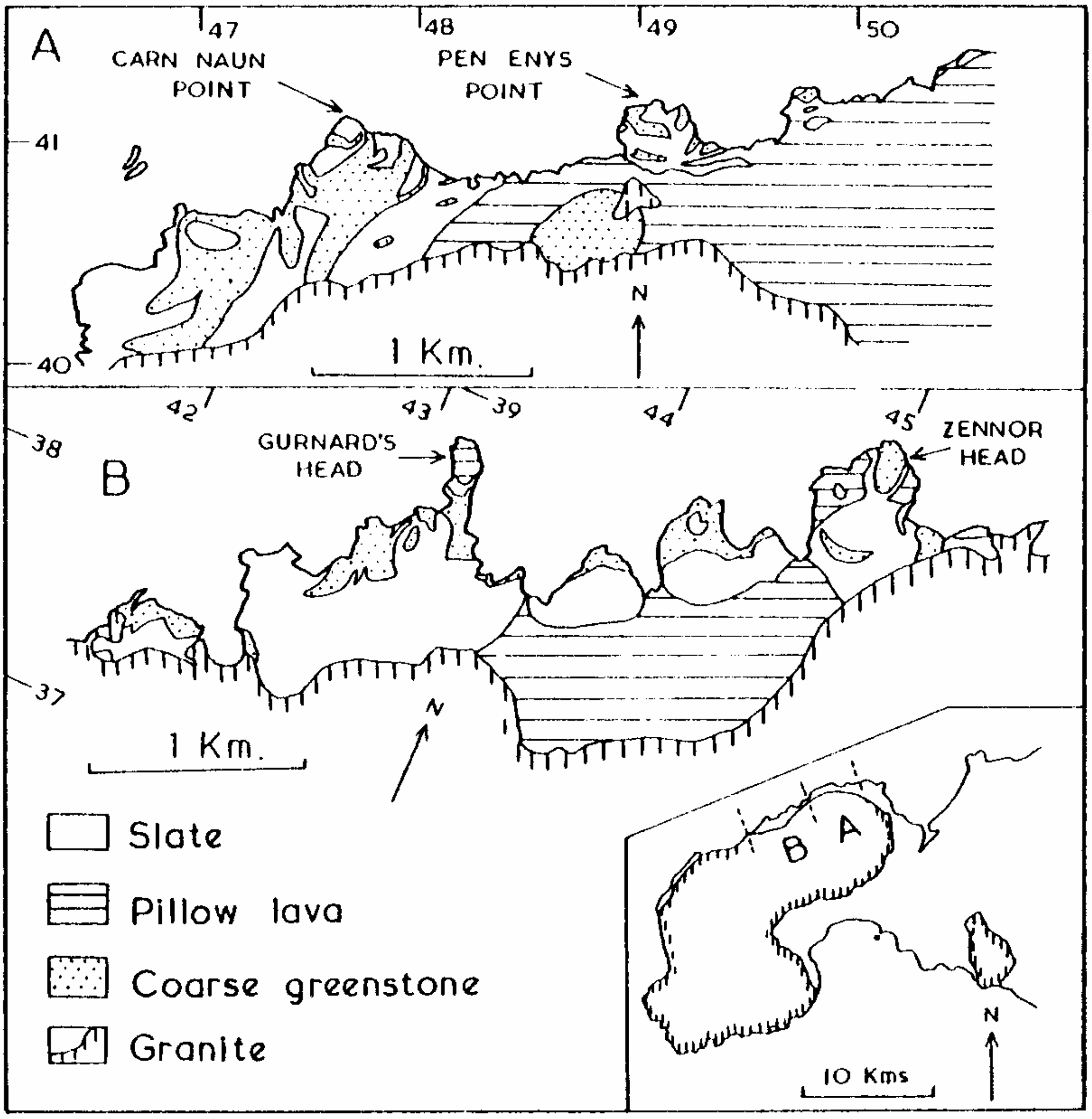

FIGURE 1. Map showing the location of extrusive (pillow lava) and intrusive greenstone types along the northern margin of the Land's End Granite. Inset: the Land's End peninsula.

metres. These greenstones were extruded on to the sea-floor as flows. The other greenstone variety occurs as concordant, massive, medium- to coarse-grained bodies up to several tens of metres thick interdigitated with the surrounding slate. Their gabbroic textures and narrow chilled margins indicate an intrusive origin but their injection caused only localized disturbance of the bedding and no more than at the base or top of a pillow-lava sequence. The regional association of these two greenstone types suggests a genetic affinity, which is supported by their similar continental alkali basalt geochemistries (Floyd 1972, pp. 387-391; Bluxam and Lewis 1972, pp. 134-136).

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(ii) Relative age and origin of the coarse greenstones of the St. Ives area

Since the coarser greenstones are not involved in minor F_1 or F_2 folds it is only possible to date their emplacement with respect to their relationships to the associated cleavages. Foliation-producing stresses have had little effect on the lavas and even less on the massive intrusions but examination of the margins of the latter indicates that they are cut by the S_1 cleavage. Thus the intrusions could have been emplaced either contemporaneously with the extrusive phase or as a result of migration of basic magma in areas of former volcanism but prior to the first deformation. The intrusive greenstones show vesicular and slaggy margins, auto-brecciation and crude pillow structures (several times larger than normal pillows), from which it is concluded that they were injected into wet silts and clays just below the sea-floor and almost certainly, therefore, concurrently with extrusion of the pillow lavas and sedimentation of the Mylor Slates. Adinolized slate is present above and below both the intrusive and extrusive greenstones, indicating that autometasomatic processes operated during this igneous episode (Floyd 1972, p. 388). The concordant aspect of the coarse greenstones suggests that they may represent sub-horizontal feeders for the pillow lavas, within which some intrusions terminate, but a few may have reached the sea-floor as static, slowly-cooled masses.

Other Devonian and Carboniferous successions in South-West England contain associated extrusive and intrusive igneous rocks and it is probable that, as in West Cornwall, some of the latter are of intra-volcanic origin.

(iii) The extrusive greenstones between Marazion and Kenneggy Sands

Along the south coast the association of greenstones is rather different from that near St. Ives, the extrusive rocks being less common. Small, isolated outcrops of amygdaloidal pillow lavas occur at Ternis Cove (SW 535 292) and Piskies Cove (SW 554 277). At the former locality some large pillow-like lava masses, 1 to 2 metres in length and with calcite-filled amygdales, are surrounded by slate and may have formed by extrusion into soft, wet sediments. Other small outcrops of possible lavas occur just north of Basore Point (SW 531295) and at Arch Zawn (SW 550 279).

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A spectacular development of volcanic rocks occurs on the offshore reefs of Great Hogus (SW 515 305) and Little Hogus (SW 511 307) near Marazion. On Great Hogus two horizons of coarse agglomerate and tuff are interbedded with slates and folded into an upright, south-westerly plunging anticline. This fold appears to be an F_1 isocline lying on the steep northern limb of a northerly verging F_2 fold. The agglomerates consist of coarsely amygdaloidal lava fragments with some sedimentary fragments, set in a tuffaceous matrix. The clasts are mainly about 0.2 to 0.3 metres across but some are up to 0.5 metres across. They are flattened in the plane of the S_1 cleavage but many retain angular outlines when viewed normal to this plane. Some small pillow-like masses with concentric amygdales occur in the agglomerates, particularly on the south-eastern side of Great Hogus, where the upper horizon of agglomerate appears to be passing into pillow lava.

Little Hogus is formed of agglomerates very similar to those of Great Hogus. They also appear to be folded. No junctions with slates are exposed but lavas may be present on the north-west extremity of the rocks.

These agglomerates appear to be unique in the district, although some of the greenstones on the coast near Levant Mine (SW 366 345) show some resemblance but are much more highly deformed. The large size of the clasts in the agglomerates points to the proximity of a volcanic vent.

(iv) The intrusive greenstones between Marazion and Kenireggy Sands

The major outcrops of greenstones east of Marazion, such as those at Trenow Cove (SW 530 300), Basore Point (SW 532 295) and Cudden Point (SW 549 276), are coarse grained, formerly gabbroic, rocks. Floyd and Lees (1972) have shown that the Cudden Point greenstone, which is typical of these greenstones, is chemically distinct from the majority of Cornish greenstones in having a tholeiitic composition. At several localities there is clear evidence of their intrusive nature; for example, at Puffer Cliff, where stoping relationships can be seen, and at Temis Cove, where coarse greenstone cuts across pillow lavas. The general form of the bodies is sill-like, with margins lying approximately concordant with the

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south-westerly dipping foliation (S_1?). Locally, contacts are concordant with steeply-dipping bedding traces.

In the main the intrusive greenstones are too massive to have acquired a foliation, although at Cudden Point the lower margin of the greenstone is schistose, but at Temis Cove the S_3 foliation can be seen to pass into coarse greenstone at a steeply inclined contact. It has not yet been possible to elucidate fully the exact position of the greenstones in the sequence of structural events. It seems likely that they postdate the F_1 isoclinal folding and they clearly predate the flat-lying F_3 folds. The sills may have been warped by the northerly verging F_2 folds to produce the occasional steeply-dipping concordant contact, but the attitude of the cleavage or bedding may have controlled the intrusion.

2. The Tregonning-Godolphin Granite

(i) The granite varieties

The variation between the granite of Godolphin Hill (SW 593 313) and that of Tregonning Hill (SW 600 300) and the coastal exposures has long been recognized (Hall 1930, Stone 1960). The results of the present attempt at defining the extent of the two main types of granite are shown in Fig. 2. The Godolphin type, a biotite granite with small potash feldspar megacrysts, has been found to extend from Godolphin Hill to the vicinity of Rinsey Croft, where similar granite is found on the dumps of Wheal Fancy (SW 605 280). The outer part of the intrusion is formed of an even-grained granite containing a pale brown mica which has been shown by Stone (1965) and Exley and Stone (1966) to be a lithium bearing variety.

The contact between the two types of granite is nowhere exposed. The mapped relationship gives the impression of a composite body, but it is possible that the lithium-mica granite results from a metasomatic replacement of the biotite granite (Stone 1963) and forms a capping over the latter which has been partially removed by erosion.

(ii) Features of the contact of the Tregonning-Godolphin Granite

Along the southern margin of the intrusion an extensive series of rafts and roof pendants of hornfelsed slate occur. They indicate the

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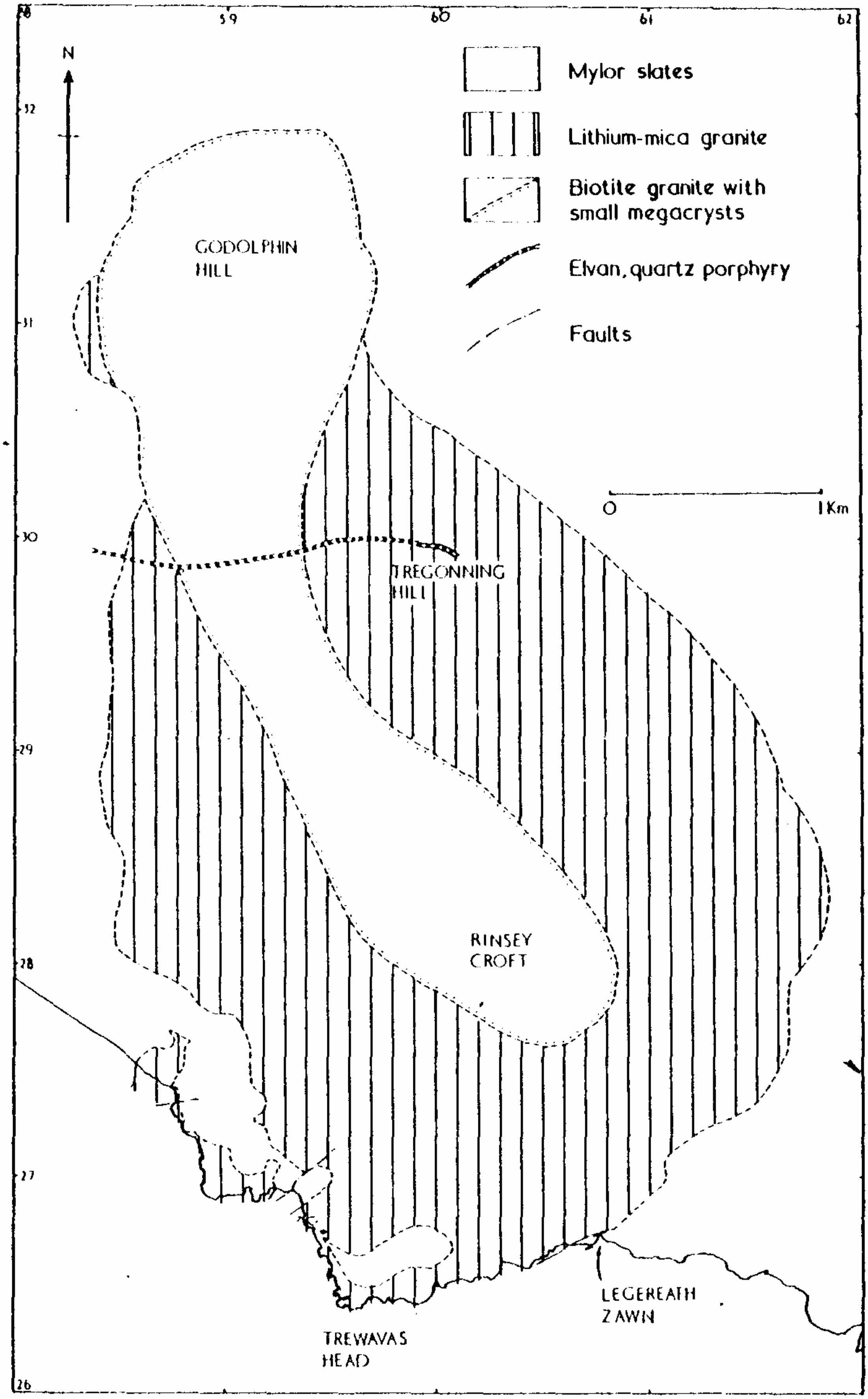

FIGURE 2. Map of the Tregonning-Godolphin Granite showing the distribution of the two main granite types.

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shallow inclination and close proximity of the contact offshore, although west of Legereath Zawn (SW 6073 2576) the contact between granite and slates appears to be vertical.

A feature of the contact at Legereath Zawn, reported by Exley and Stone (1966), is an elvan-like quartz-porphyry intrusion in the slates which is cut by the granite. A similar quartz-porphyry forms part of a raft on the cliffs (SW 5945 2675) between Trewavas Head and Rinsey. Here the porphyry has a vertical contact with hornfelsed slate and cuts across the foliation. The porphyry is underlain and veined by granite. The Tregonning-Godolphin Granite is itself intruded by a porphyritic elvan (Stone 1963, Exley and Stone 1966). Thus the elvan dykes of the district, some of which resemble the Legereath intrusion in appearance, may be of more than one age.

(iii) The contact aureole

To the north and west, the Tregonning-Godolphin Granite has an extended contact-metamorphic aureole. A broad bulge of the aureole westwards to the St. Hilary area (SW 551 313) is indicated by thermal spotting and recrystallization of the slates, while traces of andalusite and chiastolite occur in the slates up to 1.5km from the mapped contact. To the north, the aureole extends into the Leedstown area (SW 605 344) and it seems likely that to the north-east the aureole of the Tregonning-Godolphin Granite may join up with that of the Carnmenellis Granite. The nearness of the granite to the surface, indicated by the extent of the aureole, has been confirmed by recent gravity surveys carried out by the Institute of Geological Sciences (Beer and others, 1975).

ACKNOWLEDGEMENTS. We are grateful to our colleague Dr. J. R. Hawkes fur helpful discussions concerning various aspects of this paper.

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Institute of Geological Sciences
Hoopern House
101 Pennsylvania Road
Exeter

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The Devonian limestones of Newton Abbot and their equivalents at Torquay (Abstract):

by Colin T. Scrutton

The Devonian limestones in eastern South Devon have been considered by many workers to contain reef facies. Interpretation of these rocks, however, is made difficult by structural dislocation and the lack of adequate correlation between the limestone masses. Although many problems still remain, recent contributions to the dating of the limestones and an improved knowledge of the limestone successions in the Torquay - Newton Abbot area allow a reassessment of the broad facies distributions.

Alter carbonate deposition began across the area at different times during the Eitelian with thin-bedded, impure limestones, a stronratoporoid bank was developed in the succeeding pale massive limestones of the Givetian in the Torbay area. Stromatoporoids of laminar to massive form, up to 2-3m width and 1.5m high, trapped sediments of variable grain size to build a reef *(sensu lato)* barrier which restricted the circulation of normal marine waters to the north. This is reflected in the development, in the Givetian limestones of the Newton Abbot area, of horizons rich in the characteristically back-reef or lagoonal organism *Amphipora.*

In late Givetian times the stromatoporoid bank facies was succeeded in the Torquay area by a mixed coral fauna in bioclastic limestones; the same facies also appears in the Newton Abbot area. This probably represents the drowning of the bank.

Massive limestones were apparently succeeded by deeper-water goniatite shales early in the Frasnian in the Torquay area. To the north, however, carbonate deposition persisted into Middle or Upper Frasnian times culminating in the development of *Frechastraea - Phillipsastrea* bioherms comparable with those of a similar age in Belgium.

Dept. of Geology
The University
Newcastle-upon-Tyne

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CORRELATION AND SEDIMENTOLOGY OF TOM'S COVE SHALE, BUDE FORMATION

by J. P. B. Lovell

Abstract: A study of lateral variations in sandstones and siltstones within Tom's Cove Shale (Bude Formation) supports a previous tentative correlation of this mudstone along several km. of coastal cliff section. The lateral variations also support previous ideas of a main northern primary source of sediment supply, and indicate increased effectiveness of eastward-flowing currents in reworking coarser-grained sediment in southern outcrops further away from the primary sediment source. Longer-range correlation of Tom's Cove Shale indicates a major regional transgression.

1. Stratigraphical correlation In the Bude Formation

In correlating the folded and faulted coastal sections of the Bude Formation, emphasis has been placed by Lovell (1965), King (1966), Freshney, McKeown and Williams (1972) and Freshney and Taylor (1972) on the mudstone horizons and the "slump beds". Lovell's (1965) correlation of mudstones in the Bude to Widemouth section (Fig. 1) was substantially modified, and extended north of Bude by King (1966), and then extended tentatively further north again to Hartland Point (Fig. 1) by Freshney and Taylor (1972). According to these later correlations, Tom's Cove Shale (King, 1971), one of the thickest and apparently most laterally persistent of the Bude Formation mudstones, appears several times between Henna Cliff and Widemouth (Fig. 1). King (1971) takes the base of Tom's Cove Shale as a stratigraphical datum. It was this datum which I chose as a basis for a study of lateral variation. Six outcrops were measured (Figs. 1 and 2).

2. Tom's Cove Shale

Tom's Cove Shale (hereafter "T.C.S.") "comprises the distinctive black *Rhahdoderma elegans* nodular shale and the overlying siltstone-shale-sandstone sequence" (Freshney and others, 1972,

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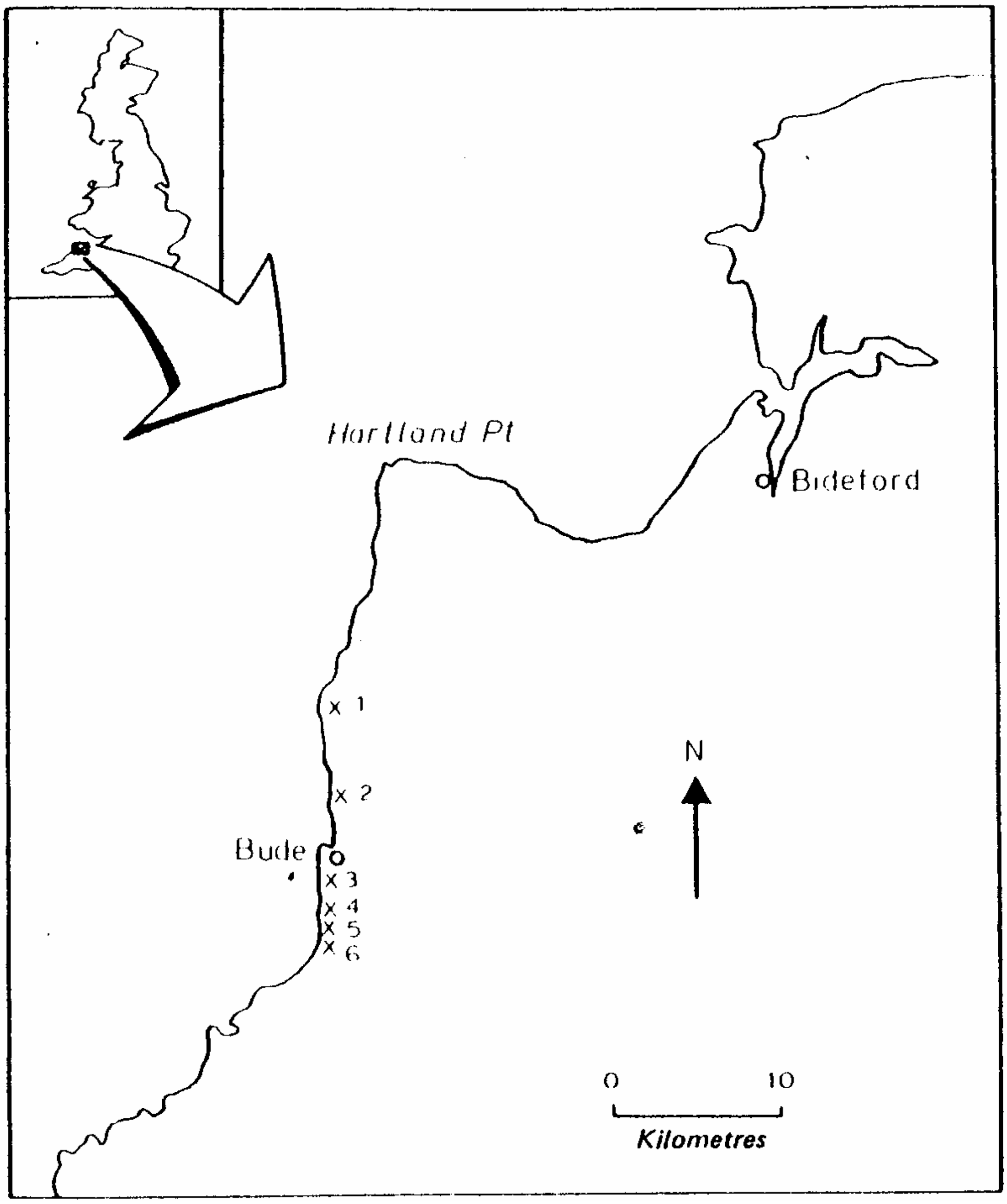

FIGURE 1. Outcrops of Tom's Cove Shale studied: 1. - Henna Cliff (National Grid Reference SS 199159). 2. - Maer Cliff (201077). 3. - Upton (200050). 4. -Tom's Cove (198037). 5. - North Widemouth (199031). 6. - Central Widemouth (198022).

p. 39). The lower part of the T.C.S. contains two main facies, a fissile black mudstone and a black mudstone with interbedded thin grey silty mudstones and siltstones. The upper part of T.C.S. consists mainly of black mudstone with interbedded thin siltstones and sandstones. Some of the coarser-grained beds are amalgamated, parallel-, wavy- and cross-laminated and have well-developed sole marks. Interpretation of these coarser-grained beds varies from

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distal turbidite (Lovell, 1965) to submarine fan channel levées (Burne, 1969, p. 118), to topset delta platform deposits (Williams, p. 25, in Freshney and others, 1972).

3. Lateral variations in Tom's Cove Shale: results

The lateral variations in the lower part of T.C.S. are shown in Fig. 2. The lateral variations in the whole T.C.S. south of Bude (see below) are shown in Table 1. No attempt has been made to compensate for any tectonic thickening or thinning of beds; the structural data in Chapter 6 of Freshney and others (1972) give an indication of just how seriously tectonic effects may limit interpretation of thicknesses.

Correlation of the lower, mudstone part of T.C.S. is relatively easy. A black, fissile mudstone is followed everywhere by black mudstone with interbedded thin grey silty mudstones. It is in the upper T.C.S. that problems arise. First, this upper part is absent north of Bude (Fig. 2). Second, attempts to correlate individual coarser-grained beds from exposure to exposure were not successful. The most profitable approach may be to consider the average properties of the coarser-grained beds within T.C.S.

4. Lateral variations in Tom's Cove Shale: discussion

The data on *current directions* from T.C.S. present a special problem, because they differ from the results from the Bude Formation as a whole (see also Burne, 1969, p. 118). Earlier results from the Bude Formation as a whole, derived from sole marks, indicate flow from between north-west and north-east (Ashwin 1957), between north and east (Lovell 1965) and north (Burne 1969, 1973). The few flute marks within T.C.S. (Table 1) show the varied directions noted by Lovell in this and similar facies in an earlier study (1964). The groove marks indicate a more consistent east-west trend, while the cross-laminations show current flow from between west and north-west.

One explanation of the variations in *thickness* of the whole T.C.S. and of thicknesses of facies within T.C.S., is that the overlying thick sandstones arrived earlier in the north, nearer the supposed source.

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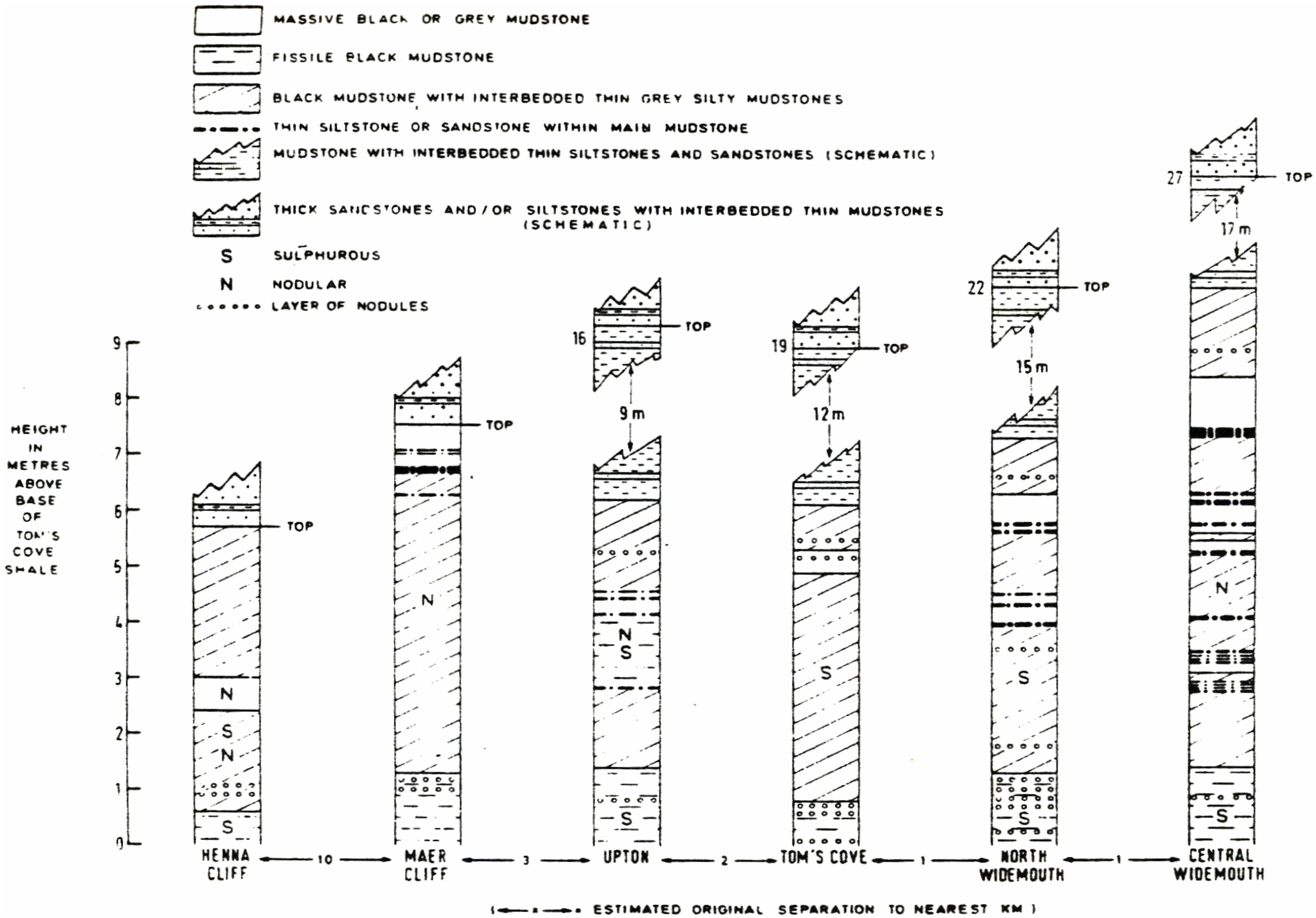

FIGURE 2. Lateral variations in Tom's Cove Shale

TABLE 1. Lateral variations in Tom's Cove Shale south of Bude.

		Upton	Tom's Cove	North Widemouth	Central Widemouth
1. Thickness of Tom's Cove Shale (in metres). (Top defined by markedly thicker coarser beds, base by first development of thick mudstone - see Fig. 2.)		16	19	22	27
2. % thickness of sandstone (and sandstone plus siltstone in brackets) at various heights (in metres) above the base of Tom's Cove Shale:	10	6 (9)	6 (8)	7(11)	1 (7)
	20	24(29)	17(25)	18(25)	10(17)
	30	37(41)	40(45)	33(40)	19(26)
3. % thickness of sandstone and siltstone within Tom's Cove Shale itself:	sandstone	14	15	18	13
	sandstone + siltstone	20	22	25	20
4. Average thickness (in metres) of beds in 30m above base of Tom's Cove Shale. (number of beds shown in brackets):	sandstone	0.15 (75)	0.12 (104)	0.15 (68)	0.12 (48)
		0.03 (35)	0.04 (36)	0.05 (44)	0.05 (47)
	mudstone	0.12 (78)	0.14 (116)	0.20 (89)	0.28 (80)
	sandstone + siltstone	0.11(110)	0.09(140)	0.11(112)	0.08(95)
5. Average thickness (in metres) of beds within Tom's Cove Shale itself (number of beds shown in brackets):	sandstone	0.07 (35)	0.07 (44)	0.08 (51)	0.09 (37)
	siltstone	0.03 (35)	0.04 (34)	0.04 (40)	0.04 (45)
	mudstone	0.24 (57)	0.19 (76)	0.22 (76)	0.30 (73)
	sandstone + siltstone				
6. % of amalgamated sandstone beds within Tom's Cove Shale:		26	16	27	8
7. % of beds with cross-lamination within Tom's Cove Shale:	sandstone	34	39	33	54
	sandstone + siltstone	26	31	35	43
8. Direction (in degrees) towards which current flowed as indicated by cross-lamination and flute marks within Tom's Cove Shale itself (number of readings in brackets):	cross-lamination	090(2) 180(1)	090(12)	090(7)	090(2) 140(7)
	flute marks	310(l)	-	310(l) 340(1)	160(2)
9. Orientation (in degrees) of currents as indicated by groove marks within Tom's Cove Shale itself (number of readings in brackets):		070(1) 100(2) 120(l) 130(1)	070(l) 090(1) 110(1) 120(2) 140(l) 150(2) 160(l)	070(l) 080(1) 110(1)	030(l) 040(l) 090(1) 110(1) 140(l)

The percentage of beds within T.C.S. with *cross-lamination* increases southwards. The orientation and type of the cross-laminations may be interpreted as having been formed by reworking of material previously deposited by other currents.

These results lead to an interpretation of the deposition of the coarser-grained beds as follows. A major primary source of at least the coarser-grained sediment lay north and possibly east of the depositional area. I believe the coarser-grained sediment in T.C.S. was first moved into the area by turbidity currents. It was then reworked by currents flowing mainly towards between east and south-east. The nature of these other currents, and how saline the water was, are still open questions, of more than local significance (Burne 1973).

5. Re-examination of correlation of Tom's Cove Shale

The best correlation from structural considerations is that between north and central Widemouth. The next best is these two Widernouth outcrops with Tom's Cove itself, the least good that of the three southern outcrops with those at Upton, Maer Cliff and Henna Cliff to the north, progressively worse northwards. The data for the two Widemouth outcrops offer clearer support for a north to south, proximal to distal, transition, than do these two Widemouth outcrops taken with one or more of the outcrops to the north. Does one therefore abandon the correlation? The correlation is not based on the T.C.S. alone, but on other mudstones and facies, and the vertical separation of these facies. But thicknesses of facies, and even the type of facies, may be seen to vary laterally over folds within a few tens of metres. It is the coherence of the regional picture drawn by Freshney and Taylor (1972) that offers strong support for the correlation, which I accept as a working hypothesis.

6. Longer-range correlation of Tom's Cove Shale

Freshney and Taylor (1972) hint at a correlation of their Hartland Quay Shale, at or near the base of the Bude Formation as defined by them, with the black mudstone at the base of Cycle 3 of the Abbotsham Formation (Bideford Group, see Fig. 1) of de Raaf, Reading and Walker (1965). This suggests a correlation of T.C.S. with either of the thick black mudstones at the bases of Cycles 4 and

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5 in the Abbotsham Formation; this would indicate a major transgression in this area.

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Grant Institute of Geology
University of Edinburgh
West Mains Road
Edinburgh

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MICROFAUNAL ANALYSIS OF THE MEMBURY CHALK SUCCESSION

by Malcolm B. Hart

Abstract. The chalk succession of the Membury outlier is described in the light of excavations undertaken over the past eight years. The total thickness of chalk exposed is some 16.0m., of which only 1.5m can be attributed to the Upper Cenomanian. The greater part of the succession is therefore of lower Turonian age, and compares favourably with successions on the Devon coast, NW. France and NE. France.

1. Introduction

The outlier of chalk near Membury, Devon, is preserved by a north-south fault that downthrows to the west. Exposures in the chalk are rare at the present time, with only one workable succession being found in the old quarries (ST 276042) on the north-east side of the lane from Membury to Furley (see Fig. 1). The other old pits in the outlier, which were not even available for study at the time of Jukes-Browne and Hill (1903), are now almost completely overgrown. The pit near Crib House, and those on the hillside above Rock, are completely overgrown, and chalk cannot be exposed by digging. The old pit near Brinscombe Farm and the series of pits on the west side of the lane north of Membury village reveal chalk after some digging but they are still unsuitable for detailed stratigraphical analysis.

The quarry near the Membury-Furley lane shows an incomplete exposure through several metres of rough, cream/off-white chalk, and this has been variously described by Jukes-Browne and Hill (1903), Smith (1957, 1961) Smith and Drummond (1962), Hart in Kennedy (1969), Kennedy (1970), and Drummond (1970), Over the past eight years several trenches and pits have been dug in the quarry, all of which have allowed the sampling of the complete succession. This account therefore presents a complete report of the microfaunal succession.

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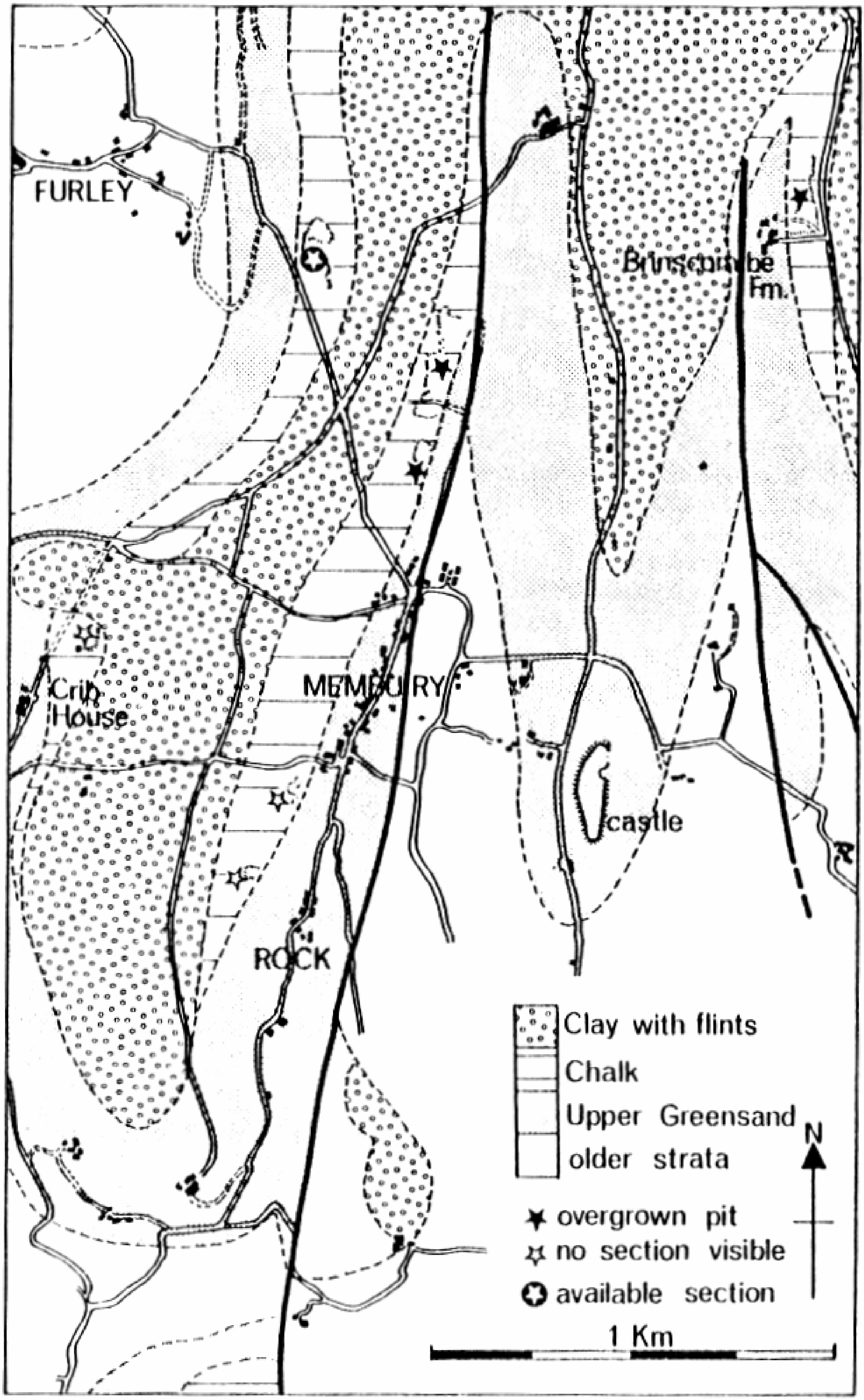

FIGURE 1. Locality map of the Membury outlier (based on maps of the Institute of Geological Sciences as well as the author's own field work).

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2. **Description of the succession**

After excavation, the quarry shows about 16.0m of chalk, resting on a complex 'Basement Bed' (Kennedy 1970, Drummond 1970), which in turn rests upon, and is piped into, the Upper Greensand. The upper surface of the Upper Greensand is glauconitized and phosphatized. The overlying 'Basement Bed', which is approximately 30cm thick, contains abundant grains of quartz and glauconite with a large selection of phosphates. The latter occur either as small fragments, or as broken, reworked, fossils. The rich macrofauna suggests a complex admixture of fossils from several stratigraphic levels. There is an abundant Middle Cenomanian phosphatized macrofauna, as well as a glauconitized Lower Cenomanian macrofauna (Kennedy 1970). While the true 'Basement Bed' lithology only extends some 30cm up the succession, the detrital grains of glauconite, quartz, and phosphate can still be found several metres into the chalk (see Fig. 2). The macrofauna from these lower levels of the quarry suggest (Kennedy 1970, p. 656) a correlation with Bed C of the Cenomanian Limestone succession of the SE. Devon coast. The remaining 14-15m of the chalk at Furley show few distinctive lithological features apart from an intermittent flint horizon 4.60m above the base of the chalk. At a level some 0.80m. above the flints there is a thin marl seam which marks the upper surface of more massively-bedded chalk that is characteristic of the lower levels of the quarry. Higher in the succession the cream/off-white chalk is markedly bedded, with the only feature of interest being the three layers of nodules (between 10.0-10.80m above the base of the chalk) shown in the section in Fig. 2.

In general the chalk at Furley contains few fossils apart from *Inoceramus* cf. *I. lubinlus* (Schlotheim), which is more common in the lower levels of the succession (up to the nodule horizons). An earlier report of a specimen of *Schloenbachia* sp., which would indicate a Cenomanian age for the chalk, has been discounted by Kennedy (1970, p. 656), the specimen now being referred to the genus *Watinoceras,* of Lower Turonian age.

3. **Microfaunal analysis**

The microfaunal evidence (Fig. 2) agrees in most respects with the macrofaunal succession, and the present research has confirmed

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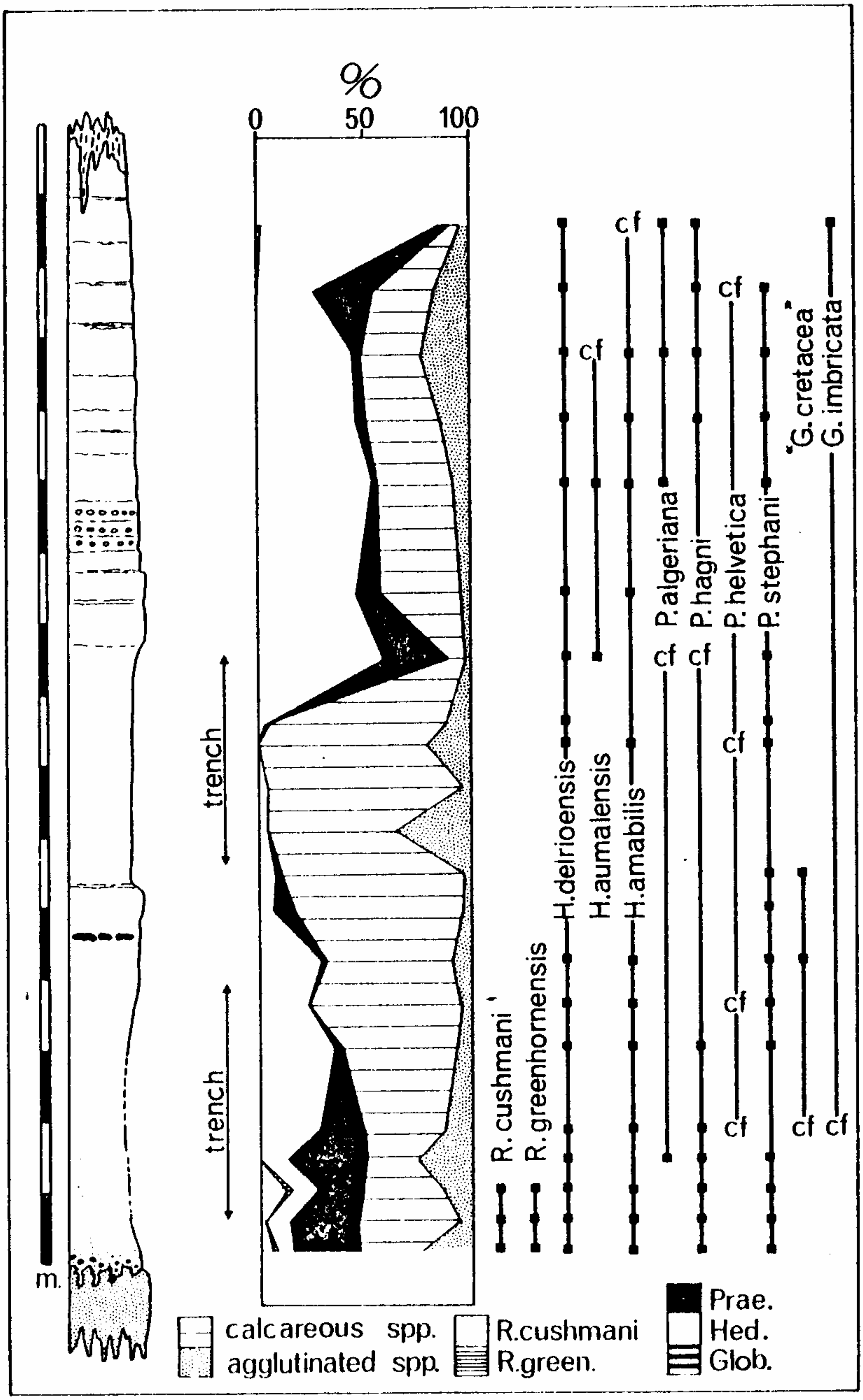

FIGURE 2. Microfaunal analysis of the Membury chalk succession. Abbreviations used are as follows: Prae. - *Praeglobotruncana sp.;* Hed. - *Hedbergella* spp.; Glob. - *Globotruncana* spp.; R. green. - *R. greenhornensis.*

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some earlier results (Hart in Kennedy 1969). In Fig. 2 the ranges of the more important planktonic Foraminiferida are shown, together with a percentage analysis of the foraminiferal fauna found in the 30-60 (0.25-0.50mm) size fraction. On the basis of this fauna it can be seen that the succession falls into two very distinct parts. The lowest 1.5m shows a typically Upper Cenomanian fauna which includes *Rotalipora cushmani* (Morrow), *R. greenhornensis* (Morrow), *Praeglobotruncana stephani* (Gandolfi), *Hedbergella delrioensis* (Carsey), and *H. amabilis* Loeblich and Tappan. The overlying chalk, which shows a fauna dominated by *P. stephani, P. hagni* Scheibnerova, and *P. algeriana* Caron, together with primitive, early, forms of *P.* cf. *P. helvetica* (Bolli) and *Globotruncana imbricata* Mornod, is probably Lower Turonian in age (Butt 1966; Owen pers. comm.). The same faunal turnover can be recognized at this level all over Southern England and Northern France, including those areas where the Stages were first described (Sarthe and Touraine). When Jefferies (1962, 1963) described the lithology and fauna of the *A. plenus* marls he was able to establish eight divisions that could be traced with some accuracy throughout the Anglo-Paris-Belgian Basin, which can be shown to include the succession at Membury.

The lowest 1.5m of the succession above the Upper Greensand can be tentatively referred to Bed 1 of that series, as witnessed by the occurrence of *R. cushmani* and *R. greenhornensis,* together with a distinctive (typically Cenomanian) benthonic fauna (including *Pseudovalvulineria* sp. Jefferies, *Gavelinella baltica* Brotzen, *G. cenomanica* (Brotzen), and *Arenobidimina advena* (Cushman). The overlying 1.5m of chalk is characterized by an association of P. *hagni, P. algeriana,* and *P. stephani,* together with a benthonic fauna dominated by *Gavelinella berthelina* (Keller) (syn. *Gavelinopsis tourainensis* Butt (1966)) and *Lingulogavelinella globosa* (Brotzen). This is the fauna typically found in the *A. plenus* marls (Beds 4-8) - above the extinction of the *Rotalipora* fauna. This replacement of the *Rotalipora* fauna by a twin-keeled *Praeglobntruncana/Globotruncana* is taken by the majority of micropalaeontologists as being the Cenomanian/Turonian boundary. This agrees with the work of Butt (1966), Marks (1967) and Bellier (1971), who have variously worked on parts of the type successions. The authors' own fork on the type section (Lecointre 1959) of the Turonian in the Cher Valley has shown that the Beds 4-

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8 fauna (described above) typifies the lower part of the Fretevou Chalk, as well as the ‘Craie à *T. carantonensis*’ of the Sarthe. The same association can also be seen in the lowermost chalk seen in the sections at Mézières s. Ballon and Pavigne l'Evêque.

4. Stratigraphic implications

The excavations and subsequent faunal analysis of the Membury chalk succession have shown that only 1.5m of the glauconilic chalk is of Cenomanian age, and that the larger part of the succession is therefore of Turonian age. The lithological succession at Membury is however of local significance as it is unlike any of the other exposures of the Lower Turonian in the SE. Devon area. At Membury there are none of the pale brown, nodular, phosphatic horizons which characterize this level in the succession at Beer Roads. The characteristic lithology of the Beer Stone (rich in comminuted *Inoceramus* spp.) is not seen at Membury. The flint free (*I. labiatus* Zone ?) chalk at Membury is also different in thickness from that seen at other localities in the SE. Devon area, where the thickness ranges from 7.5-9.0m. It is estimated that the total thickness of chalk in the Membury outlier could be as much as 20.0m., and at no locality near Membury can chalk be found that contains flints. All the coastal localities indicate that the *T. lata* Zone is characterized by the appearance of flints, together with a distinctive planktonic microfauna which is dominated by *Whiteinella archaeocretacea* Pessagno, *W. aprica* (Loeblich and Tappan), *Globotruncana sigali* Reichel and *G. pseudolinneiana* (Pessagno). The lack of this association at Membury would seem to indicate that the succession there is all within the *I. labiatus* Zone, and there must therefore be some local reason for this thickening. It can only be suggested that the main depositional control is the minor folding that is associated with the non-sequences that are seen below, within, and above the Cenomanian Limestones. Unfortunately, away from the coast, exposures are so few that it is almost impossible to obtain a regional picture.

When one compares the Membury chalk microfauna with that recorded from Bed C of the Cenomanian Limestones at Little Beach (SY 225879), it is possible to recognize a close correlation. The percentage analysis (Fig. 3) of the Little Beach succession shows a great similarity to the Mernbury faunal succession, although the

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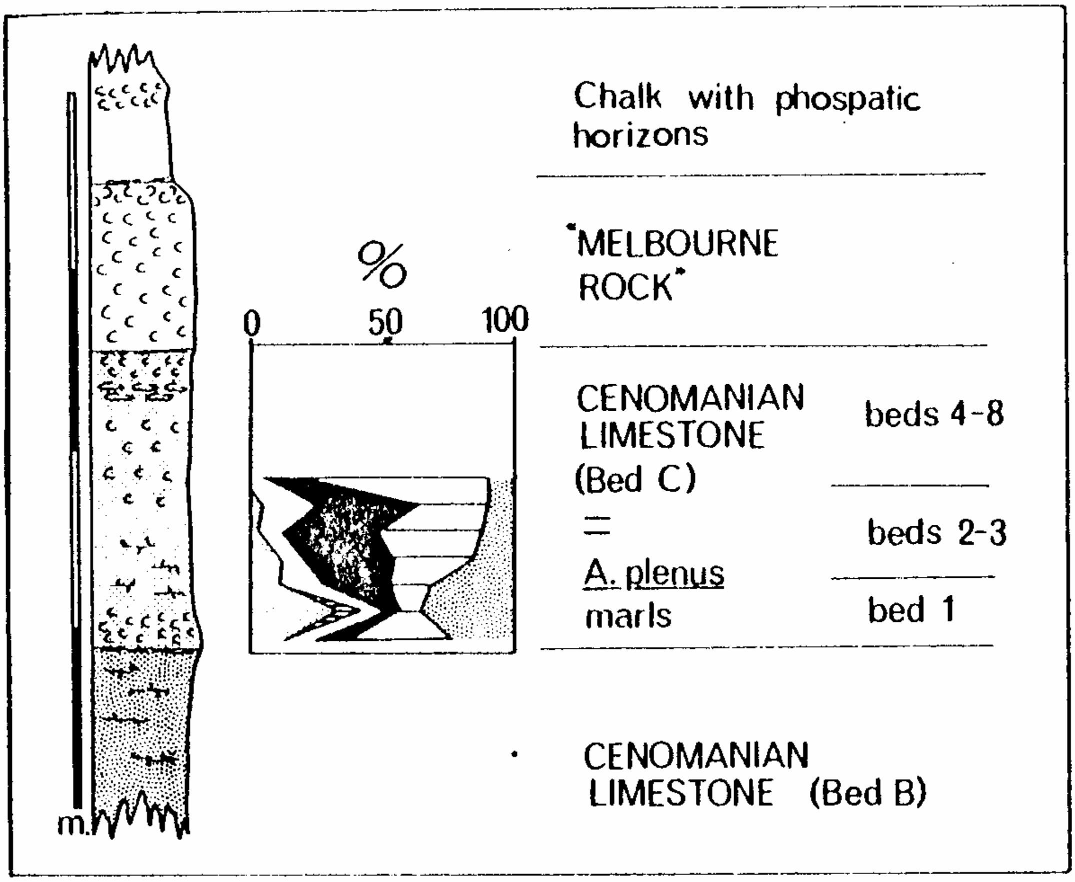

FIGURE 3. Microfaunal analysis of Bed C (Cenomanian Limestones) at Little Beach, Devon.

thicknesses under discussion are clearly different. In Bed C it is possible to show the presence of three units based on Jefferies' Bed 1 Beds 2-3, and Beds 4-8. This is similar to the bed-by-bed analysis provided by Kennedy (1970, pp. 656-670) for the macrofauna. The main difference from the Membury succession is seen in the relative ranges of *R. cushmani* and *R. greenhornensis,* and this allows the separation of Beds 2-3 from Bed 1. The present sampling at Membury has not yet picked up this amount of detail. The fauna of Beds 4-8 on the coast is almost identical with that of the overlying chalk, although there are some differences in the relative proportions of the benthonic fauna. The hard ledge seen 5.35m above the base of the Membury succession is taken as the local equivalent of the top of the Melbourn Rock, and this is confirmed by the presence of abundant 'microspheres' in the fine fractions of samples taken from below the ledge.

The exposures at Wilmington (White Hart Sandpit (SY 208999) and Hutchins Pit (ST 216003)) show similar microfaunal

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successions to that at Membury, with the Cenotnanian microfauna extending only a few centimetres up into the glauconitic chalk that overlies the top of the Cenomanian Limestones succession. The overlying white chalk with inoceramids contains a fauna that in all respects is identical with the Lower Turonian fauna described from Membury.

It is interesting to compare the Membury succession with similar ones in NE. France and South Belgium. In that area, bordering the Ardennes, Robaszynski (1971a, 1971b) has described a microfaunal succession very similar to that seen at Membury. The timing of the events at Membury (see Hart and Tarling 1974) and near the Ardennes, once correlated, should provide a very useful guide to some of the more important events in the Cretaceous depositional history of the Anglo-Paris-Belgian Basin.

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School of Environmental Sciences
Plymouth Polytechnic
Plymouth

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A PRELIMINARY MICROFAUNAL INVESTIGATION OF THE LOWER SENONIAN AT BEER, SOUTII-EAST DEVON

by H. W. Bailey

Abstract. The position of the Turonian -- Senonian stage boundary at Beer is discussed in the light of recent work carried out on the microtaunal assemblage and its correlation with the macrofauna. Changes in the Globigerinacea are used as indicators in the recognition of this boundary.

1. Introduction

Previous workers on the microfauna of the Upper Cretaceous succession at Beer have examined almost all the exposed chalk strata. The Albian and Cenomanian stages have been studied by Hart (1970, 1971, 1973) and the Turonian stage by Owen (1970).

Owen, however, did not examine the junction between the Turonian stage and the Coniacian sub-stage which, if Rowes' (1903) macrofossil zones are used, corresponds to the *Holaster planus* - *Micraster cortestudinarium* zonal boundary. Rowe used a lithological correlation from the Pinhay Bay section to establish the macrofaunal boundary in the cliff exposure at Beer, known locally as Annis' Knob (SY 232892). Jukes-Browne and Hill (1904), in some disagreement with Rowe, placed the top of the *Molaster planus* Zone approximately 4 metres lower at the base of a prominent, black, tabular flint, 0.13 metres thick. This flint is found approximately 5 metres above the base of the section.

The usefulness of this lithological boundary in the field has been proven by a preliminary investigation of the macrofauna. The brachiopod *Orbirhynchia cuvieri* (d'Orbigny) is found in some abundance at a level 1.4 metres below the tabular flint, which suggests a Turonian age for this horizon. A Coniacian age has been attributed to the beds above the flint because of the abundance of *Micraster cortestudinarium* (Goldfuss) two to three metres above the boundary. An examination of the microfauna from this section has been made to see if there is any correlation with the macrofaunal succession.

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Samples were taken initially at one metre intervals; later it was found that a more detailed examination of the chalk immediately above the flint was required. The sampling interval was therefore reduced to 0.25 metres over this part of the section. The study is based on total counts of the foraminiferal assemblage found in the 30-60 (0.50-0.25mm) grain size fraction, as it is within this size range that the majority of the mature, adult individuals are contained. Other size fractions have been studied but not counted.

2. Lithological succession

The Annis' Knob section is approximately 11 metres thick, although a further 6 metres can be added by a second cliff section, separated from the first by a belt of brecciated chalk which probably represents a minor fault. The displacement along this fault is difficult to determine, but it probably throws down a few metres towards the east. It is hoped that the microfauna taken from the second section will give some indication of its stratigraphical position.

The whole of the exposure has a rubbly, nodular appearance on the exposed, weathered cliff face, but minor variations allow a division into three distinct lithological units:

(i) Below the tabular flint the grey/white chalk shows a relatively highh clay content in the form of abundant diagenetic solution seams. This reaches an extreme at the base of the section where clean surfaces have the appearance of white chalk nodules within a matrix of dark grey marl. Grains of phosphatic material, including microcoprolites, are common in this unit, as are discrete grains of glauconite which are occasionally in the form of indeterminate foraminiferal chamber infillings. Unfortunately it is not clear whether the glauconite grains were formed in situ or derived from a source (such as the Lower Chalk) in which glauconite is extremely abundant. Scattered flints occur throughout this unit, the base of which is marked by a nodular flint band.

(ii) Immediately above the 0.13 metre tabular flint there is a pale cream flintless horizon, rich in marl solution seams. This forms a distinctive base to the second unit which continues to the top of the cliff as a very nodular chalk characterized by the presence of hard, yellow/brown phosphatic horizons. These range in thickness from 0.10 to 0.40 metres and are extremely nodular. As the rock is too

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hard to crush, many of the samples taken from the upper part of the cliff were thin-sectioned. Assemblage counts cannot be made on material prepared in this way, so that these samples were used for identification purposes only. Numerous *M. cortestudinarium* occur within these phosphatic bands. Scattered flints and microcoprolites are again present but glauconite is absent from samples taken over 1.4 metres above the tabular flint.

(iii) The section to the east of the fault provides the third lithological unit. The base is marked by a phosphatic horizon, but between this and the top of the section, which shows a pale yellow colouration (possibly due to phosphate content), the chalk has a smooth texture and lacks the nodular character of the cliff. Large, scattered nodular flints are present throughout the unit, but banding becomes apparent towards the top.

3. Microfaunal succession

The benthonic foraminifera of the superfamilies Lituolacea, Nodosariacea and Cassidulacea are by far the most dominant part of the microfauna, often totalling over 95% of the assemblage. Whilst these groups show minor variations which could be interpreted as being of stratigraphic significance locally, it is the planktonic foraminifera which provide the major changes that may be used for wider correlation.

The planktonic population (Fig. 1) has been divided into four types. Those with simple round inflated chambers and an umbilical aperture have been identified as *Whiteinella* sp. The others are referred to *Globotruncana bulloides* Vogler, *Globotruncana pseudolinneiana* (Pessagno) and *Globotruncana* sp., which appears to be an intermediate morphological form between the other two species.

Owen (1970) uses *G. pseudolinneiana* as the index species of the highest planktonic foraminiferal subzone of the Turonian. The results shown on the graph (Fig. 1) appear to confirm this (as in the lowest lithological unit, *G. pseudolinneiana* is the most abundant representative of the genus). The most important feature is the

FIGURE 1. Lithological section of Annis' Knob, Beer, and graph to show planktonic foraminiferal count expressed as a percentage of the total foraminiferal assemblage. *(M. cortest. –Micraster cortestudinarium, O. cuvieri - Orbirhynchia cuvieri.)*

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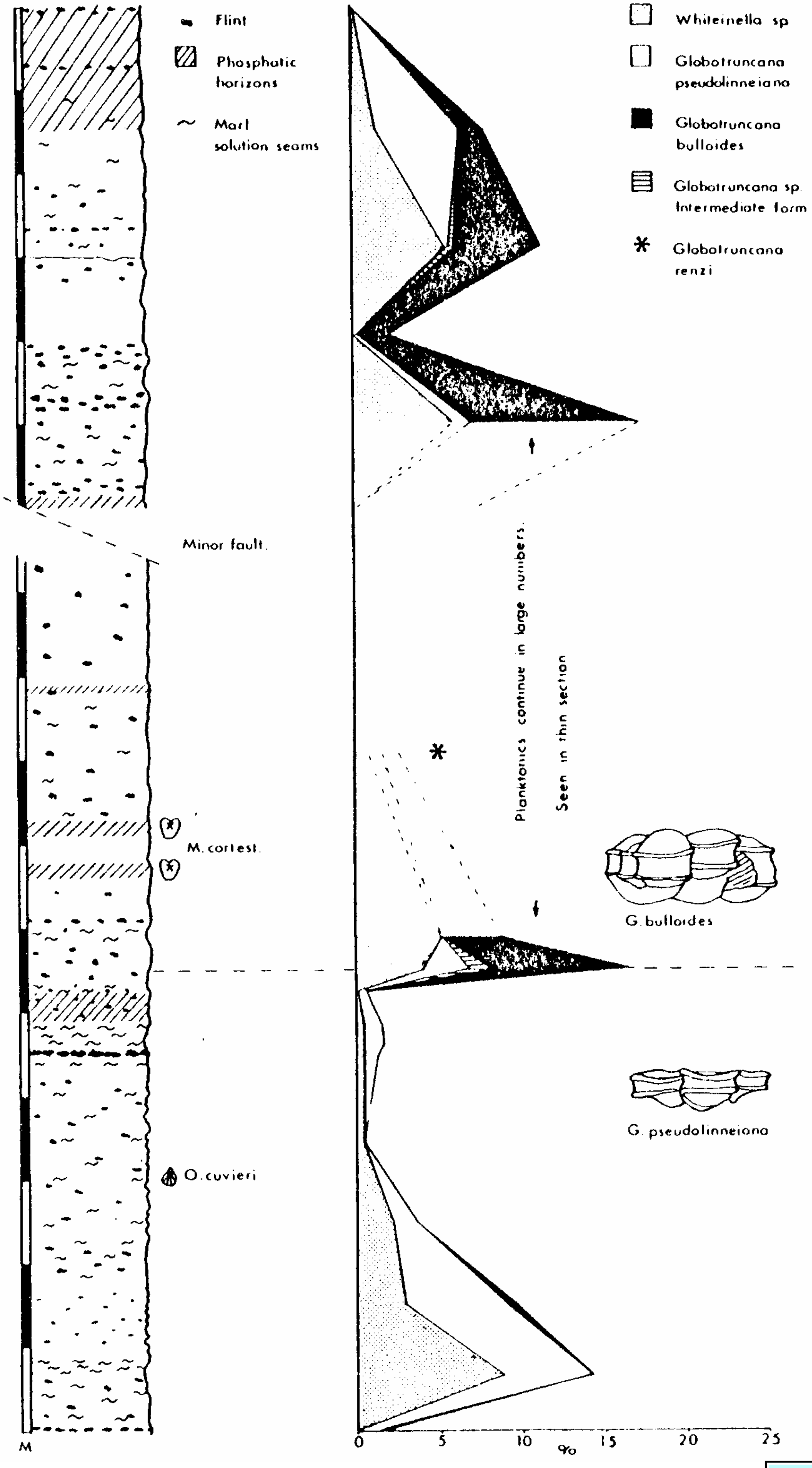

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distinct change in planktonic foraminiferal fauna which occurs 1 metre above the tabular flint. At this point in the section, not only is there a marked increase in the total number of planktonic foraminifera, but *G. pseudolinneiana* is replaced by the inflated form *G. bulloides*. This change is believed to mark the base of the Coniacian sub-stage, and thus the Senonian stage in this area.

The Coniacian age is confirmed 3 metres higher by the presence of *Globotruncana renzi* Gandolfi, which is used as the zonal indicator for the sub-stage in more southerly regions such as Trinidad (Bolli 1957) and the Western Gulf Coastal Plain of the U.S.A. (Pessagno 1967), and which is considered to be a Tethyan form (Douglas and Rankin 1969).

The planktonic forms *G. bulloides* and *Whiteinella* sp. continue in large numbers in those samples which have been thin-sectioned, and it is only at the top of the third lithological unit that a further faunal change is apparent. This is recorded as a total disappearance of the planktonic fauna with a corresponding increase in the Cassidulacea.

Further examination of this part of the cliff is required to give additional information on this change. The section can only be extended by two to three metres at most, as the chalk above this has been removed. At present, therefore, the exact stratigraphic position of the third lithological unit remains uncertain.

In addition to the foraminiferal assemblage the following Ostracoda have been identified from the section, with reference to Kaye (1964): *Cytherella ovata* Roemer, *Cytherella parallela* (Reuss), *Bairdia subdeltoidea* (Munster), *Macrocypris* sp., *Neocythere (Physocythere) virginea* (Jones), *Monoceratina* sp. cf. *umbonata* (Williamson), *Veenia harrisiana* (Jones), *Trachylebridea acutiloba* (Marsson), *Cythereis* sp. cf. *lurmannae* Triebel, *Cythereis* sp. cf. *ornatissima* (Reuss), *Cytherelloidea hindei* Kaye and *Cytherelloidea oblinquirugata* (Jones and Hinde).

C. ovata and *C. parallela* have a distribution throughout the whole section. The others, apart from *Macrocypris* sp., appear as scattered individual specimens at various levels. *Macrocypris* sp. has been separated off as it appears to be common only in the second cliff section.

ACKNOWLEDGEMENTS. I would like to express my thanks to Dr. M. B. Hart for his assistance throughout this project and to Mr. P. Weaver for his comments on

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School of Environmental Sciences
The Polytechnic
Plymouth

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A revision of the geology of the St. Agnes outlier, Cornwall (Abstract):

by K. Atkinson, M. C. Boulter, E. C. Freshney,
P. T. Walsh *and* A. C. Wilson

A specimen of lignitic clay housed in the Museum of Practical Geology, London, No. MR 10401, is thought to have been collected by Dr. H. Dewey in 1932 from the Beacon Cottage Farm claypits, St. Agnes (Grid reference SW 705 502). That specimen was prepared for palynological analysis by the Institute of Geological Sciences by W. A. Watts about ten years ago. Preliminary determinations of the microflora suggested that the sample was much older than the Pliocene age previously generally accorded to it, and an Oligocene age was suggested in Mitchell's account of the St. Erth Beds.

The slides have been re-examined and new preparations have been made at the Palynology Laboratory, North-East London Polytechnic. From these three sources 32 pollen and spore taxa have been identified and photographed to produce a palaeobotanically meaningful assemblage. Tricolpate and tricolporate angiosperm pollen account for over 90% of the assemblage, whilst the remainder is made up of other taxa commonly found in Oligocene deposits of Europe. Of these, the following are of particular significance when determining the age of the samples: *Cicatriocosisporites* sp., *Triatriopollenites coryphaeus punctatus* R. Pot., *T. coryphaeus microcoryphaeus* R. Pot., *Intratriporopollenites indubitabilis* R. Pot., *I. instructus* R. Pot. and Ven., *Alonocolpopollenites tranyuillis* (R. Pot.) Th. and Pf., *Gothanipollis corruaerius* Kr. The age is considered to be Middle-Upper Oligocene because:

1. The very large proportion of tricolpate and tricolporate pollen is similar to assemblages from deposits of that age from Germany, Poland and Czechoslovakia.

2. The seven taxa listed are particularly characteristic in deposits of that age when found together.

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3. There is an absence of forms characteristic of both Eocene, Lower Oligocene and Miocene both in particular association and proportions.

There seems to be little doubt that the Dewey sample is quite authentic because unfossiliferous lignitic clays are currently exposed nearby in Dobles Sandpits (SW 705 510). However, a search for the precise source of the fossiliferous Museum sample has not been successful so far. The dating of the Museum sample indicates that the St. Agnes sediments must now be considered to be basal remnants of a late-Oligocene continental, mainly fluviatile deposit of yet unknown extent. Field mapping, borehole and geophysical surveys and sedimentological and geotechnical analyses of the St. Agnes deposit are currently being conducted with a view to determining the full palaeogeographical significance of the revised dating.

KA
School of Mines
Carnborne
Cornwall

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Observations on the basal hardpan of the St. Agnes Beds, Cornwall (Abstract):

by Keith Atkinson

Present exposures suggest that the basal pan of the lowest sand member of the St. Agnes Beds is widely distributed in the Dobles Sand pits. This hardpan varies in thickness from a few millimetres to two metres with an average thickness in measured sections of 0.5 metres. The pebbly horizon claimed by many authors to lie at the base of these sands is absent wherever the hardpan is exposed. The pan rests directly on the eroded Devonian slate surface. The grain size of the basal pan is comparable to the overlying sands. Chemical analysis of the pan and the overlying sands shows that the pan is enriched only in iron compared to the sands.

Contained within the basal pan are pseudo-tubular structures, but other true tubular structures are found sporadically developed between the pan and a horizon 3 metres above it. The average diameter of these tubes in 30mm. Most of the tubes are straight, with their axes almost horizontal directed approximately NE-SW. These tubes are frequently hollow or with their centres filled with soft sand. The sand in the cores of the tubes is identical in grain size and composition with the surrounding unconsolidated sands. The walls of the tubes are hard and enriched in most elements (for which analyses have been carried out) except manganese. The iron content of the tube walls is higher than that of the basal hardpan.

Also occurring infrequently in the sands are thin lenticular concretionary structures up to 150mm long and 15mm wide. These again lie with their long axes horizontal. In contrast to both the hardpan and the larger tubes these small structures are not enriched in iron-above the background value of the sands and they are greatly enriched in manganese. They also contain greatly increased amounts of the rarer elements. Not one of the concretionary structures observed contained a nucleus.

School of Mines
Camborne
Cornwall

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A LATE-PLIOCENE MARINE TRANSGRESSION AT ST. ERTH, CORNWALL, AND ITS POSSIBLE GEOMORPHIC SIGNIFICANCE

by Alan C. Wilson

Abstract. The late-Pliocene St. Erth Beds reflect deposition during a marine transgression. This rise in sea level may have culminated in the cutting of the 131 in (430ft) coastal platform in late-Pliocene to lower Pleistocene times.

1. Introduction

The St. Erth Beds comprise about 10 metres of partly consolidated, gravels, sands, silts and fossiliferous clays which crop out east.of St. Erth (SW 551 351). Debris of similar gravels and iron-cemented sandstones is present around Splattenridden Farm (SW 535 361) at approximately the same height as the deposits at St. Erth and it is concluded that they are parts of a formerly more extensive outcrop of this formation. In view of their late-Pliocene age (Mitchell and others 1974) it was considered possible that the St. Erth Beds might contain sedimentary evidence bearing on the geomorphic evolution of the region during Plio-Pleistocene times.

2. The deposits at St. Erth

In trenches dug near formerly worked pits, Mitchell and his associates (1974) confirmed the general sequence recorded by earlier workers. The succession fines upwards from coarse clastic detritus to fossiliferous clay. Catt and Weir (in Mitchell and others 1974) found the sands within the deposit to contain two well-sorted grain populations, and their respective surface textures indicated an eolian dune and beach origin, so that the succession might reflect a marine transgression. The lowest sediment they examined (Mitchell and others 1974, sample 9) contained a very fine sand population. The very good sorting and the overprinting of aqueous on eolian grain-surface textures indicate deposition on a beach probably near

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or just above high-water-mark, where reworking of the adjacent dunes would have occurred. These very fine sands pass up into fine sands which have grain-surface textures and sorting values of a typical beach deposit. In these samples (Mitchell and others 1974, samples 7-5) there is an upward decrease in the proportion and characteristic features of eolian dune-derived grains. The highest beach horizon is a thin pebbly sand, which is overlain by sandy clay containing marine fossils and a freshwater bivalve (Mitchell and others 1974, p. 23). The mixing of these faunas, together with their vertical association with beach sediment, suggests deposition in a near-shore, sub-tidal area. The succession is capped by a blue, calcareous clay containing fossils which suggest (McMillan and Margerel, in Mitchell and others 1974) that sediment accretion probably took place in shallow water, perhaps less than ten metres below low-water-mark. In summary, the succession at St. Erth passes up from beach sands (somewhat above the base) through sub-tidal deposits into a marine clay.

3. The deposits at Splattenridden

There are no exposures of the St. Erth Beds around Splattenridden Farm but localized and abundant distinctive surface debris of gravel and hard iron-cemented sandstone and pebbly sandstone is almost certainly derived from the underlying bedrock. The distribution of these rock types across the outcrop indicates that the lithologies lie in bands parallel to the contours. As the outcrop at Splattenridden is situated on a gently-sloping hill, there has probably been little differential downhill transport of superficial detritus and consequently it is believed that the banding directly reflects an underlying stratigraphy.

The lowest band on the hill (i.e. nearest Canonstown (SW 535 354)) comprises gravels, the clasts in which are rounded and of local derivation (e.g. slate, hornfelsed spotted slate, chloritized slate, quartz and granite). The next band upwards contains pebbly sandstones and sandstones. Rock fragments collected progressively uphill across this band were disaggregated and show a general increase in sorting. Plots of the skewness of their grain-size distributions against standard deviation (or sorting) fall within the field of alluvium as delineated by Friedman (1967, Fig. 15). Medium

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and fine quartzose sandstones characterize the highest zone on the hill (i.e. nearest Spialtenridden). They are as well sorted and rounded as the postulated beach sands at St. Erth and since they plot within the field of beach sediment (in a skewness versus standard deviation plot) they are interpreted as being of littoral origin. Thus it appears that the succession al Splattenridden represents an upward passage from alluvial gravels, pebbly sandstones and sandstones into beach sandstones.

4. Possible geomorphic significance of the St. Erth Beds succession

Comparison of the successions at St. Erth and Splattenridden suggests that the coarse clastic lithologies at Splattenridden are probably laterally equivalent to the basal parts of the sequence at St. Erth. Thus it is apparent that the succession within the St. Erth Beds, in passing upwards from alluvium through beach deposits into sub-tidal and marine sediments, represents a well ordered marine transgression.

The prominent 131 metre (430 ft) marine platform of the North Cornish coast is generally accepted as being of Plio-Pleistocene age, since it has a fresh, only recently-incised geomorphic form and a back-feature which parallels the present coast-line. Therefore it is postulated that the marine transgression recorded within the late-Pliocene St. Erth Beds led to the cutting of the platform, perhaps during the early Pleistocene. It is probable that the Palaeogene St. Agnes Beds (Mitchell 1965), which lie near the back of this platform, were extensively eroded at this time. The successively lower benches and alluvial terraces of the West Penwith area (Wilson 1974, p. 121) probably reflect temporary halts in the ensuing regression and it would be expected that these would be of middle and late Pleistocene age. Partial proof of this hypothesis has been obtained from a Devensian peat (Wilson 1974, p. 121) collected from one of the youngest alluvial terraces. The preservation of the poorly lithified St. Erth Beds during the regressive phase probably indicates a rapid fall in sea-level through the vertical range of the deposit.

ACKNOWLEDGEMENTS. I am grateful to my colleague Dr. E. C. Freshney for helpful discussions concerning various aspects of this paper and to Mr. R. C. Scrivener for preparing the sandstone samples from Splattenridden.

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Institute of Geological Sciences
Hoopern House 101,
Pennsylvania Road
Exeter

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A molluscan interglacial fauna from terrace gravels of the River Cary, Somerset (Abstract):

by D. D. Gilbertson *and* R. B. Beck

In 1954 the Rev. J. Fowler presented a small piece of cemented, pebbly, terrace gravels containing non-marine molluscs to the British Museum (N.H. Palaeontology - Sample LL2067). The sample was found 2.8km north-east of Somerton in the Chadbrick valley. This area about Hurcot Farm (SY 510294) comprises terrace gravels of a proto-R. Cary, overlain by solifluction deposits. The gravels are c.30m above the modern R. Cary flood plain and are shown on Geological Survey maps as undifferentiated terrace gravels. The precise location of Fowler's find could not be determined.

The following taxa were identified from the British Museum sample by D. D. Gilbertson - *Valvata piscinalis* (Muller) 3 specimens (B.M.Cat.No. GG 15478-81); *Lynutaea peregra* (Muller), 2(GG 15482-3); *Planorbis* sp., 1(GG 15484); *Hygromia* cf. *hispida* (L), 1(GG 15485); *Unio* sp., 1(LL 2602); *Corbicula fluminalis* (Muller), 1(in LL 2067); *Pisidium henslowanum* (Sheppard), 3 (LL 2063-6); *Pisidium nitiduin* (Jenyns), 1(in LL 2067); *Pisidium spp., 1 (in LL 2067). Corbicula fluminalis* is usually characteristic of an interglacial environment. Its present day closest occurrence to Britain is North Africa.

The combination of *Va1vata, Corbiciela, Unio,* and *P. heieslowanum* indicates the former presence of a large stream or small river flowing in a temperate interglacial environment. There is no indication of any marine influence. The deposits cannot yet be dated. However, the gravels appear to grade to a mean sea level at 10-20m O.D. which suggests that either the Ipswichian or Hoxnian interglacial period may be represented. In view of recent controversy concerning possible glaciation of this area, a full study of this site would be of considerable stratigraphical interest.

DDG
Dept. of Geography
University of Adelaide
South Australia 5001

RHD
North Yarde
Bishop's Nympton
South Molton N. Devon

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A PLEISTOCENE SECTION AT GUNWALLOE FISHING COVE, LIZARD PENINSULA

by H. C. L. James

Abstract. A 600m-long Pleistocene section in Gunwalloe Fishing Cove is described. A "raised" platform cut across Gramscatho (Devonian) shales and grits, is overlain by, in upward sequence, a basal conglomerate, a thick sand layer and periglacial Head. The sand layer is thought to be largely marine in origin and contains evidence which may indicate a cooling of the climate. A tentative chronology for the deposits is suggested.

1. Introduction

Numerous accounts of raised beaches around the coast of Cornwall have been recorded during the past 150 years in various publications, notably the Transactions of the Royal Geological Society of Cornwall as well as the relevant Memoirs of the Geological Survey. More recently, attempts have been made to date these ancient marine deposits over large areas, from S. Ireland, S. Wales, SW. England, to the Channel Islands and Brittany. (See "The Glaciations of Wales and adjoining Regions" Ed. C. A. Lewis 1970 and papers by Mitchell 1972, Bowen 1973a and b, and Kidson and Wood 1974.) References to raised beach sections in South Cornwall may be found in the publications mentioned above and elsewhere, including brief references to the section at Gunwalloe Fishing Cove (G. R. SW 654 224). This cove is exposed to the southwest and is nearly 12 km NNW of the Lizard Point.

2. Geomorphic setting of the deposits

The section under consideration extends virtually unbroken for 600 in north-westwards from Baulk Head along the eastern shores of Mount's Bay and lies entirely upon an ancient shore platform cut into SE-dipping slates of the Gramscatho Series.

Beach profiles show a steeply shelving contemporary beach with maximum slopes of 10° rising up to the eroded edge of the "raised"

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shore platform, which extends as much as 29m outwards from the foot of the present cliff. The average width of the "raised" platform is 14m, and is best preserved north of the slipway at the mouth of the cove (G.R. SW 654 225) Where the width extends to more than 20ru. The mean seaward dip of this platform is 6°, ranging from 3° to 10°. The high slope angles tend to reflect the proximity of the fossil cliff line which is frequently revealed at the back of the platform. The junction between the fossil cliff and the platform may be located at a number of points and has been found by levelling techniques to vary between 10.8m O.D. at the extremities and 8.8m in the central part of the cove. These values for the altitude of the notch are comparable with similar results obtained at Caerthillian Cove, a few kilometres farther south, and from elsewhere in Cornwall (James 1975) and the Westcountry (Stephens 1970). The height of the contemporary cliff, which merges with the fossil cliff towards the north, ranges from 22m O.D. near Baulk Head to 36m O.D. at the northern end of the section.

Thus the profiles show the contemporary beach, which is generally less than 50m wide, to be narrow and steeply shelving, whilst the remnants of the "raised" platform are subjected to contemporary weathering and marine erosion at their outer edges, thereby producing an apparently lower-level surface stripped of any former marine deposits. In the centre of the cove, erosion is active where the cliff is formed almost entirely of unstable sands and clays. Cliff collapse is induced by the percolation of water through the sands.

3. **Description and interpretation of the deposits**

The Pleistocene deposits in Gunwalloe Fishing Cove were sampled on a random basis and the essential stratigraphical features of the section may be summarized as follows:

Head - 1 m l0 4 m.
Upper sand layer.
Lower sand layer - coarse lens marks upper limit } 10 + m
Raised beach - average thickness 2m.
Raised Shore Platform - notch at 10.8m. O.D.

The basal section of the ancient deposits, which are largely of local origin, consists of large sub-angular to sub-rounded boulders

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together with cobbles, pebbles and coarse sands cemented by oxides of iron and manganese. The basal conglomerate may be traced for the whole 600m length of the section and it is invariably overlain by a finer layer of sand with occasional bands of small pebbles of slate, quartz and flint. This finer layer varies from 30cm to many metres in thickness and, like the basal conglomerate, is conspicuous throughout the section. In addition, individual samples taken from this layer may contain as much as 10% silt and clay possibly derived from the overlying periglacial and colluvial deposits. The latter and their associated slope wash tend to mask the underlying deposits and obscure the true thickness of the sand layer.

As a result of recent heavy rains, there has been fresh slumping of these non-indurated deposits making it possible to examine the new exposures.

The sand layers are much thicker than the preliminary observations suggested; in the centre of the cove (just north of the slipway) the layers, which are more than 10m thick, extend to within a metre of the top of this particular section. The grade of the material above the basal conglomerate varies from pebbles and large cobbles to silts and clays, with as much as 70% of the deposit consisting of medium to very coarse sands. A petrological examination of the section showed the predominance of local material in the form of slates, grits and vein quartz from the Gramscatho and Mylor beds, but occasional flints, hornblende-schist, gabbro and granitic material also make up a small proportion of the rock types present. The quartz becomes increasingly common and angular as the size of the sand particles decrease. There are also significant differences in the degree of roundness of the included pebbles with the lower horizons containing bands of well-rounded pebbles as well as one 40cm thick lens of rounded pebbles and cobbles, whereas the upper horizons contain angular slates and grits appearing either as isolated blocks or as discrete beds of frost-shattered slates. Throughout this section there is little or no shell carbonate, a feature that has been noted elsewhere in the county (James 1968).

It would seem that at least three different processes could have resulted in the formation of the 10+m sand section. A beach origin can be ascribed to the deposits in the lower horizons. The presence of well-rounded interbedded pebbles, cobbles and sands, as well as the 40cm thick lens of coarse rounded material, seems to confirm

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this hypothesis. This lens, which occurs more than two metres above the basal conglomerate, has a seaward dip of 2° which is similar to some dips on the contemporary beach; it consists of pebbles of slate and quartz, amongst granules and coarse sands. Granules make up 70% of the finer material and can be subdivided on petrological grounds into 70% slate, 25% quartz and 5% flint. Mechanical analysis of the lens material produces very similar results to that obtained from a comparable survey of material from the contemporary beach. Though the evidence would seem to point to significant littoral action, at this stage it would be unwise to completely rule out an aeolian component, the possibility of which is being assessed by statistical analysis.

In contrast, the explanation of the main features of the upper sand layer is more complex. The total depth of sand (6m), its height above the platform, extending up to at least 20m O.D., and the absence of rounded pebbles make a marine origin seem unlikely. Close examination of the horizons above the coarse lens reveals the presence of many alternating coarse and fine sand bands with an average seaward dip of 12° compared with 2° for the coarse lens. The individual pattern commences with a marked content of fines (10%) amongst the sands, and grades upwards into sands free front both silt and clay, followed by a marked lithological break and a re-commencement of these lithologies, the cycles ranging from 10cm to 20cm in thickness. The presence of this reverse grading and banding discounts direct leaching of the fines front the overlying Head. The marked change in dip from the underlying marine deposits, the degree of sorting and the lack of geomorphological evidence for an alluvial deposit, suggest re-deposition of what were probably aeolian sands. Thus, the agent of deposition would seem to be water associated with solifluction processes. It is envisaged that aeolian sands were periodically washed seaward and that occasionally this process was interrupted by incorporation of irregular lenses of shattered head material into the sand layers. The bands of angular periglacial deposits become increasingly common towards the top of the upper sand layer and form the top 1 m of the cliff to the exclusion of sand. The intercalated Head-like material shows evidence of shattering, probably as a result of periglacial frost action.

In conclusion, the Pleistocene section at Gunwalloe Fishing Cove betokens a complex process by which marine and wind deposits were modified by sheetwash and soliflual action as the climate became

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colder and sea level began to fall. The following chronological interpretation of the deposits is suggested:

Head deposits - 1 m to 4m.	Devensian.
Upper sand layer - approximately 6m.	Early Devensian.
Basal conglomerate and lower sand layer - 1m to 4m.	Ipswichian.
Shore platform - 10.8m O.D.	Early Ipswicltian.

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Berkshire College
Reading

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AN EXAMINATION OF RECENTLY EXPOSED PLEISTOCENE SECTIONS AT GODREVY

by H. C. L. James

Abstract. At Godrevy, 7 kms WNW of Camborne, Cornwall, an ancient marine platform, cut across Devonian Mylor slates, is overlain in upward sequence by basal pebbles, a thick sand layer, soliflucted Head deposits and Holocene wind-blown sands. Clay bands in the sand layer have a ripple-like appearance and were deposited under quiet conditions by water flowing off the land before burial by wind-blown sand.

1. Introduction

The presumed Pleistocene sections at Godrevy on the north coast of Cornwall have received considerable attention from researchers interested in various aspects of Quaternary studies, especially by those concerned with establishing a Pleistocene chronology for the Westcountry. (See Everard *et al.* 1964, Stephens 1961 and 1970, Mitchell 1972.)

Recent cliff falls have revealed new sections which may solve some problems and also produce interesting details of former environmental conditions. The Godrevy coastal section consists of a 'raised' shore platform cut across Mylor Devonian slates which are highly contorted and intersected by quartz veins. The slates vary from harder, more resistant blue-coloured types to more easily weathered, soft, yellow varieties. This platform is as much as 100m wide and the notch was found at various points to be about 8m O.D. The deposits overlying the platform are, in ascending order, basal pebbles, sands both marine and aeolian and locally cemented to form sandrock, head or solifluction material, Holocene aeolian sands and soil.

2. **Description of the deposits**

The basal pebbles form a well marked horizon of local and exotic material occasionally cemented by oxides of iron and manganese

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(Hosking and Pisarski 1964); they are overlain by considerable thicknesses of sands (2-4m) often masked by slumping of the overlying Head. Just above the horizon of basal pebbles, and 100m south of the exposure of sandrock, clay bands have been identified in an undulating pattern at the base of the sand layer. These bands of yellow clay vary from 2-5cm in thickness and appear to be ripple-like; they would seem to indicate deposition from slowly-moving water permitting the deposition of fines prior to being buried by 23m of wind-blown sand. The undulating pattern appears to be the result of the fines filling ripple marks on a former marine surface. Further analysis of these clay bands is proceeding. In a valley 200m to the south, thicker, more numerous, hands of clay have been located in sands just below the Head and could be related to wash deposits prior to the onset of severe periglacial conditions. In fact, the Head deposits can be seen to interdigitate and gouge into the non-indurated sands in this section; nearby the Head/sand junction is marked by a convoluted band of manganese cemented sands.

The sand layer passes into sandrock or aeolianite (Stephens 1970) near Godrevy Point and it is made up of pale yellow, cemented, shelly sands of medium to coarse size. More than 60% of the sandrock consists of shell, and the deposit is similar in appearance to the sandrock near Saunton in North Devon; it has comparable structures to the type of bedding found in modern sand dunes and beaches.

The sandrock near Godrevy Point is penetrated by vertical pipes with an average diameter of 12-13cm and a depth of more than one metre. Until recently, only sections of *empty* pipes could be seen, but, following falls of large blocks of sandrock within the past three months, pipes filled with brown sand have been revealed. These dark uncemented sands form a surface layer between the cemented sandrock and the overlying Head material. Analyses of the sands show them to be decalcified aeolianite, as their grade size and petrology is almost identical to that found in the cemented sandrock. These unconsolidated sands, which prove to be susceptible to denudation, are an ephemeral feature of this section.

The lower horizons of the sandrock are probably of marine origin, as they differ in grade size from the upper part of the sandrock, and occasional well-rounded pebbles are found at least one metre above the base of the sand. However, the remainder of the

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sandrock is very similar in texture and composition to the wind-blown Holocene sands which overlie the Head.

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A STATISTICAL ANALYSIS OF THE BEACH METAQUARTZITE CLASTS FROM BUDLEIGH SALTERTON, DEVON

by Alan P. Carr and Michael W. L. Blackley

Abstract. Samples of beach metaquartzile clasts taken over a one-year period are statistically analysed. The data show that only the roundness is normally distributed. Grading for the linear parameters varies both in respect of sample occasion, section and zone. Generally clast sizes and shapes grade along the whole beach, but it is possible (June 1972) for clast size grading to occur in each direction away from the central supply/-landslip area. Mean axial ratios are more variable than for the metaquartzite population at Chesil Beach, suggesting that the more spherical quartzites, which are unrepresented at Chesil, are either less mobile, less durable, flattened through abrasion, or that the Chesil metaquartzites were not derived from the Budleigh area.

1. Introduction

The main purpose of this study was to see to what extent the presence of landslips, and the existence of a nearby source of (pre-rounded) metaquartzite pebbles and cobbles, could be detected through their influence on the longshore grading of coarse beach material in an otherwise apparently closed system.

Budleigh beach is situated on the south coast of Devon, England (Fig. 1). On average it is approximately 40m wide from landward limit to low water mark, with its maximum height at 5± 1 in O.D., i.e. about 3.3m above high water mark, spring tides. It is terminated at its west end by the rocky headland of Straight Point and at the east by the R. Otter and Otterton Ledge. From Otterton Ledge to midway between Sections 4 and 5 there is either no cliff backing the beach or else only a low, intermittent, feature. However, further west, where the cliffs reach a maximum height of over 120m, the area is characterized by considerable instability with small mudflows and larger landslips. At the time of the research described here the slips were most prominent adjacent to Sections 10 and 13.

The Budleigh Salterton Pebble Beds, probably of Lower Triassic (Scythian) age, crop out in the cliff face between a position just east

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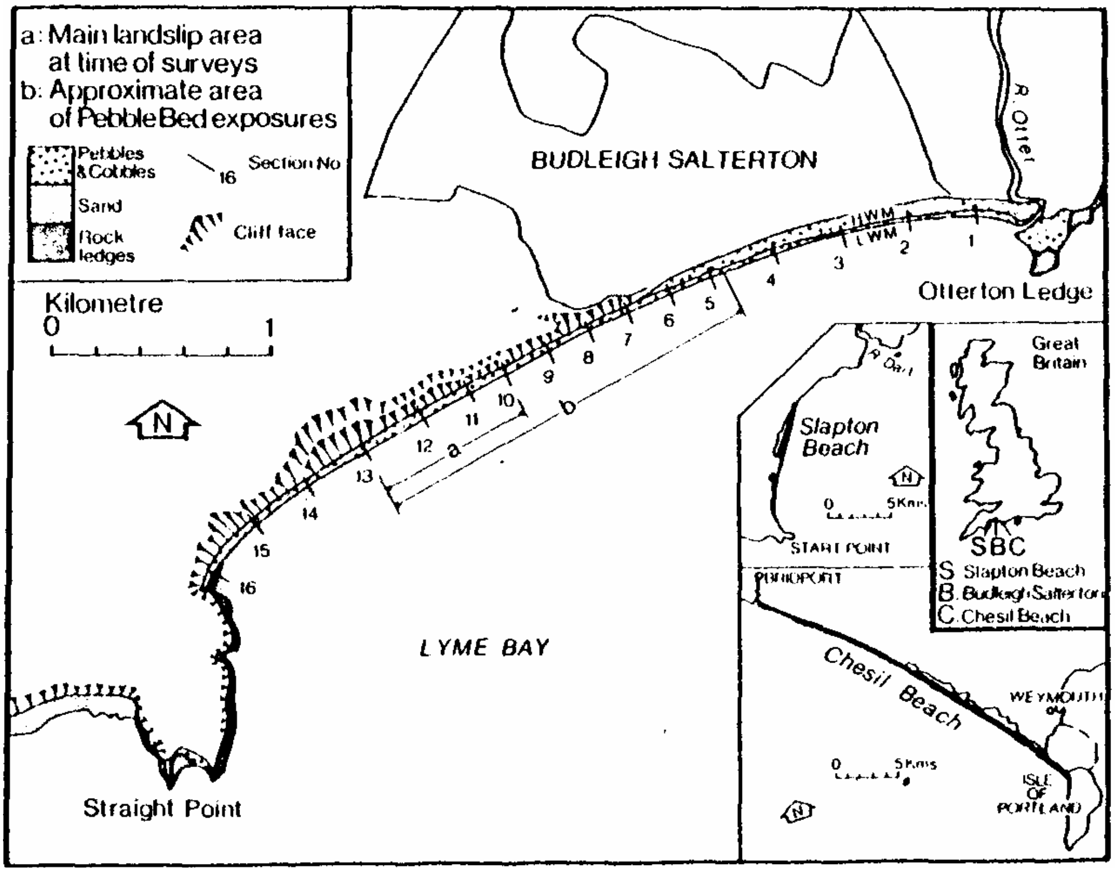

FIGURE 1. Budleigh Salterton, Devon. Site map to show location of Sections, area of landslips (a), and outcrop of Pebble Beds (b).

of Section 5 to as far west as Section 13, or thereabouts. The outcrop increases in height from east to west, and has been described by various workers, of whom Henson (1971) is the most recent.

The pebbles and cobbles which comprise the beach extend seawards approximately as far as low water mark, where there is an abrupt change in grade of sediment to sand and silt. They fall within the range 0.019 ± 0.005m and 0.104 ± 0.018m for means and standard deviations of long axis *(a)*, and are very largely meta-quartzites similar to those in the Pebble Beds, from which they have apparently been derived.

2. Method

Between October 1971 and October 1972, 16 sections were sampled on each of four occasions. The section lines were spaced at 300111 intervals at the ends of the beach (between lines 1 and 5, and 12 and 16) and at 200m in the centre (Fig. 1). Initially up to six surface samples were obtained from each section corresponding to high, mid and low tide levels throughout the length of the beach with,

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additionally, samples from the cliffs, cliff/beach junction, and storm crest, as applicable. Only high and low water samples were obtained in February 1972 (because of the close horizontal proximity of the 2 zones); thereafter, high, mid and low water zones were sampled in June 1972, while, in October 1972, physical conditions changed dramatically during the sampling period so that low water sampling was discontinued midway through the programme. Beach samples were obtained within 1½ hours of low water.

Some 200 metaquartzite pebbles and cobbles were measured for each sample, except for the cliffs where the number *(n)* was generally 500, and on Section 16 where, because of size, only 100 were analysed. To facilitate comparisons, fragmented pebbles, geological types other than metaquartzites and, in the case of the cliff samples, the matrix also, were all rejected. The pebbles were measured in the laboratory by means of an electronic device, based on sliding calipers, with the resulting data punched onto paper tape (Hardcastle, 1971). All 3 axes were measured (where *a, b* and *c* were long, intermediate and short axes, respectively). In addition, roundness was computed using Kuenen's formula (Kuenen 1956), which employs the ratio $2r/l$, where $2r$ is the diameter of curvature of the sharpest corner, and l is the largest diameter at right angles to the long axis (i.e. in effect the intermediate axis, b). Means, standard deviations, skewness and kurtosis were calculated, for size and roundness data. Ratios $\left(\frac{a}{h},\frac{a}{c},\frac{b}{c}\right)$ and representative shape indexes $\sqrt[3]{\frac{c^2}{ab}}$ Sneed and Folk, 1958; $\sqrt[3]{\frac{bc}{a^2}}$ Krumbein, 1941**;** $\frac{a+b}{2c}$ Wentworth, 1922 - Cailleux, 1945) were computed subsequently (Table I). Linear, log and distance squared (d^2) regression equations were calculated with the sediment parameter as y and the distance travelled as x; these statistics assume a normally distributed population.

3. Results

The results are best considered separately in relation to roundness, and to linear parameters, together with the latter's ratio and shape index derivatives.

(a) Roundness Most of the samples have skewness and kurtosis values closely reflecting those of a normal distribution (Figs. 2b, c;

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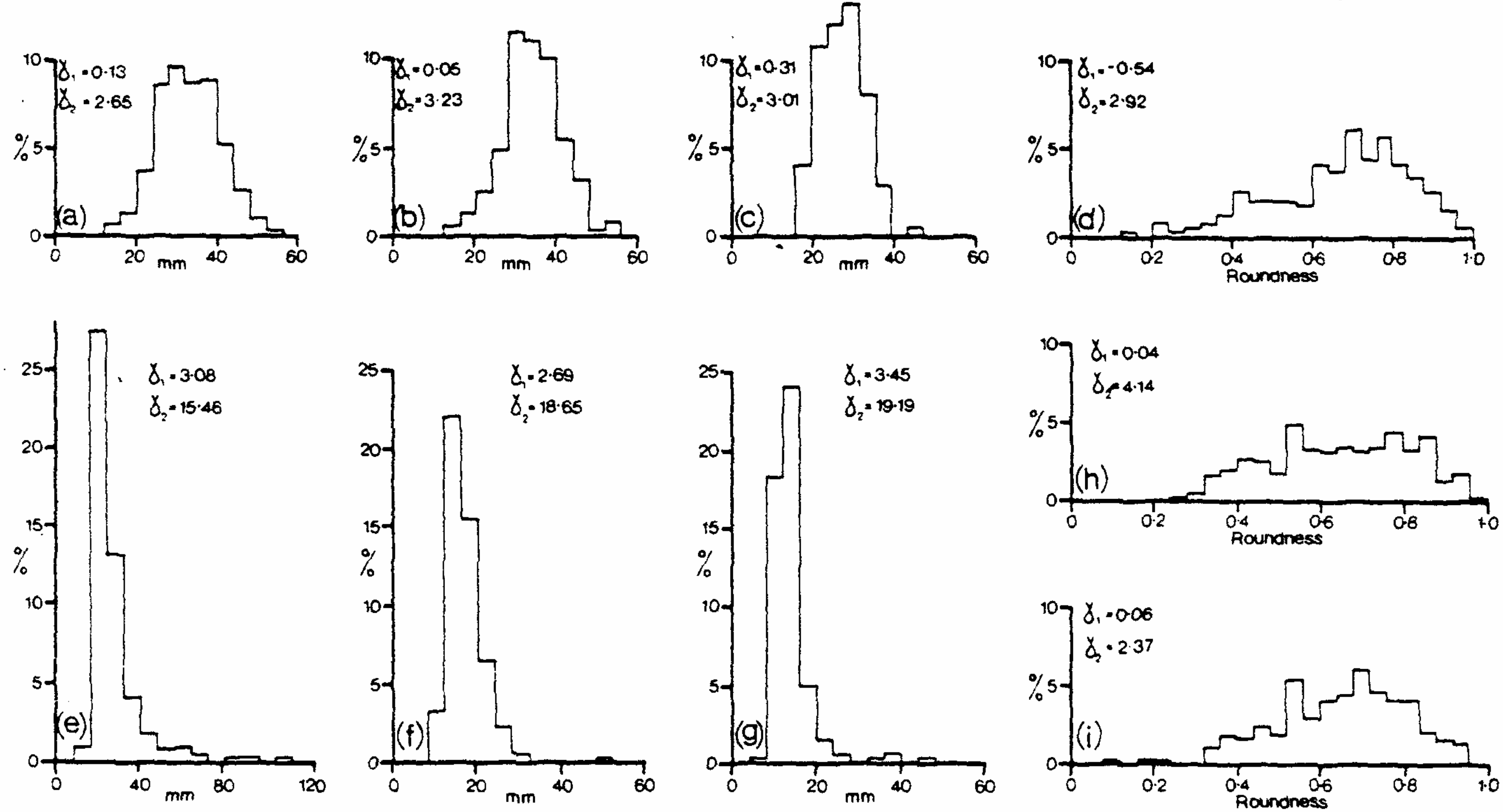

FIGURE 2. Cliff sample histograms: (a) to (c) roundness for Sections 6. 8 and 11 respectively. Note the bimodality of the histogram for (a). (d) corresponding short axis for Section 11 showing positive skew. Values for skewness (γ_1). and kurtosis (γ_2) are given.

and 3h, i). Although 87% of the 195 samples had a negative skew (e.g. Fig. 3d) in 79% of the total this skew was less than ± 0.5. On only 3 occasions did it exceed - 1.0. Similarly, in less than 7% of the samples was the kurtosis greater than 4.0 or less than 2.0.

The results reflect the geographical position of the samples. Thus, mean roundness values are lowest for the cliff samples (where r varies between 0.35 and 0.59) and in which, exceptionally, marked bimodality may also occur (e.g. Section 6; Fig. 2a). Throughout the beach, irrespective of section or zone, and on every sampling occasion, mean sample roundness showed remarkably little variability, 70% of all values falling within the narrow range 0.63 to 0.68.

(b) Linear parameters A positive skew was characteristic of all samples to some extent. This was especially marked with those derived directly from the cliffs which give an overall mean skewness value of + 1.37. For cliff Sections 9 and 11 the tail takes the form of an ill-defined secondary peak suggesting an element of bimodality in the samples, but, in these particular instances, outside the ranges which Henson (1971) noted (Fig. 2d). Kurtosis for the cliff samples was very variable, ranging from 3.51 to 9.94. Standard deviations were, expectably, proportionately greater in respect of the cliff samples than elsewhere. The remaining non-routine samples, taken from the beach at the foot of the cliff and the storm beach, also displayed a considerable degree of variability in skewness and kurtosis but no obvious trends occurred.

Unlike in the case of roundness, the degree of normality of the beach sample distributions showed a marked variation in relation to the sampling occasion, the particular section, and the respective zone. As far as specific sections are concerned, samples generally were more normally distributed away from the centre of the beach. Some inconsistency was shown by data from Section 1, perhaps as a result of its situation close to the mouth of the R. Otter. However, taking the total of all high, mid and low water samples obtained throughout the study, 71% on Sections 1 to 6 (43 out of 65) had a kurtosis value between 2.0 and 4.0 and skewness below 1.0. For Sections 14 to 16 the proportion within these ranges reached 23 out of 29 (79%) with Section 16 equalling 100%.

Significant correlations between distance alongshore v. linear parameters, ratios and representative shape indexes only occurred in

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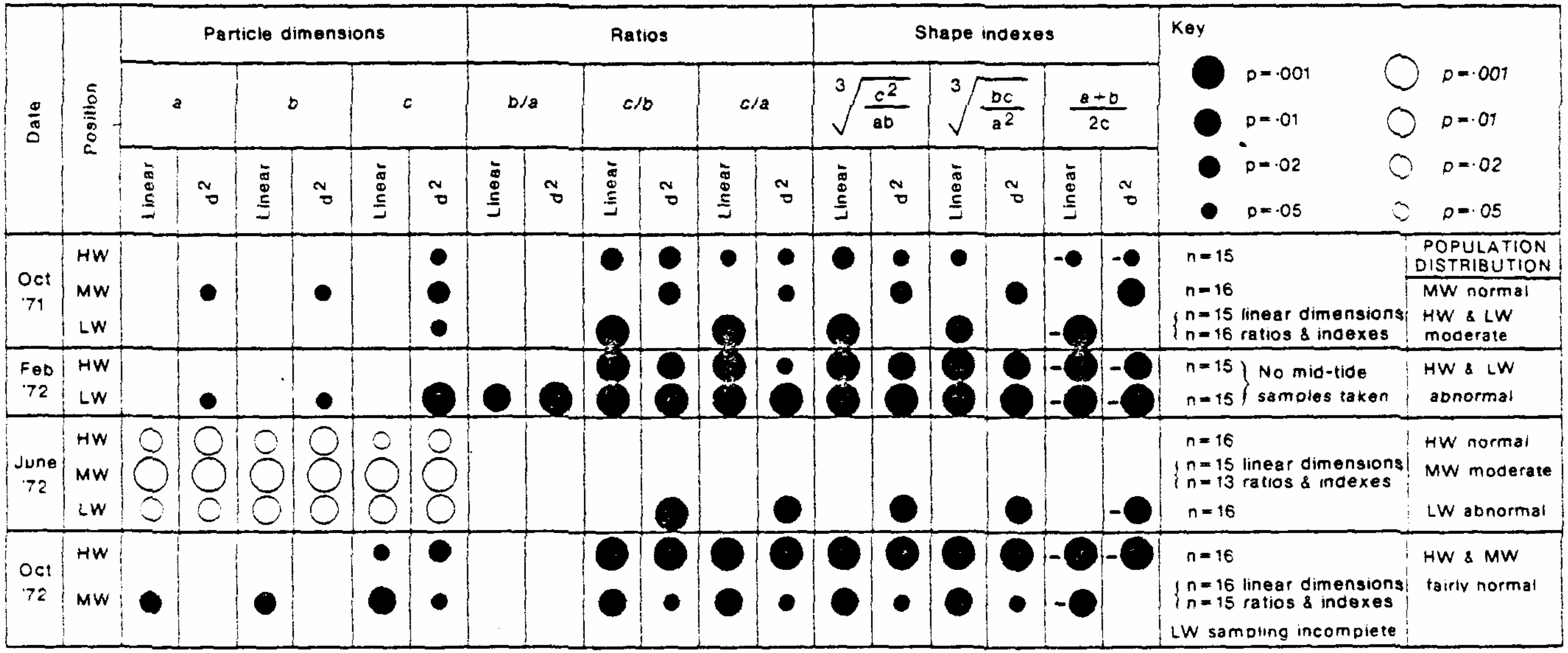
Table 1 Longshore grading of indigenous beach pebbles and cobbles.
Probability levels for correlation coefficients (where $p < 0.05$) for dimension/ratio/index *(y)* v. linear and squared distance alongshore in metres (x). All regression equations are from (east) end of beach except June 1972 linear parameters (open circles) which were calculated from centre outwards (see text).



Date	Position	Particle dimensions						Ratios						Shape indexes							
		a		b		c		b/a		c/b		c/a		$\sqrt[3]{\frac{c^2}{ab}}$		$\sqrt[3]{\frac{bc}{a^2}}$		$\frac{a+b}{2c}$			POPULATION DISTRIBUTION
		Linear	d 2	Linear	d 2	Linear	d 2	Linear	d 2	Linear	d 2	Linear	d 2	Linear	d 2	Linear	d 2	Linear	d 2		
Oct '71	HW						●			●	●	●	●	●	●	●		-●	-●	n=15	
	MW		●		●		●				●		●		●		●		●	n=16	MW normal
	LW						●			●		●		●		●		-●		n=15 linear dimensions n=16 ratios & indexes	HW & LW moderate
Feb '72	HW									●	●	●	●	●	●	●	●	-●	-●	n=15 } No mid-tide	HW & LW
	LW		●		●		●	●	●	●	●	●	●	●	●	●	●	-●	-●	n=15 } samples taken	abnormal
June '72	HW	○	○	○	○	○	○													n=16	HW normal
	MW	○	○	○	○	○	○													n=15 linear dimensions n=13 ratios & indexes	MW moderate
	LW	○	○	○	○	○	○				●		●		●		●		-●	n=16	LW abnormal
Oct '72	HW					●	●			●	●	●	●	●	●	●	●	-●	-●	n=16	HW & MW
	MW	●		●		●	●			●	●	●	●	●	●	●	●	-●		n=16 linear dimensions n=15 ratios & indexes	fairly normal
																				LW sampling incomplete	

Key

●	p=·001	○	p=·001
●	p=·01	○	p=·01
●	p=·02	○	p=·02
●	p=·05	○	p=·05

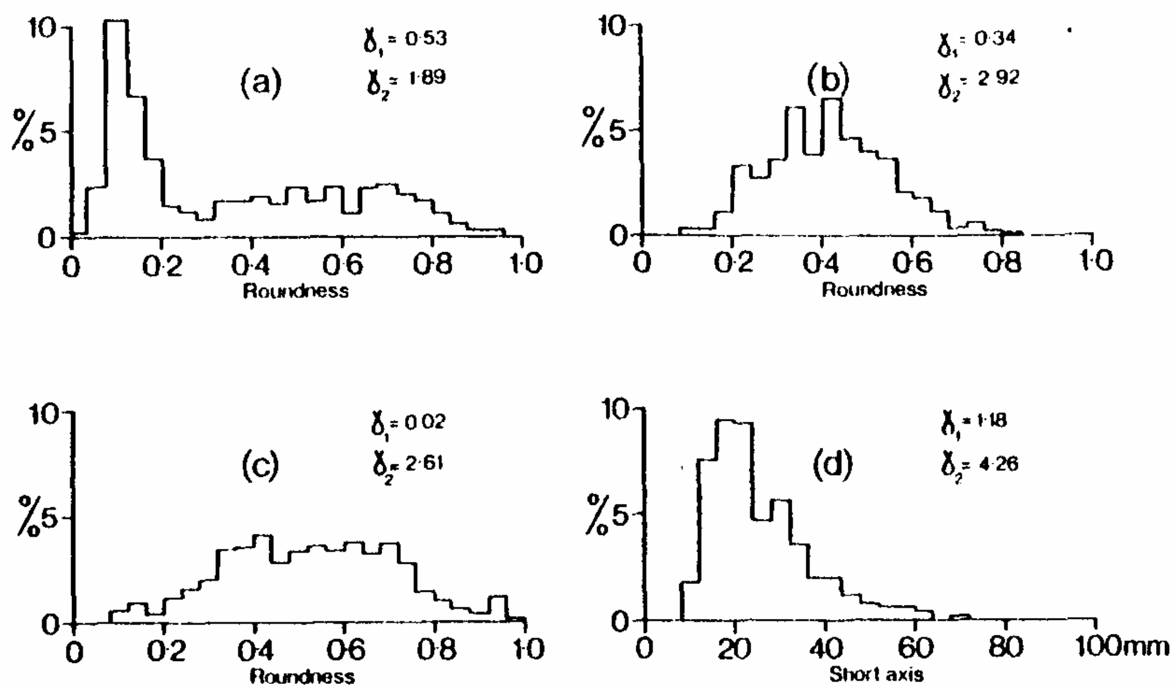


FIGURE 3. Beach sample histograms. A: (a) to (c) normally distribution linear parameters. (a) upper beach limit, short axis for Section 12, Oct. '71. (b) short axis for Section 4; LW, Oct. '72. (c) short axis for Section 15, HW, June '72. (d) negatively skewed roundness for same date and sample as (c). B: (e) to (g) peaked distributions for linear parameters, Feb. '72. (e) long axis for Section 12, LW. (f) short axis for Section 7, HW. (g) short axis for Section 4, LW. (h) roundness for same date and sample as (e). (i) roundness for same date and samples as (g). HW, MW, LW refer to high, mid and low water sampling zones, respectively. Values for skewness (γ_1), and kurtosis (γ_2) are given.

respect of those zones of the beach regularly subjected to hydraulic processes. Table I indicates the probability levels for the correlation coefficients with the minimum level of acceptance being taken at $p \leq 0.05$ (i.e. up to 5 per cent probability of a relationship occurring by chance). Although regression equations were calculated for sediment parameter v. linear, log and distance squared (d^2) relationships, the logarithmic ones are omitted because they failed to attain the same order of significance.

4. Discussion

Table II give the values of means, standard deviations, skewness and kurtosis for the cliff samples on Sections 5 to 12. The variability of one sample with another and the departure of the linear

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Table II Mean, standard deviation, skewness and kurtosis for pebble and cobble samples obtained from the cliffs. n=500 except Section 11 where n = 251. Means and standard deviations for long (a), intermediate (b), short (c) axes are in mm x 10. Roundness (r) is according to Kuenen (1956).

Section	$\bar{\bar{a}}$	S.D	skew	kurt	$\bar{\bar{b}}$	S.D	skew	kurt	$\bar{c}$	S.D	skew	kurt	$\bar{r}$	S.D	skew	kurt	
5	628	248	1.01	4.15	480	194	0.91	3.93	304	123	1.02	4.39	0.43	0.19	-0.13	2.21	
6	478	249	2.23	9.54	367	189	2.17	9.27	250	116	1.84	8.76	0.35	0.26	-0.53	1.89	r bimodal: see Fig. 2a
7	615	258	0.99	4.78	473	193	0.77	3.90	332	142	1.03	4.96	0.49	0.21	-0.12	2.42	
8	458	187	0.89	3.75	343	154	1.28	5.34	217	103	1.60	6.72	0.42	0.16	-0.34	2.92	r shown on Fig. 2b
9	552	255	1.43	5.33	400	201	1.56	6.48	267	128	1.27	5.20	0.59	0.18	-0.12	2.84	c ill-defined secondary peak
10	557	249	1.78	7.53	422	191	1.89	8.46	279	119	1.35	5.57	0.53	0.16	-0.13	2.91	
																	c ill-defined secondary peak; see Fig. 2d
11	491	217	1.11	3.80	372	161	1.21	4.23	256	113	1.18	4.26	0.53	0.19	0.02	2.61	r approximates to normal distribution; see Fig. 2c
12	530	232	1.47	6.58	392	173	1.50	6.65	264	120	1.31	5.30	0.38	0.26	0.25	1.77	r bimodal

dimensions of the sample populations from normal distributions is very striking. To some extent, particularly on Sections 7 to 12, these characteristics may reflect selective transport down the cliff slope, but, in general, they must indicate variability within the Pebble Bed deposits themselves.

In research at Chesil, Dorset (Carr, 1969), and more recently, on Slapton Beach in Devon (Gleason, Blackley and Carr, 1975) (Fig. 1), the linear parameters of the indigenous pebble populations were shown to be essentially normally distributed in respect of section, zone and sampling occasion. Kurtosis was close to 3.0, and, although there was a positive skew, this was not marked. For Budleigh a much greater variability is apparent in the indigenous beach material. Similar variability, however, has been observed over the short term in tracer studies, using introduced material, at the other two sites (Carr, 1971, 1975; Gleason, Blackley and Carr, 1975) where it probably reflects inadequate opportunity for sorting by beach processes since only a small range of wave heights, periods and directions would have been experienced. In the case of Budleigh a similar effect could be produced by the introduction of new, atypical, pebbles and cobbles from the cliffs and by interruption of transport by landslipping. It is precisely in the central area of Budleigh beach that normality of linear parameters is lowest.

There are certain other points of interest in considering the Budleigh data in a more general context.

The relationship between roundness and size on the beach appears largely at variance with that reported elsewhere. Thus Cailleux (1948) and Humbert (1968) working on present day beaches, Sneed and Folk (1958) on the Colorado River, and Laming (1966) on a palaeo-environment near Budleigh, all found it necessary to restrict comparisons to pebbles within the same size class because their experience showed that, within the ranges with which they were working, smallest pebbles were most angular. This positive relationship was shown for the cliff sample on Section 8 at Budleigh but, even there, the probability at the 0.001 level is brought about solely by the large sample size (n = 500). In general, for the present day beach, there was either no correlation between roundness and particle size (e.g. Section 3 MW, Fig. 4a) or, rarely, increased angularity with increasing size (Section 16 MW, at the 0.02 level; also shown, as Fig. 4b). The latter may reflect the inadequacy of contemporary beach processes at the site to round the

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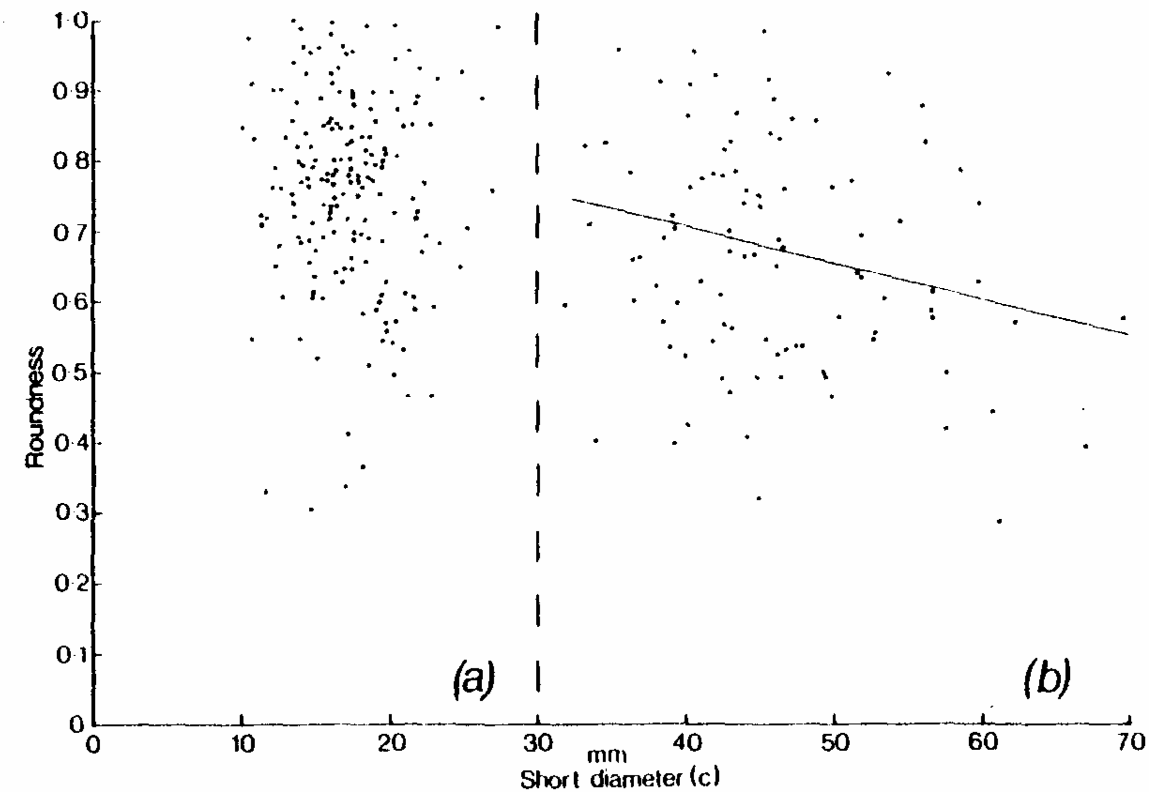

FIGURE 4. Plot of roundness v. size (short axis) for (a) Section 3, MW, Oct. '72 (n=200) and (b) Section 16, MW, Oct. '72 (n=99). (a) is not significant at any level; (b) has a negative slope and is significant at 0.02 probability level.

largest cobbles, either because of their discoidal shape or absolute size.

At Chesil there was an indication that the most spherical, but not the largest, metaquartzites, were to be found along the middle length of the beach, in spite of the progressively increasing wave energies towards the east (Carr, Gleason and King, 1970). No such relationship is apparent at Budleigh where pebbles become progressively more discoidal towards one end (in this case the west where wave energies are highest), as they also increase in size.

It has been widely suggested in the literature (e.g. Pengelly, 1870; Baden-Powell, 1930) that Pebble Bed clasts from Budleigh occur on Chesil Beach. However, the ratios of the 3 axes, one to another are widely different at each site. At Chesil the mean values of the metaquartzites had an 8:6:3 (100:75:38%) relationship while the flints/cherts had ratios of 8:6:4 (100:75:50%) and the latter therefore produced a characteristically blockier shape as compared with the discoidal quartzites. At Budleigh, however, while the relationship *a:b* remains remarkably constant, that with *c* shows

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considerable variability, and proportionality for sample means varies between 5:4:3 (100:80:60%) and 5:4:2 (100:80:40%). The 5:4:3 value corresponds with the flints/cherts at Chesil while the 5:4:2 is more representative of the metaquartzites at the latter site. It may be that the disc population is either more durable, having been less deeply weathered in the past, or that it is more mobile; the concentration of discs on Budleigh Section 16 suggests the latter as a possibility. Although relative mobility of discs versus spheres has been discussed in a broad context in the literature it is, in fact, likely to depend on the effectiveness of the various hydraulic processes and the nature of the underlying traction carpet at any specific site. Other alternatives for the greater preponderance of discs at Chesil are that the initial source of the apparently similar metaquartzites may be different, or that the increased flatness is a measure of abrasion. This latter view was held by Coode (1853) and Prestwich (1875) for Chesil, but has been denied in the general case (e.g. by Emery (1960), and Kuenen (1964)).

Along Chesil Beach, while pebble size-grading is well defined, shape does not show the appreciable variation (Carr, 1971; Carr and Blackley, 1974) reported by other workers elsewhere. At Slapton, Gleason, Blackley and Carr (1975) showed that linear dimensions, ratios, and shape indexes could each be of prime importance at different times. For neither Chesil nor Slapton did the type of variability observed at Budleigh occur. Table I shows that for all 4 Budleigh surveys the ratios using c, and the shape indexes, appeared to he graded alongshore from east to west. This included the June 1972 low water samples (where probability levels for d^2 regression equations were apparently at ≤ 0.01 or ≤ 0.001 levels) and all the zones sampled on the other occasions. Table I also indicates that longshore grading of the 3 axes occurred to some extent in the October 1971, February 1972 and October 1972 sampling although, because the population distribution for February was often excessively peaked, the statistical procedures used are less strictly applicable for that date. In all these instances the smallest material was at the eastern end of the beach. However, in June 1972, in contrast to the ratios and shape indexes, the grading of the 3 linear parameters was from the centre of the beach outwards with the coarsest material at the extremities. This applies to high, mid and low water samples. For both d^2 and linear regressions (Fig. 5 and Table I) probability levels for high and mid water zones varied

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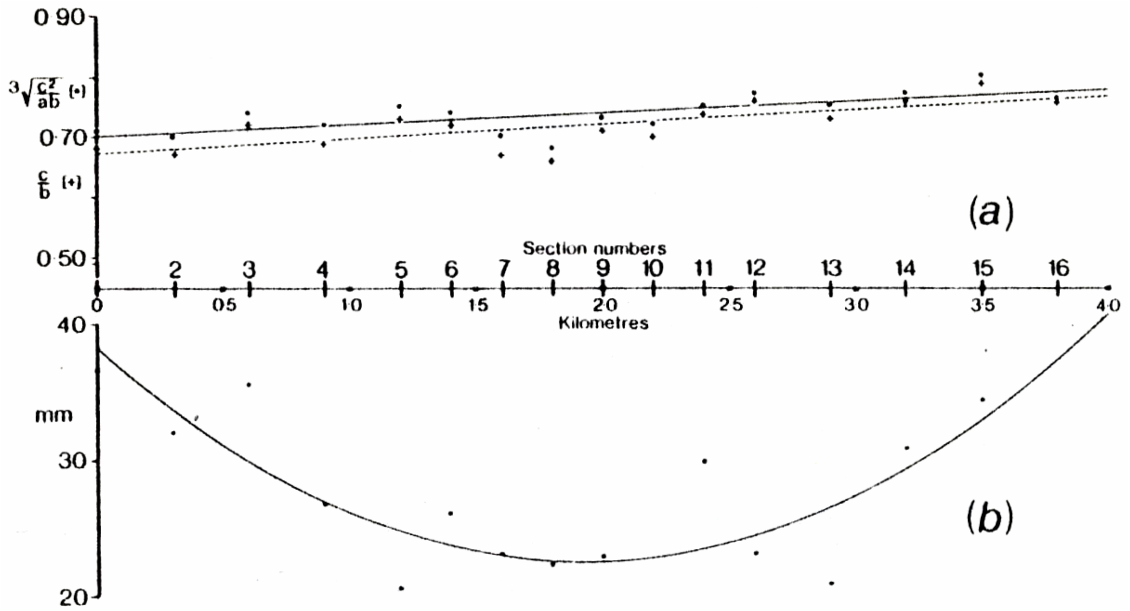

FIGURE 5. June '72, (a) linear regression at low water between shape ($\sqrt[3]{\frac{c^2}{ab}}$) and ratio ($\frac{c}{b}$) v. distance alongshore; (b) second order curve calculated from mid water data: size (long axis) v. distance alongshore. See text and Table 1.

between ≤ 0.05 and ≤ 0.001, with low water apparently between ≤ 0.02 and ≤ 0.01. At both high and mid water zones longshore shape grading appeared to have broken down, although there was some suggestion of sorting by size away from the centre of the beach and by shape from one end to the other at low water mark. Unfortunately, this interesting feature was complicated by the abnormal population distribution at low water. Nevertheless, the data reflect an influx of smaller pebbles from the cliff deposits at the rear of the centre of the beach between February and June 1972, while the correlation of ratios and shapes with distance squared at low water - in so far as it is real - may be either a legacy of earlier beach processes or a subsequent readjustment.

It is clear that while the nourishment of tile beach by material from the Pebble Beds is a conspicuous element in the overall sediment distribution pattern the abnormality of the various population distributions prevents a fully valid assessment of the situation. 'These abnormalities, particularly in respect of the Pebble Bed exposures in the cliffs, warrant further study.

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Institute of Oceanographic Sciences
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