PROCEEDINGS
OF THE
USSHER SOCIETY

VOLUME ONE

PART FIVE

Edited by
M. R. HOUSE

REDRUTH, SEPTEMBER 1966
PRICE: 7/6

THE USSHER SOCIETY

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CONFERENCE OF THE USSHER SOCIETY HELD AT BIDEFORD, 1966

Accommodation for the fourth Annual Conference was arranged at Edgehill College, Kilstrasna House, Bideford and the meetings were held in the school buildings. On Wednesday morning, 5th January, Dr. H. G. Reading led an excursion to examine the Upper Culm sequence at Westward Ho ! The meeting was followed on Friday 7th, by an excursion led by Dr. R. Goldring to see the stratigraphy and sedimentation of the Baggy Beds, Pilton Beds, and Lower Carboniferous at Croyde Bay and Baggy Point, and, during the afternoon, Dr. Goldring and Dr. J. E. Prentice led visits to Fremington Pill and other localities to see features of the stratigraphy of the uppermost Devonian and Lower Culm.

PROGRAMME

Contributions which are printed in the text are marked with an asterisk.

4th January, 1966

101. *Dr. J. R. Hawkes and Mr. K. Chaperlin : “A summary of the Geological Survey's findings to date in relation to the Cornish bodies and granites in general.”
102. *Dr. M. Stone : “Some aspects of variation in granitic rocks with particular reference to the granites of S.W. England.”
103. *Dr. B. Booth : “Potassium metasomatism in the thermal-chemical gradient.”
104. Dr. B. Booth: “Granites by differential anatexis.”
105. *Mr. A. N. Lane: “The structure and stratigraphy of the Lower Devonian rocks of the Looe area, S.E. Cornwall.'
106. *Dr. J. L. M. Lambert : “The structure of south west Cornwall : a study in tectonic facies.”

107. *Dr. M. C. McKeown : “Breccias of the Gorran Haven area.”

108. *Mr. G. A. Gauss: “Some aspects of the slaty cleavage in the Padstow area of N. Cornwall.”

109. *Prof. S. Simpson : “Kink-bands of Bigbury Bay.”

110. *Dr. E. M. L. Hendriks : “Correlation of South and North Cornwall.”

5th January

111. *Dr. S. C. Matthews : “Lower Carboniferous stratigraphy in the St. Mellion area.”

112. *Mr. A. F. King: “Structure and stratigraphy of the Upper Carboniferous Bude Sandstones, North Cornwall.”

113. *Dr. S. C. Matthews : “Lower Carboniferous zone-fossils.”

114. *Dr. E. B. Selwood : “Derived fossils from the Upper Culm Measures south of Launceston, Cornwall.”

115. *Mr. N. J. Money : “Carboniferous rocks o f North Devon : the Appledore Formation.”

116. *Dr. F. J. W. Holwill : “Conglomerates, tuffs and concretionary beds in the Upper Devonian of Waterside Cove, near Goodrington Sands, Torbay.”

117. *Dr. W. R. Dearman : “Superposed structures in the Trebursye Beds of Launceston, Cornwall.”

118. *Dr. S. C. Matthews : “Remarks on the geology of the St. Mellion area.”

119. *Dr. J. E. Prentice : “Facies changes in the Chert Formation (Lower Carboniferous) of North Devon.”

120. *Mr. R. H. Balderson and Dr. A. H. Stride: “Tidal current fashioning of a basal bed.”

121. *Dr. M. E. Cosgrove and Dr. D. L. Slater : “The stratigraphical distribution of kaolinite in the post-Armorican formations of South-West England.”

6th January

122. *Dr. P. Floyd : “Greenstone sills and metamorphic zoning in the Land's End aureole at Newlyn, Cornwall.”

123. *Mr. G. M. Power: “Secondary tourmaline from the granitic rocks of S.W. England.”

124. Dr. M. C. McKeown : “Techniques and application of underwater geology using SCUBA techniques.”

125. Mr. F. J. Smith: “The geomorphology of the Bideford District.”

126. *Dr. J. M. Thomas : “Sedimentation on Instow Beach.”

127. *SUBSEQUENT CONTRIBUTION : Dr. M. R. House : D.Phil. and B.Sc. theses submitted at Oxford since 1950 on the geology of Devon and Cornwall.

101. The Dartmoor Granite : A summary of the Geological Survey's findings to date in relation to the Cornish bodies and granites in general : by J. R. Hawkes and K. Chaperlin.*

A study of the variation in abundance of feldspar megacrysts in the Dartmoor granite has shown that there is a transitional relationship between the two granite types of Brammall and Harwood (1923). The spatial distribution of the large feldspars indicates that the 'giant' granite is a marginal facies of the 'blue' granite and not a separate intrusive phase. It is concluded that the granite crystallized as a medium-grained, plagioclase-quartz-biotite-rock which was modified by contained, initially potassium-rich, aqueous fluids, whose chief effect was to cause the replacement of plagioclase (Ab_{70-85}) by orthoclase.

In the north, Culm rocks adjacent to the granite consist chiefly of shale and sandstone. There is abundant evidence for the assimilation of shale in the form of biotite-rich xenoliths. It is thought that assimilation occurred on a much larger scale than has previously been realised as there are large areas of granite, comparatively rich in biotite, which show continuous gradation between the xenoliths and normal 'giant' granite. Discrete xenoliths are usually small (up to 10 m.) but near Throwleigh [SX/655,907] there are indications of a shale inclusion 3 x 2 km. in extent.

There is no direct evidence for the assimilation of sandstone but it is suggested that some aplitic bodies are of sedimentary origin. They do not consistently show chilled margins and some contain zoned plagioclase of the same composition as the main granite.

Some aplite dykes, of distinctive mineralogy, consistently show chilled margins. They are composed of albite and quartz with abundant accessory topaz and tourmaline. The thicker dykes (e.g. the Meldon aplite) also contain Li-minerals. These aplites are thought to have crystallized from residual granitic fluids and are probably equivalent to the Na-Li pegmatites of the deeper zones of some orogenic belts.

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The Cornish granites contain evidence for an origin comparable with that of Dartmoor. Stone and Austin (1961) have suggested that the Carnmenellis and probably the other S.W. England granites may have been formed by the K-metasomatism of an originally aplitic rock.

The K-feldspar in the calc-alkaline Galloway granites and in the Shap adamellite also developed by the replacement of plagioclase. Thus it seems that many high-level granites crystallized as plagioclase-quartz-biotite-rocks and, provided contained K-rich aqueous fluids did not escape, an adamellite or alkali-granite resulted. Of interest is the fact that the intensity of metalliferous mineralization associated with the granites of Galloway, Shap and Dartmoor increases with the degree of K-metasomatism.

If the Dartmoor melt was saturated with water it can be inferred from the work of Luth, Jahns and Tuttle (1964) that potassium and probably metalliferous elements were selectively taken up by the vapour and thus removed from the main process of crystallization. It has long been accepted that, in deeper orogenic regions, K-rich fluids are responsible for migmatization and pegmatization of country rocks and conversion of granodiorites to alkali-granites. As the secondary K-feldspar is the lower temperature form, microcline (Marmo, 1962), it is possible that K-metasomatism at depth is due to later migrant fluids rather than contained fluids as suggested for the high-level granites such as Dartmoor.

References :

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LUTH, W. C., R. H. JAHNS and O. F. TUTTLE, 1964. The granite system at pressures of 4 to 10 Kilobars. **Jour, geophys. Res.,** Vol. 69, p.759-773.

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102. Some aspects of variation in granitic rocks with particular reference to the granites of S.W. England : by Maurice Stone.

Forced "trends" and correlations which result from closed summation of data create major difficulties in the interpretation of simple bivariate variation diagrams of Harker type (Chayes 1962, 1964). Despite this, some writers continue to use percentage data without recourse to consideration of what the data really mean. The condition of the closed array is simply

$$\sum^{M} (\overline{X_j} - X_j) = 0$$

where X_j is the amount of variable j, and $\overline{X_j}$ is the average value of variable j. From this condition, it can be readily shown that

$$s_1 + \sum_{j=2}^{M} r_{1j}\, s_j = 0$$

where s_l and s_j are the standard deviations of variables 1 and j respectively, and r_{lj} is the product moment correlation coefficient between variables 1 and j (Chayes 1962). From this equation, it is clear that **at least** one correlation coefficient will be negative. For the whole array, **at least** (M - 1) correlations will be negative.

Interpretation of data from closed arrays. When s_l or any of the other standard deviations is large (e.g., SiO_2), there are likely to be several forced negative correlations. It is impossible to satisfactorily interpret forced trends in terms of a particular process. Dartmoor data illustrate this (Brammall and Harwood 1932) : both the magmatic differentiation/contamination trend of the Types 2, 3 and 4 granites and the "granitization" trend of the Type 1 granite are almost identical when $A1_2O_3$, CaO or femic constituents are plotted against $Si0_2$. There are several methods of overcoming (or partially overcoming) the effects of the constant sum. These include correlations between elements whose variance contributes little towards the total variance of the array, recalculations based upon constant "cells" (Barth 1948, Poldervaart 1953, Niggli 1954, Vistelius and Sarmanov 1961), the use of ratios (e.g., Niggli mg as in Leake 1964) provided that conclusions are based upon the ratio only and not upon its constituent parts (Miller and Kahn 1962, p.185), the use of one variable which is not part of a constant summation (e.g., total K percentage against $2V_x$ of potash feldspar or plots against geographic co-ordinates) and, finally, a comparison with variation patterns produced by known or reasonably inferred processes.

Trends and processes. Analyses of pitchstones (total rock and glassy phases) given by Carmichael (1960) are used to indicate the trends of normal magmatic differentiation of acid rocks. Two diagrams have been selected for comparison with data from Dartmoor and the Tregonning-Godolphin granite. These are the Fm (total femics) — K (as atomic percentages) and Na_20 – K_2O (as mol. equivalents).

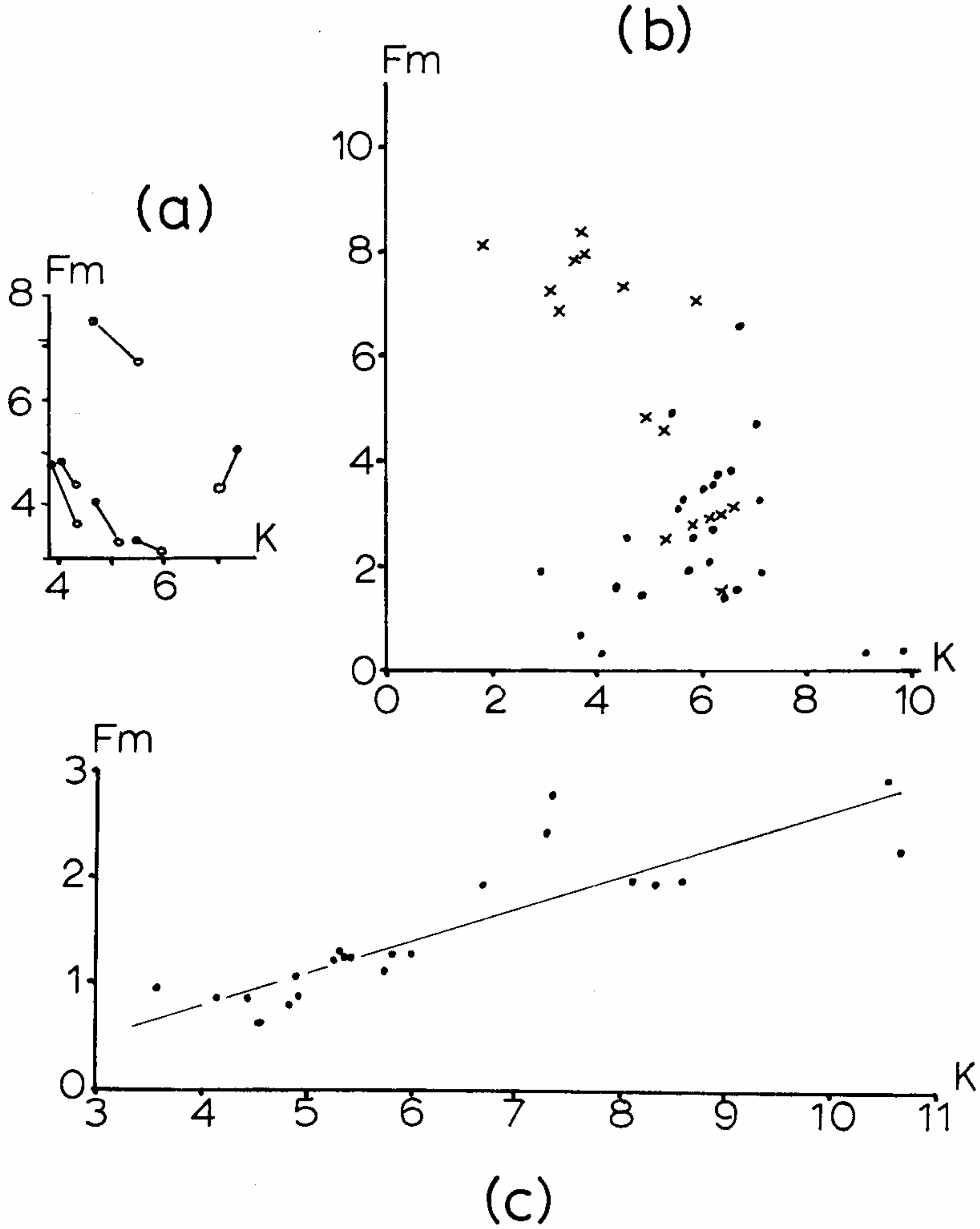

FIGURE 1. Fm-K variation diagrams (atomic percentages).
Fm = Fe"+ Fe"' + Mn + Mg.
(a) Pitchstones. Dots = rock circles = glass. (b) Type 1 granites, Dartmoor (crosses), and Types 2, 3 and 4 granites, Dartmoor (dots). (c) Tregonning-Godolohin granite. Regression equation, Y=0.31 X-0.44, r = +0.86.

Pitchstones show a decrease in Fm as K increases (Fig. la). A similar pattern is suggested by the data for Type I granites (granitized basic inclusions, according to Brammall and Harwood) of Dartmoor (Fig. 1b, crosses). As both magmatic differentiation and granitization lead to an increase in alkali feldspars and a decrease in femic constituents, these patterns are to be expected. However, Dartmoor Types 2, 3 and 4 granites show a poor, though distinct positive correlation between Fm and K (Fig. lb, dots), and the Tregonning-Godolphin analyses show a marked positive correlation between these constituents (Fig. lc). A tendency towards positive correlation would be expected if the granites were contaminated by pelite, resulting in an increase of biotite (cf. Stone and Austin 1961).

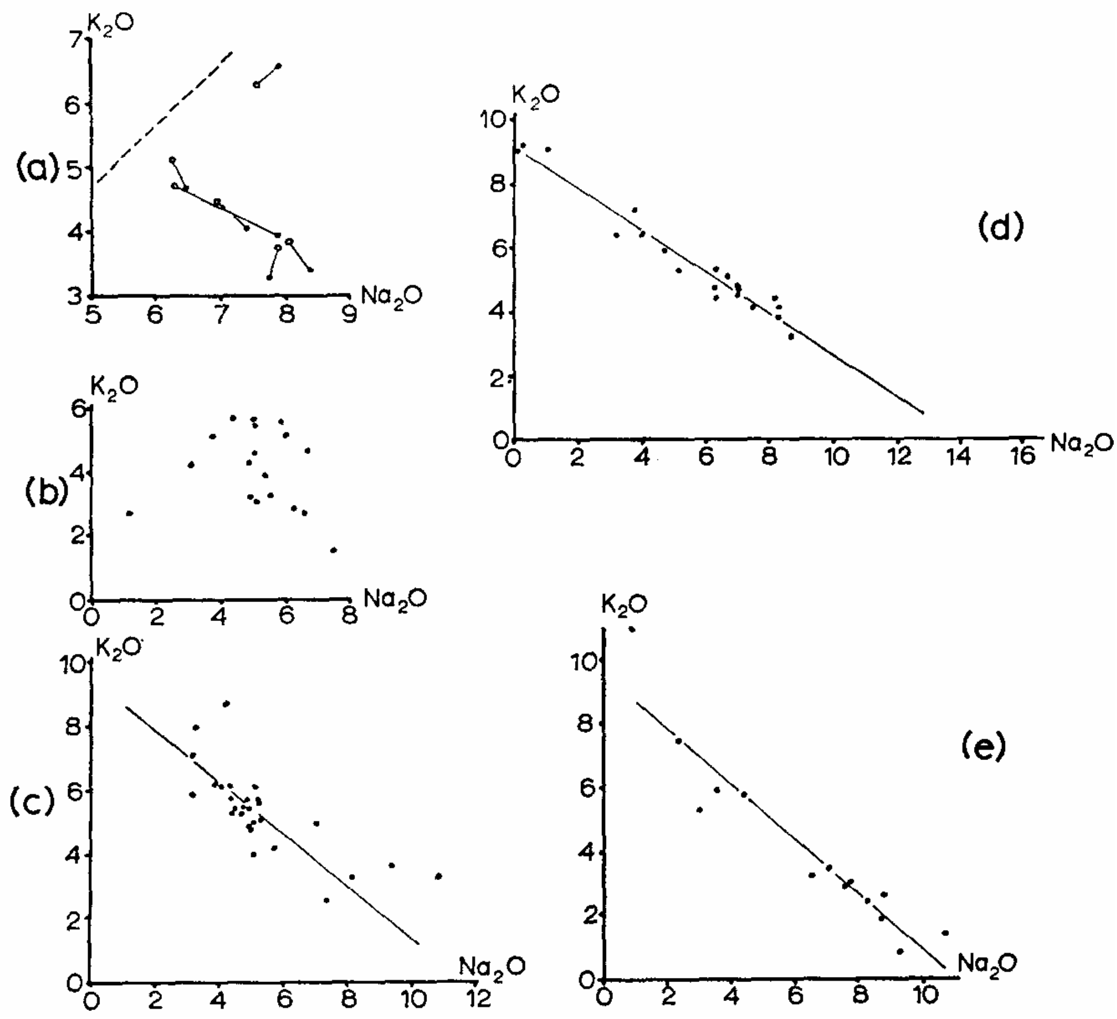

FIGURE 2. Na_2O-K_2O variation diagrams (molecular quotients x 100). (a) Pitchstones. Dots---rock; circles=glass. Dashed line = alkali ratio of the ternary minimum at 500 bars P_{H_2O}. (b) Type I granites, Dartmoor. (c) Types 2, 3 and 4 granites, Dartmoor. Regression equation, Y = -0.82 X +11.6, r = -0.92. (d) Tregon ning-Godolphin granites. Regression equation, Y = -0.66 X +9.20, r= -0.98. (e) New Zealand keratophyres. Regression equation, Y= -0.87+ 11.07, r = -0.94.

The pitchstone data in the Na_2O – K_2O diagram (Fig. 2a) show a restricted trend of increasing potash and decreasing soda (in four out of six pairs of analyses) towards the alkali ratio of the 500 bars P_{H_2O} ternary minimum. (In the ternary Q-Ab-Or diagram, all pairs trend towards the minimum). The pitchstone trend differs from the trends of the granites in being more restricted, although the trend path is similar. Only the Type 1 granites of Dartmoor show scatter (Fig. 2b). The extended trend of the Types 2, 3 and 4 granites of Dartmoor (Fig. 2c) and the markedly extended trend shown by the Tregonning-Godolphin granites (Fig. 2d) are similar to the metasomatic trend of the New Zealand keratophyres described by Battey (1955) and shown in Fig. 2e. It is clear that only alkali ion exchange, like that described by Orville (1963), could produce this pattern of variation. Additive alkali metasomatism (feldspathization) appears to produce scatter in the Na_2O - K_2O diagram : this is seen in the Older Granodiorite of Donegal (Mercy 1960) and in the Dartmoor Type I granites.

It is concluded that the patterns of variation considered above are inconsistent with magmatic differentiation as the sole agent for the production of the variation in the granitic rocks of south-west England. The tendency towards positive Fm-K correlation is probably a function of contamination and the strongly negative alkali correlation is indicative of ion exchange.

It is important to realise that a given variation pattern may be the result of a given process, although it may also result from the nature of the raw data, irrespective of the process.

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103. Potassium metasomatism in a thermo-chemical gradient (Abstract) : by B. Booth.

The Laud's End granite is unique in the number of aplite and aplogranite veins exposed around its margin. The majority of these occur along the northern coast where they cut the coarse porphyritic granite envelope and the pelitic and meta-igneous hornfels.

This account concerns an aplite vein which cuts meta-igneous hornfels in Gwavas Quarry, Newlyn. The vein post-dates north-south tourmaline veins and varies in width up to 3 feet ; it strikes approximately at 150° and dips to the north at 40°. In hand specimens it is a light grey, compact saccharoidal rock with a very fine matrix. It is demonstrably intrusive into the hornblendeplagioclase hornfels and contains many accidental xenoliths of this rock. The xenoliths and marginal hornfels are brown in colour in contrast to the parent rock which is greenish black over twelve inches from the vein ; both are fine grained compact rocks which are extensively quarried for road stone. In thin section they are seen to be composed of interlocking plagioclase laths interspersed with hornblende plates, the composition of the plagioclase is about andesine and the hornblende is sometimes chloritised to penninite or replaced by calcite and epidote. Adjacent to the contact the hornblende is replaced by biotite to form a plagioclase-biotite hornfels, while the actual contact is occupied by a 1-2 mm. wide zone of biotite crystals, which on the hanging wall are sometimes partly replaced by tourmaline. Adjacent to the margin within the aplite, the biotite selvedge is corroded where it projects into the fine grained quartz, plagioclase, orthoclase groundmass.

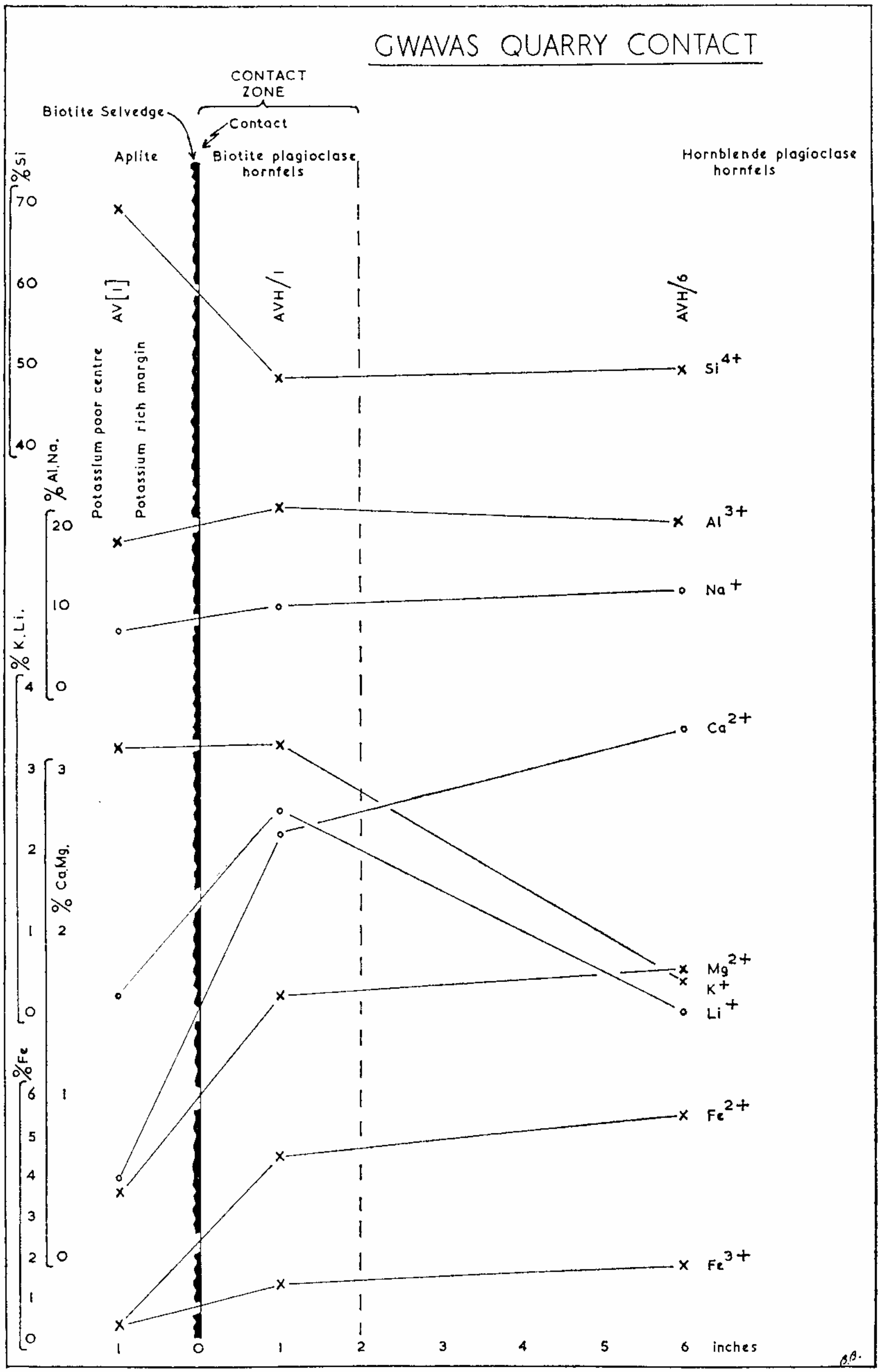

FIGURE 1. Cation per cent of various elements plotted against distance either side of the aplite/hornfels contact. The extent of the biotization is shown by the vertical dashed line between the biotite - plagioclase hornfels and the hornblende-plagioclase hornfels.

Figure 1 shows : (a) The high value of potassium and lithium in the contact zone of the hornfels, and (b) the decrease in calcium, magnesium and iron in the hornfels on approaching the contact zone.

Specimens of the aplite stained for potassium feldspar show the centre of the vein to be potassium deficient relative to the margin ; this sequence is supported by data from other aplites at Land's End which frequently show feldspathization of the margins. Other similarly feldspathized aplite veins occur containing acicular tourmaline in the marginal feldspar with the "c" axis normal to the aplite-hornfels contact.

The 1963 Orville experimentally produced alkali ion exchange in a thermal gradient and suggested that alkali metasomatism would naturally occur under the physico-chemical conditions within the earth's crust, while Green (1963) confirmed this view by explaining that alkali metasomatism in the Kragero pegmatites occurred in a similar manner.

It is believed that potassium metasomatism is responsible for the biotization of these hornblende plagioclase hornfels, and that both potassium and lithium ions migrated into the meta-igneous or pelitic hornfels displacing both calcium, iron and magnesium. The potassium-rich margin may be due to the diffusion of this element towards the cooler potassium-deficient meta-igneous hornfels, the low value of sodium in the hornfels contact zone is attributed to back-diffusion to replace the incoming potassium, which appears to have built up outside the hornfels to form the biotite selvedge ; this may be due to the relative impermeability of the hornfels to this element. Where the biotite selvedges are absent, feldspar selvedges are sometimes present and these are similarly interpreted as a build up of potassium ions against the margins.

In view of these data it is suggested that biotization and feldspathization of aplite vein margins was due to potassium ions migrating along a thermo-chemical gradient in the natural state in a manner similar to that artificially produced in the laboratory.

References :

GREEN, J. C., 1963. Alkali metasomatism in a thermal gradient. Two possible examples. **Jour. Geol.,** Vol. 71, No. 5, p.653-657.

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105. The structure and stratigraphy of the Lower Devonian rocks of the Looe Area, S.E. Cornwall (Abstract) : by A. N. Lane.

Ussher's division in 1907 of the Lower Devonian into three groups, the Staddon Grit, the Meadfoot Group and the Dartmouth Slates, has been subsequently split into smaller units for convenience in structural interpretation. The units are based purely on lithological characters. The outcrop pattern is shown on the map. All junctions are gradational. In ascending order these units are : (1) The Dartmouth Slate Unit - characterised by red and grey colour banding, and by bands of calcite and dark slaty nodules. (2) The Transition Beds - showing irregular colour mottling, an increase of grey slate, and only slaty nodules. (3) The Lower Meadfoot Unit - the sediments are grey throughout and nodules are rare. There is an upper development of silt and slate laminae, showing good sedimentary structures. (4) The Upper Meadfoot Unit - an increase of carbonate results in fossilferous calcareous sandstone, silts, slates and impersistent limestone bands. This latter unit grades into a well defined band of sandy decalcified red brown rock traceable from Millendreath just inland to W. Looe.

Structure. The Portnadler Bay Fault and the suggested major anticlinal axis, (Fig. 1) divide the coast into three structural zones : (1) W. of the Portnadler Fault. Bedding and cleavage dip N. The beds are inverted and young S. Minor folds face S. and plunge W. (2) Portnadler Fault to Murrayton. Bedding and cleavage dip S.E. The beds are again inverted but young N.N.W. Folds face N.N.W. and plunge gently E.N.E. (3) E. of Murrayton. Beds dip E. and cleavage S.E. The beds are the right way up and young to the E. Folds face N.N.W. and plunge gently E.N.E.

It is suggested that the Central and Eastern zones (Fig. 1) represent the lower and upper limbs respectively of a major anticline plunging E.N.E. and facing N.W. Looe Island is structurally similar to the zone east of Murrayton. The coast immediately west of the Portnadler Fault might be occupied by the lower limb of a south facing anticline. East of the Portnadler Fault folding and cleavage maintain the same attitude for three miles along the Looe River sections. Around Liskeard, however, cleavage is flat lying and folding is recumbent. Due to lack of exposure, it cannot be determined if the change in attitude is abrupt or gradual.

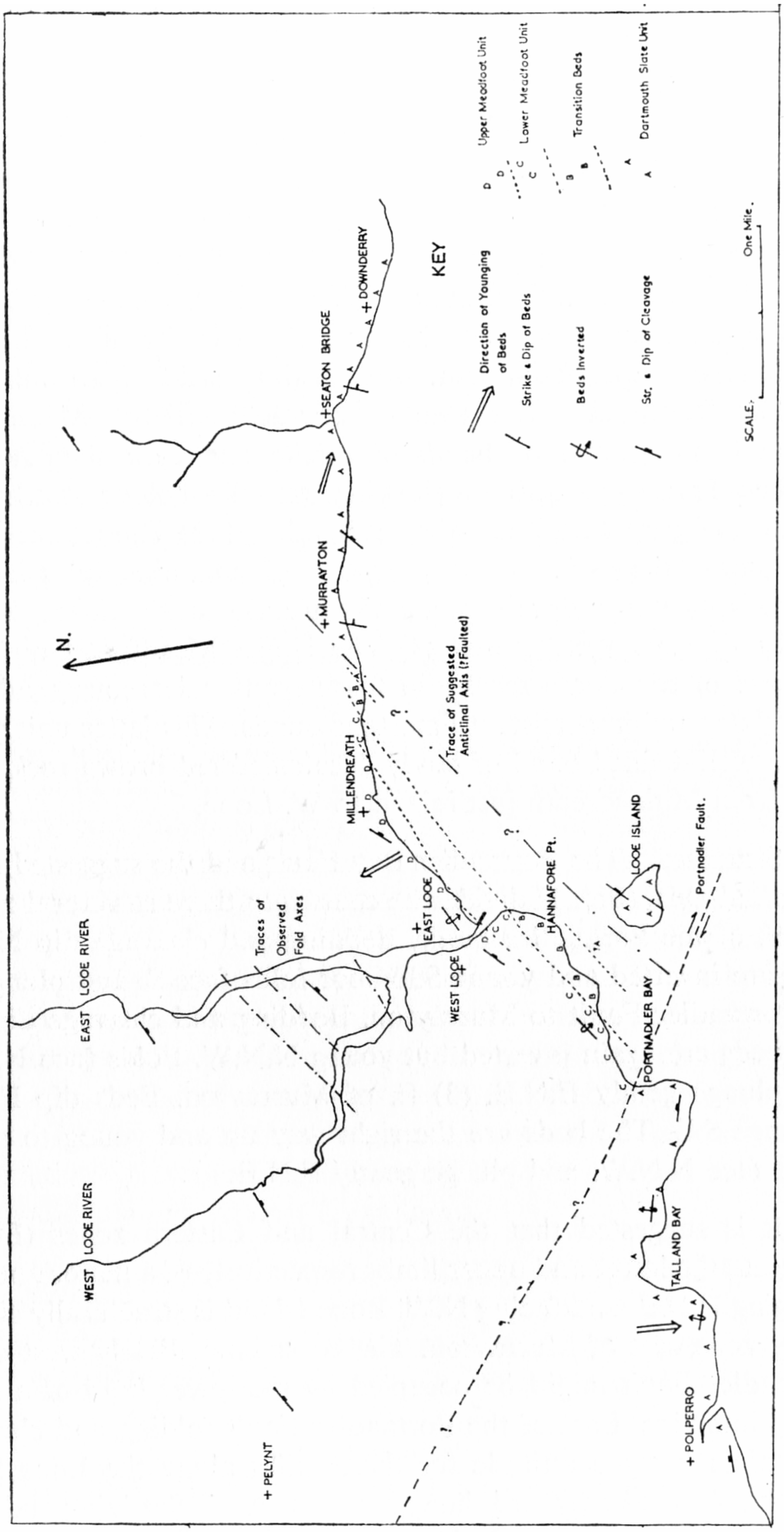

FIGURE 1. Geological map of the Looe area showing the stratigraphical units and the main structural features.

Minor folding is asymmetric, moderately inclined (Fleuty, 1964) and varies considerably in profile. The majority of folds are close (Fleuty, 1964) and on a large scale folding is non planar. There is a variation from near perfect similar styles to concentric profiles but thickening of hinge areas is common. Cleavage often intersects a fold limb at a small angle, resulting in attenuation or even boudinage of the limb. Generally the steeply dipping limb is thinned. Gently dipping limbs are rarely affected.

Cleavage has been found to depend largely on lithology, but coexisting cleavage types are probably due to successive deformational episodes. Cleaved basic dykes most frequently trend N.-S. In common with other areas of the S.W. the relationship between some dykes and folds indicates intrusion between deformational episodes. However, intrusion prior to consolidation of sediments can also be demonstrated in this area. Late stage structures fall into two trends : (1) E.-W., plunging gently W. and dipping steeply N. or S. (2) N.N.W.-S.S.E., plunging S.S.E. and dipping E. or W.

Structures include angular minor folding, monoclinal folding kink bands and strain-slip cleavage, and they are only locally developed. The N.N.W.-S.S.E. trend refolds the E.-W. structures. The Portnadler Bay Fault cuts all other structures, and it may be related to the coastal development of conjugate wrench faults (Dextral maximum at 340°, Sinistral at 50°). The difference in attitude of structures across the fault may be due just to displacement along the fault, (bringing together different structural zones). It may involve rotation of a block of country on one side of the fold relative to the other. A combination of both mechanisms is possible.

Summary of Tectonic events: (1) Dyke Intrusion, (2) Folding (and cleavage?), (3) Dyke Intrusion, (4) Cleavage development (or developments), (5) E.-W. late stage structures, (6) N.N.W.-S.S.E. late stage structures, (7) Movement associated with the Portnadler Bay Fault.

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106. The structure of south west Cornwall : a study of tectonic facies • by J. L. M. Lambert.

In a region such as south west Cornwall, in which the rocks are almost entirely lacking in fossils, the stratigraphical approach to structural analysis is of little value. Several deformation phases have now been recognised and the present outcrop pattern may reflect only the most recent important phase. Bedding surfaces, which largely control minor folding, may have been oblique to the principal lithofacies boundary between the Gramscatho and Mylor Beds. Furthermore, this boundary may well have been curved and not planar.

In south west Cornwall the concept of tectonic facies (Harland 1956) is a valuable one. A particular tectonic facies will have a distinctive structural geometry developed in lithologically similar rocks.

Three principal tectonic facies can be recognised. Only the Helford facies is analysed here.

1. Meneage facies. Slump breccias and conglomerates are penetrated by the regional cleavage S_1, however, the regular development of folds has been inhibited by the lack of stratification. Rare F_1 folds face in a direction opposite to that of overturning. This facies is restricted to the areas of the breccias between Meneage and Dodman.

2. Porthleven facies (Stone 1965). Only strata which show intense minor recumbent folding (F_2) related to a sub horizontal slip cleavage S_2 are included in this facies. These structures are most obvious in the typically striped slates of the Mylor Beds at Porthleven. All of the Mylor Beds formation belongs to this facies.

3. The Helford facies consists of a sequence of greywackes and slates belonging to the Gramscatho Beds. Asymmetric minor folds of bedding F_1, related to an axial plane cleavage S_1 and facing in the direction of overturning belong to the first and most important observerable movement phase. The trend of the folds in the region as a whole shows considerable divergence. In sub-areas where the attitude of cleavage is uniform, the axial planes of individual folds are parallel to each other and two groups, main folds and cross folds, trending approximately at right angles to each other, can be distinguished. The main and cross folds occur in alternate zones which trend parallel to the strike of the cleavage. In the Helford River area main folds trend W.S.W., cross folds trend N.W. Elsewhere fold trends are related to differing local attitudes of cleavage.

At Godrevy, in strata lithologically comparable to the Gram scatho Beds, the characters of the Porthleven facies are superimposed on those of the Helford facies, i.e. S_1 and F_1 are deformed by S_2 and F_2.

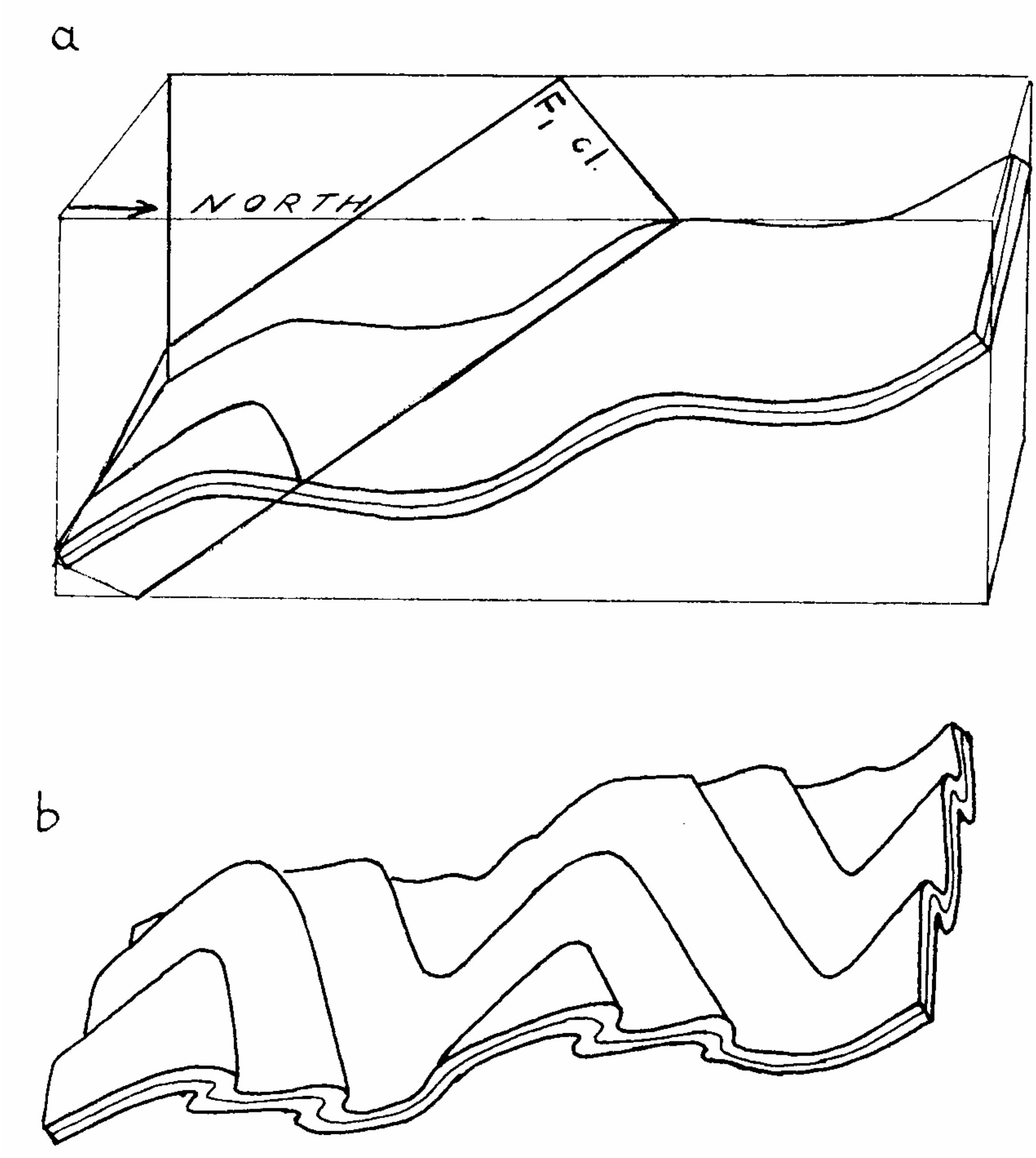

FIGURE 1. The relations between F_1 and postulated F_0 folds. (a) F_0 folds trending W.-E. (b) Superimposed F_1 folds.

An analysis of the Helford facies indicates that flattening is the most probable mechanism of deformation producing F_1 folds. To account for the two groups of folds it is necessary to infer an earlier deformation phase affecting original bedding and producing folds F_0 Main folds and cross folds were superimposed on the opposite limbs of F_0 folds (Fig. 1) The asymmetry of F_1 folds would thus be solely due to extension in a direction not at right angles to bedding. The early F_0 folds would necessarily be of a larger scale than the F_1 folds which would only develop where bedding was planar. A probable orientation of F_0 axes is horizontal, trending W.-E.

Both deformation phases, F_0 and F_1 can be attributed to the Variscan orogeny. The phase producing F_1 folds appears to be restricted to south west Cornwall. The development of superimposed folds with an implied re-orientation of stress suggests a phase in the orogeny when movement became more restricted. The structure of south west Cornwall may therefore represent a deeper level in the Variscan orogenic belt than that exposed elsewhere in south west England.

It is significant that the Porthleven facies is confined to the areas round the Hercynian granites. It may well be that S_2, which according to Stone is superimposed on upright isoclinal folds (? F_0) represents near vertical compression produced by forcible intrusion of the granites.

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107. Breccias of the Goran Haven area : by M. C. McKeown.

The Goran Haven Breccias occur as a faulted block separated by normal faults from Gramscatho Beds to the north and from the Gramscatho-like sediments of Dodman Point to the south. Included in the Goran Haven Breccia zone are a wide range of sedimentary rock-types from conglomerates to elastic limestones, and almost all the rock sequence is well cleaved and faulted.

The coastal exposures show the sequence to consist of 53%> slates and siltstones, 26% sedimentary breccias and conglomerates, 12% arenaceous rocks and 9%, igneous rocks. The large proportion of breccias is interesting, particularly as these rocks show evidence that they are of sedimentary origin. This evidence is firstly, the breccias form bedded units parallel to bedding of the enclosing rocks ; secondly, many of the breccias are folded and crossed by a strong slaty cleavage, which is parallel to the axial planes of all early minor folding in this area ; and thirdly, that small-scale sedimentary structures, such as slump bedding, have not been destroyed during tectonic movements, even when they lie against the sedimentary breccias.

The shales and siltstones are commonly finely-bedded ; they show evidence of slumping and other sedimentary structures, especially where they are interbedded with turbidite sandstones. The arenaceous rocks include massive quartzite horizons which are interbedded with sandstones and shales. Quartzite boulders included in some of the sediments were presumably derived from previously formed quartzite, and because of their resistance to orogenic movements they now appear as tectonic inclusions. Amongst the igneous rocks of the Goran Haven area there is a considerable thickness of spilitic pillow lava interbedded with breccias and slates.

It does appear that the environment in which the Goran Haven breccias were deposited was one of unstable sedimentation. The differing lithologies, with their various sedimentary structures, helps to support this suggestion. The subsequent deformation of these rocks produced small-scale tectonic breccias along fault planes.

The first deformation of these rocks was strong, with a penetrative slaty cleavage dipping steeply to the south-east. Minor folds are rarely seen, but they do affect the breccias and enclosing sediments, implying that the breccias are contemporaneous with the sediments. Many moderate high-angle normal faults cross the sediments, and those which dip to the south-east commonly show a zone of intense brecciation up to 4 ft. wide. It is remarkable that in an area which is reputedly part of a major low-angle thrust zone very few thrust faults are seen. Several of the faults previously described as thrusts appear instead to be low-angle normal faults, in which the main direction of movement has been from north-west to south-east.

108. **Some aspects of the slaty cleavage in the Padstow area of** N. **Cornwall :** by G. A. Gauss.

The area investigated lies to the west of the Camel Estuary, and only the coastal sections from Dennis Hill, south of Padstow, around to Boobys Bay, on the west coast, are considered (Fig. 1). Slaty cleavage is nearly everywhere the most prominent feature of the rocks, which are dominantly argillaceous, and is a true slaty cleavage parallel to the axial planes (Fleuty 1964) of the folds of bedding, (F1), which trend E.N.E. and are recumbent, facing (overturned) north.

Two later sets of macroscopic folds of the cleavage have been recognised both of which diminish in prominence northwards, rarely occurring in the Purple and Green slates. The first is a N.W. trending set represented in the most southerly sections by rather open flexure folds several feet in wavelength. Axial planes dip steeply to the west and have both a fracture cleavage and a kink banding developed parallel to them. Parallel to the fracture cleavage-slaty cleavage intersection there is also developed on the latter a prominent lineation, really a microfolding, which, together with the kink banding, is recognisable throughout the grey slates even where cleavage is otherwise markedly undeformed. The second set is a N.W. trending set of kink bands which also dips steeply westwards and is later and less well developed than the first.

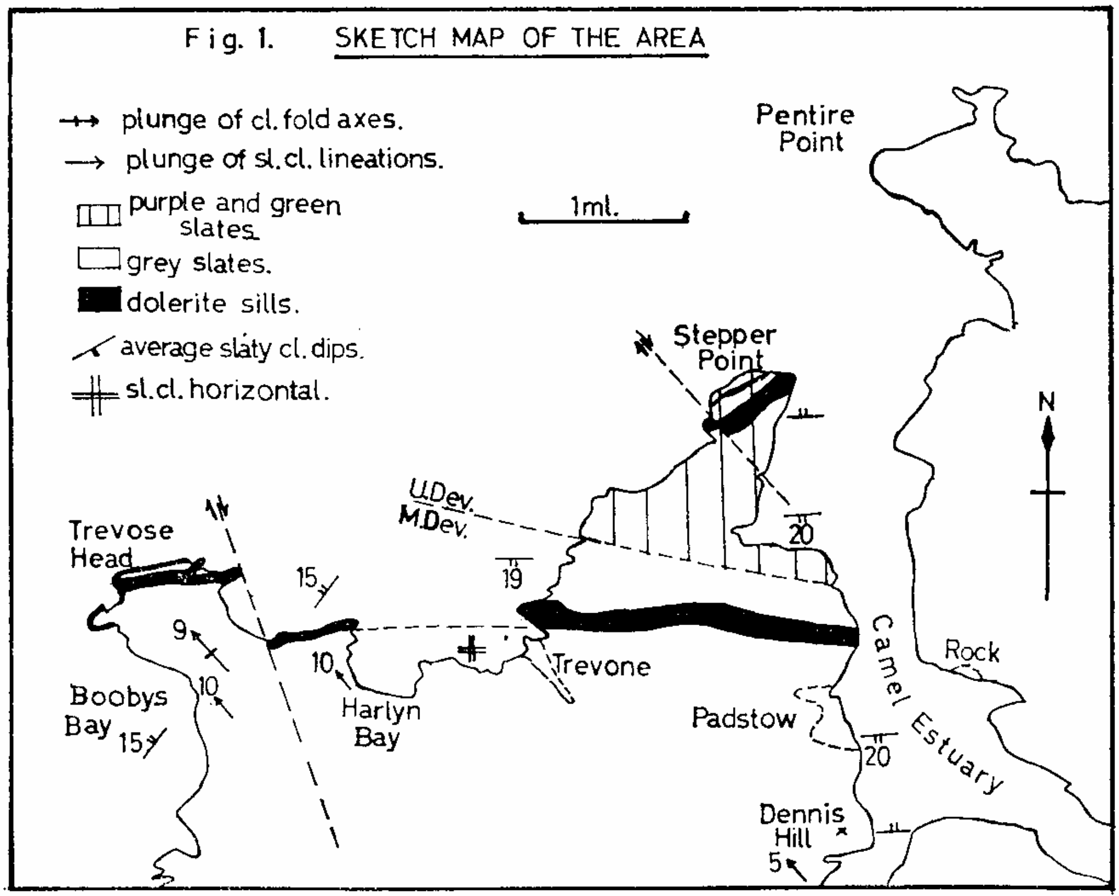

FIGURE 1. Geological sketch map showing regional variation in cleavage attitude and associated structures for the area west of the Camel Estuary.

Besides these local variations of cleavage attitude, a more significant regional variation occurs (Fig. 1). West of Trevone, at Dennis Hill, and on the east side of Stepper Point, the slaty cleavage attitude changes gradually from southerly to northerly dipping, or vice versa. Stereographic v diagrams of cleavage reveal that its regional configuration is one of broad open undulations which trend E.N.E. and are horizontal or plunge slightly to the west. Individually these undulations perhaps die out rapidly parallel to their axes for the Trevone turnover is apparently unrepresented on the west side of the estuary.

The time of formation of these major structures is thought significant. It is difficult to explain the northerly facing recumbent folds combined with an original northerly dipping slaty cleavage without invoking for the area quite large scale nappe structures and a gravity slide mechanism of formation. If, however, post F1 rotation has produced the northerly cleavage dips, no such structure or mechanism is necessary.

A comparison of the structural sections for western Trevose Head, where slaty cleavage dips to the N.W., and at Trevone, where it dips to the south, is revealing in this respect. The folds in the latter section are strongly overturned to the north and the dolerite sill is situated on the southerly dipping overturned limb of a major structure. The folds of the Trevose Head section, however, in their present attitude, suggest overturning to the south. If, though, this section is rotated about a horizontal S.W. trending axis so that cleavage has an attitude similar to that at Trevone, the styles become identical and the dolerite sill - a fairly constant stratigraphic horizon - is in the same structural position in each.

The evidence seems to indicate a post initial folding age for the regional cleavage mega-undulations, but the parallelism of their axes with those of this fold phase may indicate that no great time interval separated the two events.

Low angle normal faulting along slaty cleavage is very common in the area, particularly where the cleavage dips south, but also where it dips north. It is suggested that this faulting arose under conditions of regional N.W.-S.E. or N.-S. horizontal tension, perhaps associated with the intrusion of the Hercynian granites. Slaty cleavage, being a pronounced planar weakness in the rocks, tended to control the attitude of the fracture that actually developed from the theoretical steeply dipping pair of directions of maximum tangential stress arising from such a stress system. This implies that the regional variations of slaty cleavage were in existence before the faulting. Such a model could account for much of the low angle normal faulting of S.W. England that parallels an earlier planar weakness in the rock, such as a true or incipient slaty cleavage.

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109. Kink-bands of Bigbury Bay : by Scott Simpson.

Kink-bands of various sorts and orientations affect the slates of the Meadfoot and Dartmouth Beds exposed along the coast of Bigbury Bay. This note relates only to the coast northwards from the mouth of the Avon at Bigbury-on-Sea to Hoist Point, a distance of about two miles, and to one distinct set of kink-bands.

Along this coast the well-developed slaty cleavage dips steeply southwards at angles between 65° and nearly vertical. The kink-bands in question dip northwards at angles of more than 50°. At any particular locality the angle between the kink-band and the slaty cleavage is 40°-50°. The strike of the slaty cleavage and that of the kink-bands is closely similar and so the line of their intersection is usually roughly horizontal, though plunges towards both east and west do occur, and those towards the west tend to be higher and more numerous. The sense of rotation of the cleavage within the kink-band lamina is invariably such as to reduce its dip. Very often the rotated cleavage comes to lie almost horizontal.

There is also present along this coast a well-developed strain-slip cleavage which at any point has the same orientation as the kink-bands at that point. There has been much speculation about the relation of kink-bands to strain-slip cleavage. In this case it is clear that the relation is an intimate one, but it is certain that the two are completely distinct because the sense of shear of the strainslip cleavage is the reverse of that implied by the rotation in the kink-bands.

A very simple model serves to explain the relation of the kink-bands to the strain-slip cleavage. The rock within the band is represented by a stack of discrete plates of slate separated from one another by fractures following the slaty cleavage which act as planes of slip. Each plate is hinged at either side to the monolithic masses of rock forming the walls of the kink-band. The boundary surfaces of the kink-band lamina are thus planes in which the rigidity of the rock has been partly broken down. They may be thought of as planes in which innumerable microscopic shear fractures are present. Between these fractures cohesion is retained, and these points of cohesion act as the hinges for the rotation of the slate within the kink-band lamina. The fractures referred to are, of course, the expression of the strain-slip cleavage.

The rotation of the cleavage from a steep to a flatter attitude implies horizontal extension, and the kink-bands would thus appear to represent the effect of a tensional force acting in a general north-south line. It is worth noting that with a model of this kind no very exact statement can ever be made about the actual directions of the applied stresses causing the deformation. This is because the deformation is entirely guided by the pre-existing geometrical relations between the two cleavages.

110. Correlation of South and North Cornwall: by E. M. Lind Hendriks.

Professor F. H. T. Rhodes has kindly identified conodonts of Lower Givetian age from Middle Gramscatho limestones at Pendower Beach, Roseland (Zone 4d Hendriks 1937). In the Roseland-Gorran Crush-Zone with a similar dip further south there are Llandeilian-Caradocian quartzites, Ludlovian limestones, and other limestones with Siegenian, Emsian, and Middle Devonian conodonts. From limestones interstitial with the Mullion Island pillow-lavas W. Ziegler extracted Frasnian conodonts thus correlating these with the Frasnian Pentire-Port Isaac pillow-lava (House 1956). The Lower Gramscatho grits silts and shales are seen to dip below the Middle Gramscatho limestone at Pendower Beach and may be Eifelian. Land-plants suggest a Middle Devonian age for the Gramscatho Beds (Lang 1929).

Thus the Gramscatho Beds once believed Ordovician are mainly Middle Devonian and equivalent to the Wissenbach Slate facies *(A narcestes* and *Maenioceras* Stufe) found further north near Padstow (House 1963). To the east this facies is replaced by a limestone at Plymouth and a grit at Staddon. There are thus four unlike facies of Middle Devonian age.

South of the Plymouth Limestone are grey slates in which C. J. Stubblefield identified a Lower Emsian fauna with abundant crinoid ossicles which suggest to Erben a facies change to Herzynische Magnafacies to which he refers both the Plymouth Limestone and the Wissenbach Slate. Everything between the Plymouth Limestone and the Crush-Zone is Rheinische Magnafacies as defined by Erben (1964).

The purple and green "Dartmouth Slates" ("red-beds" facies) of Watergate Bay contain ostracoderms identified by E. I. White as *Pteraspis (Rhinopt.) dunensis* ranging in Britain and Germany from the top of the Middle Siegenian to Lower Emsian. The same fossil is found on both sides of the purple and green (" Red ") beds in the grey Hunsruckian slate of Plymouth Sound and at Ringmore further south. The psammosteid *Drepanaspis* occurs in the Dartmouth Slate and Meadfoot beds of Watergate Bay and Plymouth Sound, and at Bigbury Bay in the south. Both fishes mark the range of the continential Breconian in South Wales and marine Hunsruckian in North Germany (Simpson 1949, Solle 1951). *Pteraspis* characterises Rheinische Magnafacies (Schimdt), and both grey and red Breconian belong to this in Cornwall. In the Crush-Zone are limestones with conodonts of the same Siegenian-Emsian ages (F. H. T. Rhodes). Limestones of this age do not occur elsewhere in Cornwall though they do in Brittany and Central Europe in the Barrandian Formation in the Herzynische Magnafacies (Erben. 1964). The author is greatly indebted to Rev. **B. B.** Clarke for his help in preparing this Abstract.

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111. Lower Carboniferous stratigraphy in the St. Mellion area : by S. C. Matthews.

The Lower Carboniferous rocks of south-west England, as at present disposed, make their most southerly appearance in the St. Mellion area. Their stratigraphy is of interest in two ways. First, it is worthwhile to seek any detail of stratigraphic character different from what is seen in Lower Carboniferous sections farther north. In the German Lower Carboniferous, southerly successions do have distinctive characteristics and their evidence of derivation of material from the Mitteldeutsche Schwelle is of some significance. The St. Mellion Lower Carboniferous claims attention in a second respect. Age-determinations recently done on Cornish rocks (Dodson 1962, 1963) have indicated a “recrystallisation” in Lower Carboniferous time. The nearest Lower Carboniferous outcrops deserve to be searched for any evidence of a surface expression of such an event.

Rocks of Lower Carboniferous age occur in two different settings in the St. Mellion area (Matthews 1966). Low in the structure, much of the Lower Carboniferous sequence is faulted out right across the area. Higher, there are klippen of Lower Carboniferous material and useful information has been obtained from these, although it should be borne in mind that there is as yet no clear information on their original site in the structure. In an exposure at (SX 397665) a siliceous lens has yielded Tournaisian cephalopods The section here reveals siltstones with fragmented plant material, a massive, pinkish-grey sandstone and rare dark argillaceous beds. The thin siltstones show fine cross-stratification. It appears that there is in this sequence a greater abundance of relatively coarse terrigenes than is found in other sequences of Tournaisian age in south-west England. In another exposure at a higher level in the same klippe, at (SX 375676), Lower Carboniferous siliceous rocks have abundant conodont moulds which indicate an *anchoralis*-Zone age, comparable with that of the Erdbacherkalk. The particular interest of this occurrence in the present connection is in the fact that there are a few palmatolepids in the fauna. These are forms which are thought to have been restricted to relatively short intervals of Upper Devonian time, and their presence here may imply erosion of Upper Devonian rocks during the Lower Carboniferous, with redeposition of conodonts. However, it is possible to argue (necessarily at greater length than is permissible here) for an alternative interpretation - that the forms involved were regenerated during the Lower Carboniferous.

There is no evidence of a break in the succession. The relatively coarse Tournaisian sediments may be of a special, southerly character, but no conclusions should be drawn until their petrography and distribution are better understood. Likewise, the *anchoralis-Zone* conodont fauna, with its palmatolepids, does not yet permit a plain statement on uplift and erosion. Only when Lower Carboniferous conodont standards are more fully developed will it be possible to judge between the two alternative interpretations of the presence of "Upper Devonian" conodonts.

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112. Structure and stratigraphy of the Upper Carboniferous Bude Sandstones, North Cornwall : by A. F. King.

The name 'Bude Sandstones' was introduced by Owen (1934) to include sandstones-shales and siltstones around Bude, North Cornwall. The stratigraphic limits of this `formation' have not been defined and for the purpose of this paper the geographic boundaries include all the sediments between Duckpool and the conspicuous wrench-fault south of Black Rock (O.S. 1 inch Sheet 174).

The Bude Sandstones have been regarded both as a Coal Measures facies by Owen (1950) and Prentice (1962), and as a turbidite facies by Ashwin (1957), Reading (1963), and Lovell (1965). There has also been a difference of opinion as to the large scale structural picture along the coast, particularly between Upton Cross and Widemouth. Owen and Ashwin show an anticlinorium centered about Phillip's Point with about 4,000 to 6,000 feet of strata exposed on a near vertically dipping southern limb. With the exception of the wrench fault south of Black Rock, they say little about faults in the Bude Sandstones. Lovell shows three large anticlines between Phillip's Point and Lower Longbeak and suggests that the strata in this area are underlain by the strata to the north, with a total stratigraphic thickness of about 4,000 feet.

In the present detailed study of the cliffs and foreshore between Northcott Mouth and Wanson Mouth (Fig. 1) data were plotted in the field on controlled aerial and ground level photographs enlarged to about 40 feet to one inch and later transferred to controlled base maps. Stratigraphical measurements were taken across the limbs of folds and plotted at 20 feet to one inch in the form of graphic logs representing sedimentary properties. Structural properties such as bed thicknesses along the axial planes were also recorded.

The writer is of the opinion that previous workers have not made full use of exposures present on the foreshore, particularly between Uptin Cross and Wanson Mouth, where the cliff sections show complex structure, are poorly exposed or absent and as a result, errors in correlation appear to have been made.

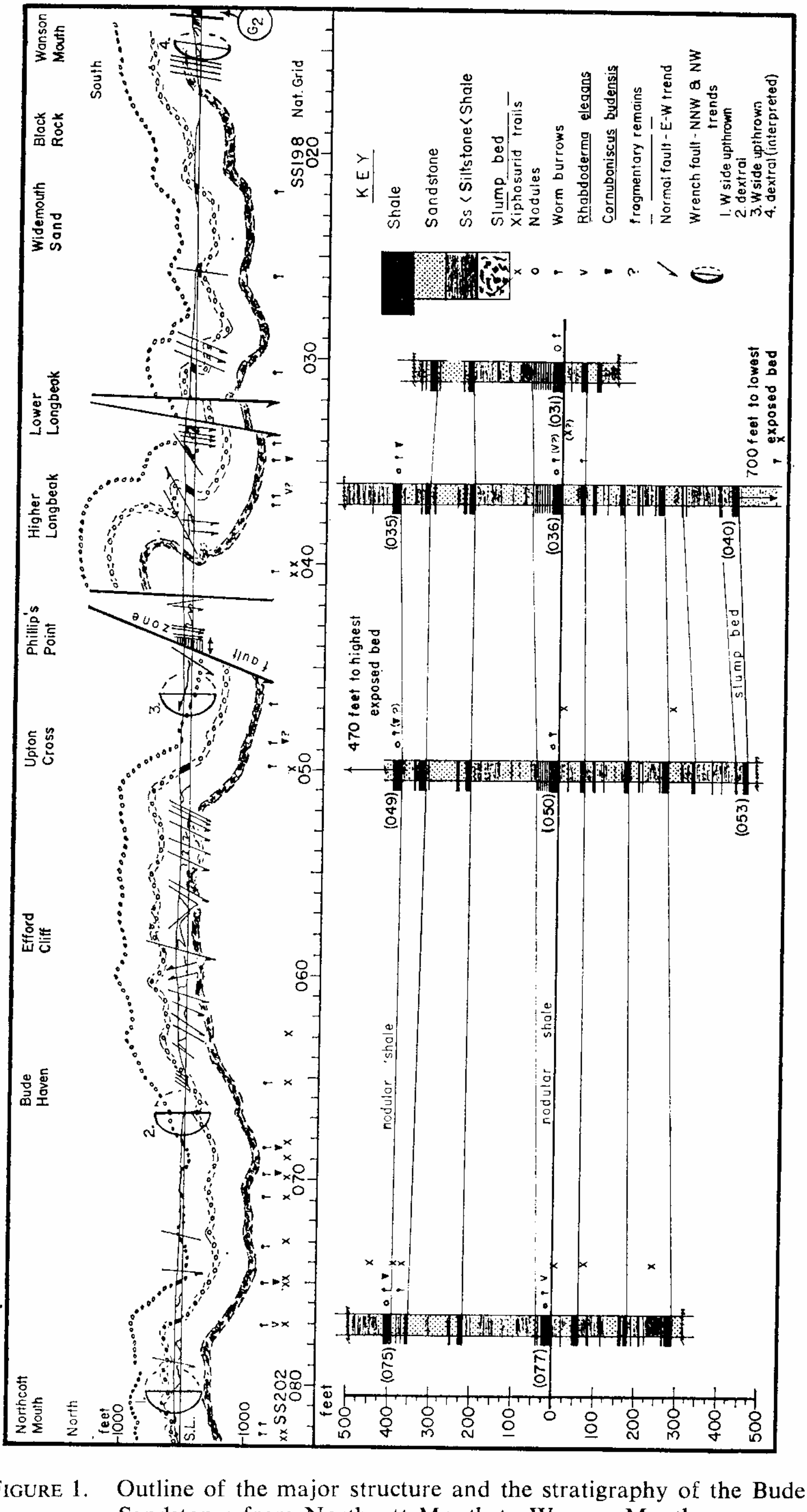

FIGURE 1. Outline of the major structure and the stratigraphy of the Bude Sandstones from Northcott Mouth to Wanson Mouth.

An outline of the major structure and the stratigraphy of the Bude Sandstones from Northcott Mouth to Wanson Mouth is shown in Figure 1. There is no one area where a complete stratigraphic column can be constructed by simply measuring from the youngest to the oldest exposed beds. Many faults are present and cause repetition of the succession. There are low-angle reverse faults, related in time to the formation of the E.-W. folds ; these are cut by a system of high-angle normal and reverse faults which in turn are cut by wrench-faults. Also, folds such as those present on the foreshore between Widemouth Sand and Black Rock reduce the overall thickness of strata as shown by Lovell.

The only previously known fossils (apart from plant remains) in the coastal portion of the Bude Sandstones now under consideration, were fish from a shale bed behind the Bude swimming pool, and these were described by White (1939). Nodules from this shale were found to contain the palaeoniscids **Cornuboniscus budensis** and **Elonichthys** aitkeni, an ancanodian **Acanthodes wardi,** and a crustacean **Crangopsis huxleyi.** This bed has now been traced throughout most of the section and Dr. M. Williams of the Geological Survey and the writer have discovered **C. budensis** as far south as Lower Longbeak (fossil locations and their stratigraphic position are shown in Fig. 1). The writer has discovered ellipsoidal clay-siderite septarian nodules, up to six inches diameter, containing a coelacanthid **Rhabdoderma elegans,** similar to the species from the Instow fish bed of north Devon (Rogers 1907). Carbonaceous siltstones with xiphosurid trails (King 1965) have now been found at eleven stratigraphic levels. These trails are considered to have been made under shallow water conditions and it seems reasonable to suppose that although depositional environments in the intervening levels were variable,, there were no great fluctuations in depth of water. Worm burrows, mainly **Cochlichnus** and **Planolites ophthalmoides,** are present in nodules, in the shales and in the carbonaceous siltstones. The nodular shales together with the slump bed form the principal marker beds. Correlation has not been made by these marker beds alone and there are many individual sandstone and shale units which have been traced throughout most of the section.

The exposed stratigraphic thickness of the strata between Northcott Mouth and the wrench-fault south of the Black Rock slump bed is about 2,000 feet ; the oldest exposed beds north of Higher Longbeak are similar in lithology to the Crackington Measures near Wanson Mouth (G2) and may be equivalent in age.

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113. Lower Carboniferous zone-fossils (Abstract) :
by S. C. Matthews.

H. Schmidt's work on the Carboniferous goniatites in the nineteen-twenties produced a major advance beyond previous understanding of these faunas. His proposals were built into the Carboniferous time-standard finally approved by the Heerlen Congress of 1935. In constructing his scheme for the Lower Carboniferous, Schmidt was obliged to employ material from widely scattered localities and his statement on the Lower Carboniferous sequence of index-cephalopods relies to some extent on his reading of the morphogeny. Since no continuous succession of Lower Carboniferous cephalopod-bearing beds has been available, it has not been possible to guarantee the completeness of the standard approved in 1935. It is equally difficult to discount the possibility that certain of the indices might be to any extent contemporaries of one another. The nature of the boundary between cu I and cu II has never been understood, and Schmidt's (1941) addition of a new unit to the scheme accepted in 1935 is itself a comment on the scheme's fullness. The need to find stratigraphic confirmation of the Lower Carboniferous cephalopod sequence was clearly stated in Delepine's (1930, 1940) papers on Belgian occurrences.

Schmidt's zonal symbols have come into familiar use in work on the Lower Carboniferous in Germany. When Voges (1959, 1960) produced his conodont zonal sequence, he suggested orthochronological equivalents of his units and it is now usual to find the age of a Lower Carboniferous conodont fauna stated in terms of Schmidt's symbols. Most interesting is one recent case in which preliminary results of a study of conodonts in the Belgian Lower Carboniferous succession, produced by Conil, Lys and Mauvier (1964), have been in part translated into orthochronological terms by Paproth (1964). It emerges that what Paproth distinguishes as cu IIα does not include these high Tournaisian horizons which were the sources of the IIα indices recommended by Schmidt. The Belgian sequence which supplied Schmidt's cu IIα indices is, apparently, a time-equivalent of some part of what is now often referred to in Germany, rightly or wrongly, as cu II(β/γ). That lower part of the Belgian Tournaisian sequence to which Paproth has applied the term IIα is perhaps better regarded as a representation of the interval between the top of cu I and the late Tournaisian occurrences of the cu IIα indices, a range of time of which Schmidt's zonal scheme made no account.

Conodonts are increasingly widely used as Lower Carboniferous zonal indices. Their time-sensitivity may be abused if results are always to be stated in terms of the present cephalopod-based standard. It should be possible to organise a relatively refined scheme of conodont zones, founded on a good stratigraphical basis and with no need of morphogenetic presumptions. The readier availability of conodonts suggest that students of Lower Carboniferous stratigraphy would have freer access to a conodont-based standard than to the present standard. These microfossils are present and useful in the cleaved rocks of the Lower Carboniferous of Devon and Cornwall. They can be collected from limestones and can also be found in the field on the bedding surfaces of non-calcareous rocks. Although only moulds survive in some cases, they may still give good information on age.

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114. Derived fossils from the Upper Culm Measures south of Launceston, Cornwall : by E. B. Selwood.

Upper Culm rocks are extensively represented on the Tavistock and Launceston Sheet of the Geological Survey ; the principal outcrops occur immediately around Launceston but outliers also occur to the south. Within the Woodabridge outlier, which lies on the west side of the Tamar between Launceston and Stoke Climsland, rocks represented on the map as Upper Culm Measures consist of a variety of lithologies and include cherts (which would now be included within the Lower Culm), Exeter Type Culm, and a series of feldspathic sandstones and slates. The last, which may be compared to the Crocodon Beds of Matthews (1966), was recently exposed in a new cutting on the west side of the road (A.388) immediately north of Woodabridge (5X 347769). This section, which includes inverted beds, reveals coarse feldspathic sandstones associated with dark micaceous slates and silts, and conglomeratic horizons. Two principal conglomerate horizons exist, one four feet thick and the other seven feet thick; these are ill-sorted and contain well-rounded pebbles, seldom exceeding six inches in diameter, lying in a fine silty matrix. The pebbles are composed of a great variety of material including Lower Culm chert, quartzite, vein quartz, vesicular lava and decalcified limestone. The limestone pebbles have yielded a variety of fossils including a clymenid, *Gattendorfia,* and small evolute goniatites which Dr. J. M. Thomas suggests to be of Lower Namurian age.

The conglomerates thus indicate intra-Carboniferous movements involving uplift and erosion sufficient to expose Upper Devonian rocks in post-Lower Namurian times. Unless the beds are post-Lower Westphalian in age, which is unlikely for the beds are clearly involved in the orogeny, it is inconceivable that they could have been derived from the north, for in this direction no break has been recorded in the Culm sequence. A southerly source is thus postulated involving uplift and erosion in post-Lower Namurian and probably pre-Lower Westphalian times. The relation of the conglomeratic beds to the underlying rocks at Woodabridge is obscure, but if deposited at some distance from the source it need not necessarily be an unconformity.

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115. Carboniferous rocks of North Devon : the Appledore Formation : by Narayana J. Money.

The Carboniferous rocks of the Appledore Peninsula, north Devon, were first mapped by Prentice (1960a, b) as Northam Beds, with the exception of a small area in and to the north of Hubbastone Quarry (GR 464298) where he considered Instow Beds to crop out. De Raaf (*et al.* 1965) and Walker (1964) have divided the coastal section of Prentice's Northam Beds into two formation, a paralic unit, the Northam Formation, above, and the Westward Ho ! Formation, below, composed of laminated silty mudstones with turbidites (Figure 1).

The present mapping of the Appledore Peninsula has shown that the rocks are folded to form a major east-west trending anticline and are sufficiently distinct both lithologically and geographically from the Northam and Westward Ho ! Formations to warrant separate description as the Appledore Formation ; this is divided into three members (Money 1966).

Lower Appledore member (c. 1,700 feet +). This member consists principally of parallel bedded sandstones and mudstones. The sandstones are commonly graded, occasionally amalgamated, and have sole marks including groove, flute and prod casts. They are feldsspathic and contain over 25 per cent matrix. They are interpreted as turbidites and are well exposed in the northern part of the Hubbastone Quarry and north of Appledore Quay (GR 465307). The top may be exposed in Hubbastone Quarry, but as no complete section is available and the base is not exposed the thickness is conjectural. Isolated outcrops suggest that the upper part (perhaps 400 feet) is essentially sandstone, and the lower part mudstone.

Middle Appledore member (110 feet). This member consists of coarsening upward units each passing gradationally from black mudstone to sandstone with a sharp upper junction. One sandstone portion is over 10 feet thick and is cross bedded (GR 458307). Possibly the southern part of the Hubbastone Quarry displays the mudstone of the lowest cycle.

Upper Appledore member (c. 670 feet +). This consists of mudstones, muddy siltstones and complexes of sandstones. The sandstone bodies are generally massive and lenticular. Slumps,

STRATIGRAPHIC COLUMN FOR THE AREA WEST AND NORTH OF BIDEFORD, NORTH DEVON.

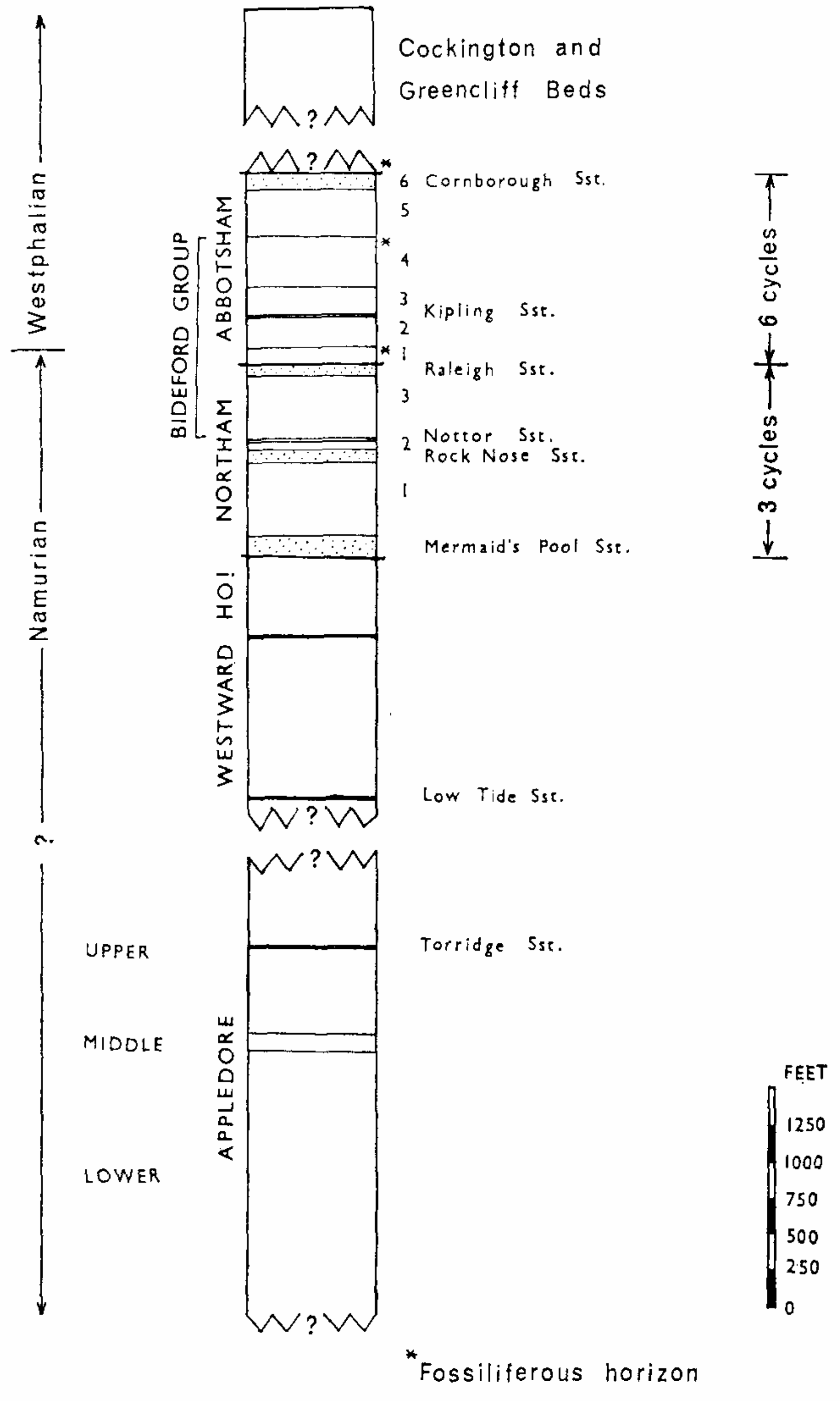

FIG.1

njm

scoured and loaded bases, sole marks and graded beds occur and the sandstones are feldspathic and contain 20 to 40 per cent matrix. In sedimentary facies and petrography, these rocks resemble the Westward Ho! Formation as described by Walker (1964). The rocks of the Upper Appledore member outcrop on the west coast of the Appledore Peninsula (GR 458307-461311) where the base is slightly faulted against the Middle Appledore member and the top disappears under the recent sands of the Taw Estuary.

It is probable that the Upper Appledore member grades upward into the Westward Ho! Formation. However, no definite correlation can be made because there is no palaeontological control nor any definite marker horizons.

Since no fossils have been found in the Appledore Formation its stratigraphical position is uncertain. Lithologically, the Lower Appledore member resembles the Instow Beds of Prentice (1960a) and the Upper Appledore member resembles the Westward Ho ! Formation. The simplest hypothesis on the field evidence is to place the Appledore Formation beneath the Westward Ho ! Formation (Fig. 1) and equate it with the Instow Beds which outcrop along the strike to the east. However, as Reading (1965) has pointed out, this places the Instow Beds with a Westphalian fauna (Prentice 1960a) more than 3,000 feet below the Abbotsham Formation whose base is Namurian. Two alternative explanations are possible. Either, one of the major thrust faults suggested by Reading (1965) occurs in the wide belt of unexposed ground between the southernmost exposure of the Appledore Formation and the northernmost exposure of the Westward Ho ! Formation ; or the Instow Fish Bed goniatite fauna does not actually occur in the main Instow Bed outcrop area between Instow and Bishop's Tawton. In fact the only recorded exposure of the Instow Fish Bed is to the north of Instow. The author, therefore prefers to consider the Instow Beds (but without the Instow Fish Bed) to be the equivalent of at least the lower part of the Appledore Formation which he places stratigraphically below the Westward Ho! Formation. The alternative of a major thrust fault is still possible but can only be substantiated or disproved by the finding of fossils within the Appledore Formation.

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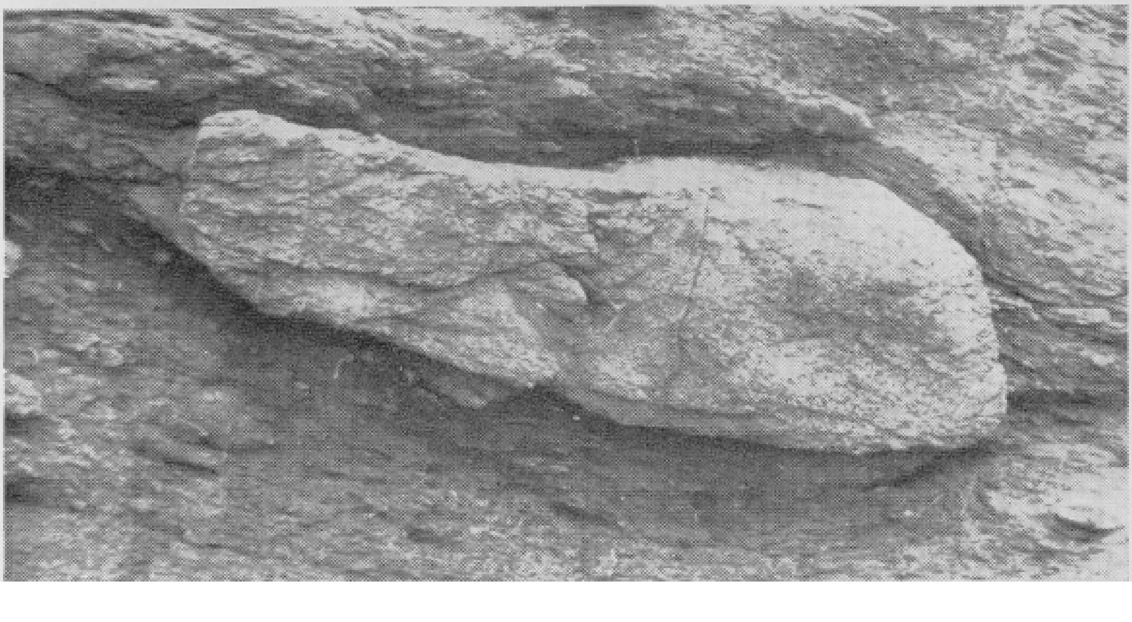
116. Conglomerates, tuffs and concretionary beds in the Upper Devonian of Waterside Cove, near Goodrington Sands, Torbay : by F. J. W. Halwill.

Introduction. Waterside Cove has long been famous for its Upper Devonian goniatite fauna which was first recorded by Lee in 1877. Anniss (1927) gave a fuller account of the geology including a measured section through the Upper Devonian sequence ; he was also responsible for naming the cove which does not appear on the Ordnance Survey Maps. The Geological Survey One Inch Memoir (Lloyd 1933) published an annotated map on which the main conglomeratic band, discussed below, is indicated as a fissure filling. More recently House (1963) has discussed the goniatite fauna in detail and has referred it to the **holzapfeli** zone, i.e., uppermost Frasnian. Above the goniatite bearing band is a succession of red shales with interbedded calcareous tuffs and conglomerates and these pass, with no apparent break, into the purplish red shales of the Famennian which contain the ostracod **Entomis serratostriata** (Sandberger). The bedding is vertical or slightly overturned and the cleavage is horizontal. There is also irregular vertical jointing which is sub parallel to the bedding. Below the goniatite band is a further succession of red shales with interbedded tuffs, usually lenticular and having a maximum thickness of 18 ins. These pass down into shales and thin limestones many of which are richly coralliferous (see Anniss 1927 and Scrutton 1965). House 1963 and Scrutton 1.965 agree in placing these beds in the Middle Frasnian (probably **cordatum** zone).

PLATE. Top - Concretions in the red shales at Waterside Cove.
Centre left - The conglomerate bed at Waterside Cove. It can be seen to taper as it ascends vertically in the cliff.
Centre right - Pebbles in the conglomerate bed showing coarse grading.
Lower - Large lenticle of calcareous tuff in the cliff face between Waterside Cove and Saltern Cove.



The main conglomeratic band of Waterside Cove. The conglomerate forms a prominent wall-like feature extending from the cliff in the S.E. part of the cove for about 30 yds. across the foreshore, striking 042° (Plate I centre); it has a maximum thickness of 2 ft. 6 ins., but it tapers as it is followed upwards in the cliff. Lloyd (1933) records it as dying out before reaching the cliff top but exposure is not good enough at the present time to confirm this observation. Small fractures trending between 265° and 314° cause minor displacements of the bed though a more powerful fault at its seaward extremity cuts off the bed completely. The conglomerate occurs about 10 ft. above the goniatite band and 20-25 ft. below the beds with **Entomis.** Other observations regarding the conglomerate are tabulated below.

(a) The maximum size of pebble occurs where the bed has greatest thickness (about midway across the foreshore).

(b) The pebbles are dominantly limestone (sometimes dolomitized) but there are also pebbles of tuff (sometimes almost agglomerate) and vein quartz.

(c) The conglomerate shows graded bedding - the larges pebbles occur on the S.E. side (i.e. at the base of the bed). Pebbles up to 18" occur but they get progressively smaller as the bed thins, though grading is present throughout.

(d) Cleavage in the conglomerate is parallel to that in the shales above and below. The pebbles have been rotated and possibly slightly flattened so that their long axes are sub parallel to the cleavage. The pebbles also show imbrication but this may not be a primary structure.

(e) Both top and bottom of the conglomerate are sharply defined, but the top grades into red shale and the sharpness is largely the result of vertical jointing.

(f) The limestone pebbles are veined with calcite and this veining is unrelated to their present environment.

(g) Fossils in the limestone pebbles are **Thamnophyllum, Disphyllum, Alveolites** and possibly **Thamnopora.** These could be Givetian or Lower Frasnian, probably the former.

The Tuff Beds. These occur both above and below the goniatite band and their petrology has been discussed by Lloyd (1933) ; he concluded that they were all of basic spilitic type. The tuffs occur in two distinct ways. The thicker bands (up to 18") are lenticular in form, tapering to zero when traced laterally. They show graded bedding and their lower surface tends to be irregularly mixed with the red shale. Other tuff bands are thin (½-1") but appear to maintain this thickness over a wide area.

One outcrop seen in the cliff-face between Waterside and Saltern Coves is quite anomalous. The tuff occurs as a lenticle 10’ x 3½’ and its ends terminate abruptly (Plate I lower). A similar, but smaller lenticle is seen in the cliff-face a few feet above the conglomerate discussed in the previous section. This appears to be associated with one of the thin tuff bands.

The Concretions. These occur in a zone about 15-20 ft. thick which lies below and in part within the goniatite band. The concretions, which may be several feet in diameter, are best seen on the foreshore at low water (Plate 1 top). They occur entirely within the red shales and appear to have no connection with tuff bands. In thin section they are seen to have a calcareous cement but otherwise they appear to have the same grain size and composition as the surrounding soft red shales. The concretions must have developed penecontemporaneously for they have resisted compaction and have failed to take on the cleavage of the enclosing shales though in section, a lineation paralleling the cleavage can be seen. Their limited vertical extent in an otherwise similar succession of red shale also indicates development at, or nearly contemporaneous with, the time of deposition. What special factors were involved in their formation is not known.

Conclusions. It seems clear that the tuff bands have accumulated in two distinct ways. The very thin widespread bands must have resulted from volcanic explosions which were either subaerial or else exploded with such force that the ash was blown out of the water into the air, which enabled it to spread over a much wider area before settling out through the water. It thus formed only thin, fine grained bands. The thicker tuff bands with graded bedding were deposited by a broad current sweeping across the bottom of the sea, churning up the soft red sediment and cutting a shallow channel in it. Such currents were probably density flows moving down a submarine slope from the region of a volcanic vent, possibly initiated by the ashes flung out by an eruption.

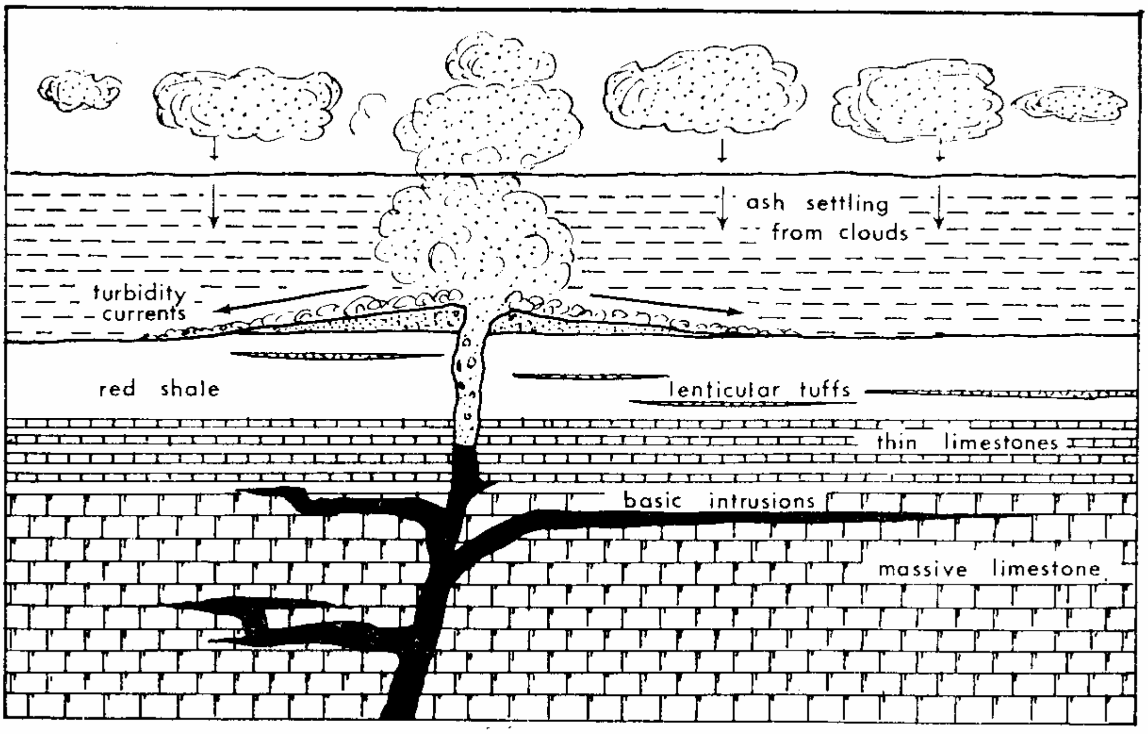


FIGURE 1. Hypothetical reconstruction of conditions of sedimentation in the Waterside Cove area during the Upper Devonian (Frasnian).

A similar mechanism probably accounts for the conglomeratic band. It seems to have resulted from a particularly violent explosion which carried limestone from at least 400 ft. below the sea floor, together with earlier deposited tuffs, up to the surface. Turbidity or density currents were initiated by the disturbance, and these were of sufficient power to carry large boulders of limestone and abrade them at the same time. Again, the present outcrop suggests a broad shallow current rather than one confined to a narrow channel ; it was probably at least 40-50 yds. wide. Such a mode of occurrence would account for most of the observed features.

The lenticular mass of tuff described above, is probably the result of a submarine slide. Ash, which accumulated at a steep angle around the vent, started to slip down-slope as the result of earth tremors which must have accompanied the volcanic activity. The mass remained coherent and ended by burying itself in the soft red shales in a deeper part of the sea floor. The instability of the sea floor has left no marks in the red shales which lack evidence of bedding and have been severely broken by cleavage.

Dolomitization of the limestone must have started very early in diagenesis and must have been the result of local factors since dolomitization does not appear to have continued in the conglomerate band. Even more significant would appear to be the veining in the limestone pebbles indicating a period of movement probably in the Lower Frasnian.

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117. Superposed structures in the Trebursye Beds of Launceston, Cornwall : by W. R. Dearman.

Black shales and slates with thin beds of sandstone were noted by the Geological Survey in the road cutting of St. Stephen's Hill leading from Newport to St. Stephen on the northern outskirts of Launceston (Reid et al. 1911, p.28-9). A massive plant-bearing sandstone capping the hill by St. Stephen's Church was considered to have Upper Culm affinities, but because of the structural difficulties involved in having Upper Culm overlain by the Lower Culm cherts of the Barracadoes Quarry just to the north, all the beds were referred to the Lower Culm Measures. These sandstones and slates have now been grouped into the Trebursye Beds considered on lithological grounds to belong to the Upper Culm, although faunal evidence of their stratigraphical position is lacking (Selwood 1961, p.166).

The exposures on St. Stephen's Hill provide a dip section ; that part selected for illustration (Figs. lb and 2a) is 65 feet long and shows tight angular recumbent folds with long limbs dipping gently north. The folds trending east and west face south since the beds in the long limbs are inverted. In this part of the section and in exposures some yards uphill on the same side of the road a slaty cleavage has been developed sub-parallel to the bedding in the short limbs of the folds. A ubiquitous strain-slip cleavage, which cuts earlier structures at moderate angles to the south-east, is subparallel to the axial plane of open flexures bending the earlier recumbent folds. The trend of these second folds, together with the lineation produced on bedding and slaty cleavage by the second cleavage, is north-east to southwest. It is likely that the strain-slips with normal faulting to the south-west are conjugate to the second folds whose symmetry is indicative of down dip bedding-slip in the opposite direction. The spatial relationships of the superposed structures are shown as a stereogram in Fig. 2e.

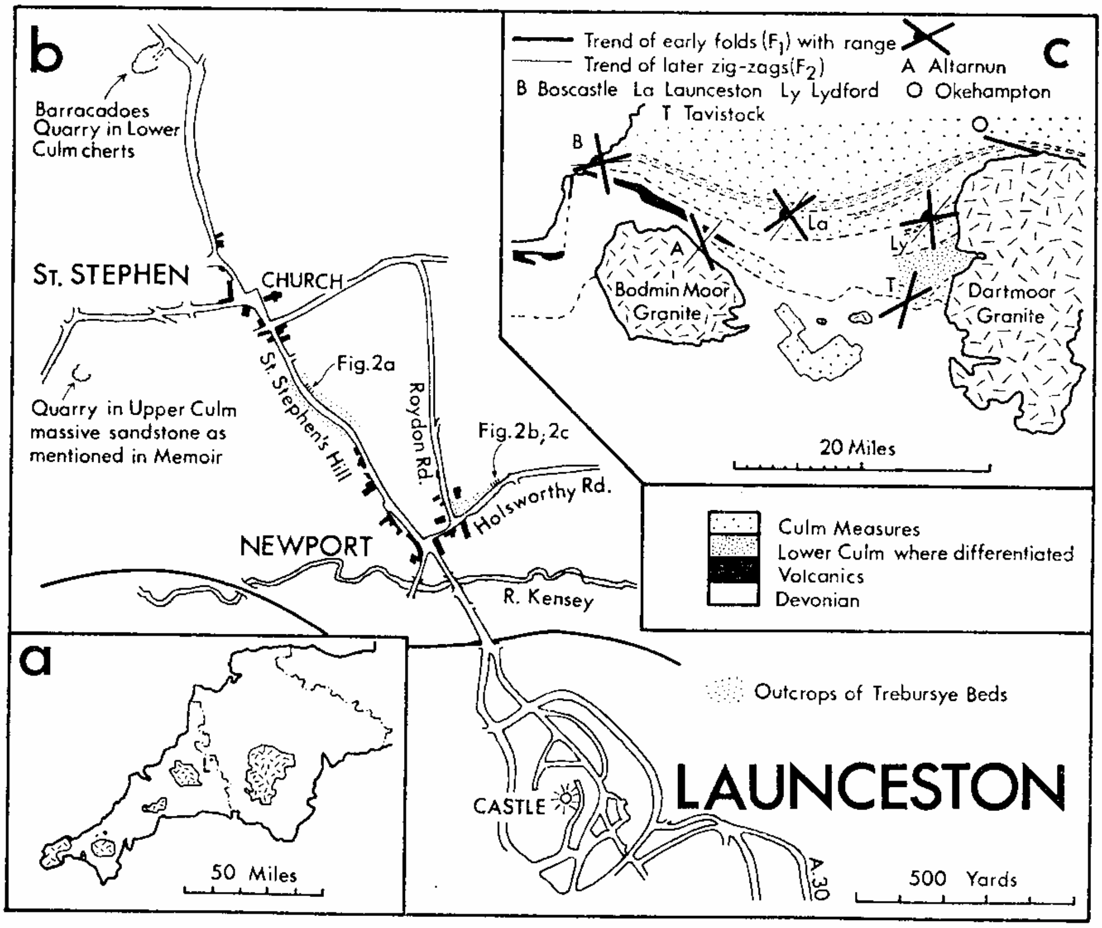

FIGURE 1. Location of the area in S.W. England. (a) Outline map. (b) Locality map for sections described. (c) Structural trends along south margin of the main Culm Measures outcrop.

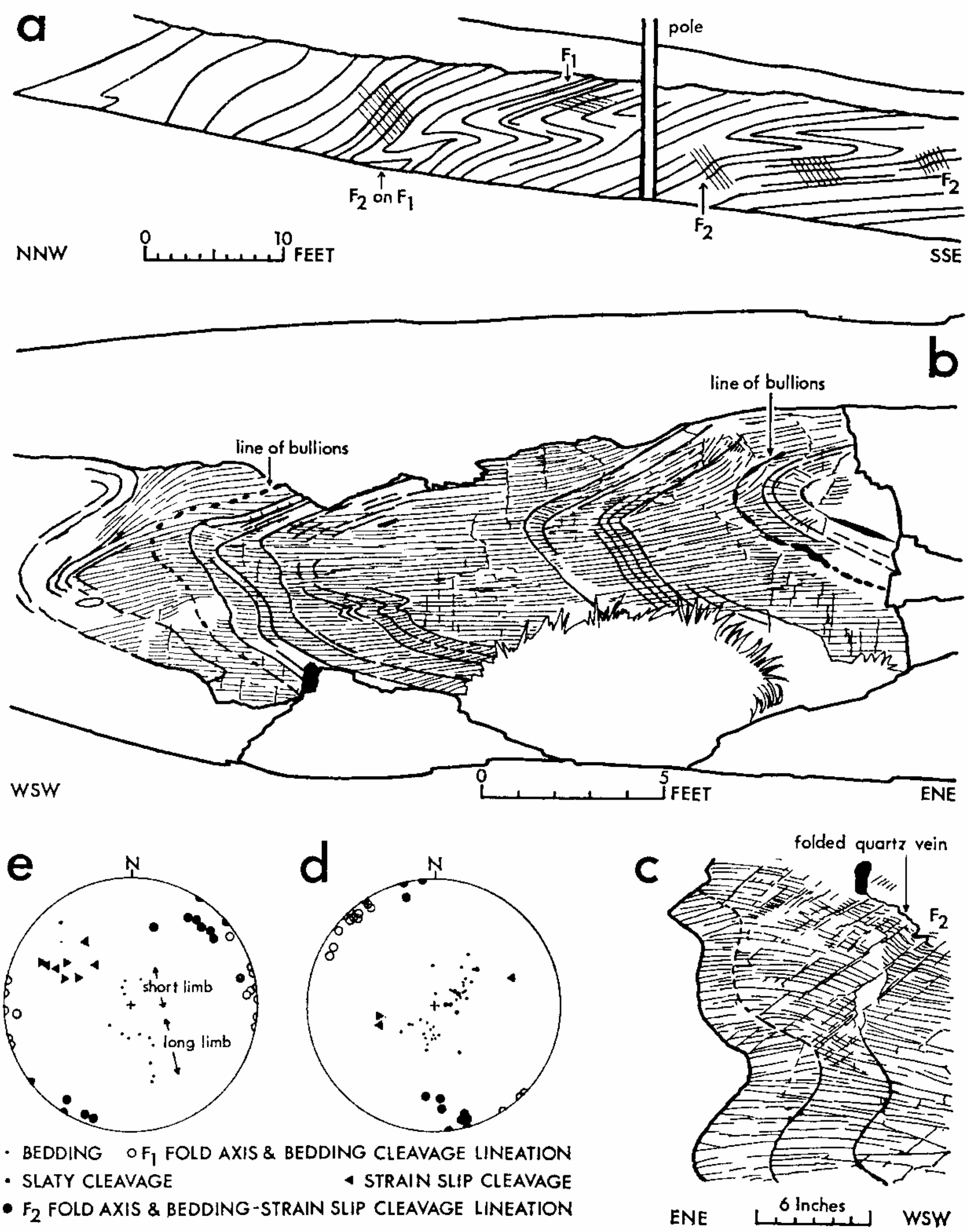

FIGURE 2. Structures in the Trebursye Beds of Launceston. (a) The St. Stephen's Hill section. Recumbent early folds (F_1) with slaty cleavage crossed and deformed by second folds (F_2) with strain slip cleavage. (b) New section in Holsworthy Road with first folds (F_1) and slaty cleavage. (c) New section in Holsworthy Road showing coarse strain-slips cutting and bending (F_2) slaty cleavage in early folds. (d) Stereogram (lower hemisphere) of structures in the Newport exposures. (e) Stereogram of St. Stephen exposures.

N.B. Note that the two-strain slip cleavages in (d) can also be seen in thin-sections of rocks from these exposures.

Structures in the roadside sections at the junction of Roydon Road with Holsworthy Road, A.388, (Fig. lb) are also represented on a stereogram (Fig. 2d). North-westerly trending early recumbent folds face south-east on the evidence of truncated cross-lamination in thin sandstones. Strongly developed slaty cleavage is parallel to the south-westerly dipping long limbs of folds in the Roydon Road cutting, while in the adjacent Holsworthy Road section (Fig. 2b) the south-westerly inclined limbs parallel to cleavage are short. This may be accepted as evidence for recumbent folds on a scale larger than the exposures, with fold limbs possibly over 100 yards long as compared with observed lengths of twenty feet for long limbs and short limbs only one to five feet long.

Shape of fold profiles is variable with the limbs parallel to the slaty cleavage thinner than those cutting across it. In anticlinal hinges there is noticeable fanning of the cleavage away from the axial plane in beds of siltstone and fine sandstone, while there are local convergences and diverg-ences as the cleavage passes between rather than through individual bullions (Fig. 2b).

Second folds with the shape and trend of those seen in the St. Stephen's Hill section have not been found in the other exposures. The Roydon Road cutting is favourably aligned to provide convenient cross-sections of second folds but none are present, whereas the Holsworthy Road section is cut in the axial direction of the second folds. However, there are strain-slip cleavages dipping at moderate angles both to the west and to the east (Fig. 2d). Resultant lineations on bedding and slaty cleavage run slightly west of north and east of south with a gentle plunge except where the strain-slip cleavage cuts across the hinges of early folds. Such a lineation running obliquely round a fold hinge can be examined in the Roydon Road exposure. Here one is clearly not dealing with an early lineation bent by the recumbent fold because on a stereographic plot the poles indicating the intersection of strain-slip cleavage with bedding lie on a great circle representing the strain-slip cleavage plane.

In the Newport exposures, the strain-slip cleavage occurs as a conjugate pair (Fig. 2d) ; both have accommodated normal faulting movements and also produce small scale flexure in all earlier structures such as bedding, slaty cleavage and quartz veins along the cleavage (Fig. 2c).

As is apparent from the stereograms, the axial trend of early recumbent folds ranges about east and west from thirty-five degrees south of west to fifty-five degrees north of west. This is the observed variation for both westerly and easterly fold plunges, but although the angular range is ninety degrees there is no suggestion on the stereograms of a bimodal distribution of fold trends at right angles.

It is considered that the divergence of axial directions of the early folds is an original feature, with trend variation probably enhanced by the flattening associated with the development of slaty cleavage. The open folds and related cleavages are tentatively grouped together as structures of a second phase of deformation unrelated genetically or geometrically to structures of the first fold phase.

The Trebursye Beds of Launceston, in the rather restricted area selected for description, have been subjected to the same sequence of structural events as has already been recorded in coastal sections from Tintagel to Boscastle (Dearman et al., 1964) and farther north (Freshney et. al., 1965), and inland on the River Lyd (Dearman 1964). Also, bedding in isoclinal folds trending N. 60° E. and N. 15° E, on the River Tavy in Tavistock is crossed by a north to south lineation formed by strain-slip cleavages dipping steeply east and west (Dearman and Butcher 1959, p.67, 92).

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118. Remarks on the geology of the St. Mellion area :
by S. C. Matthews.

In this part of east Cornwall there are outcrops of Carboniferous rock which appear isolated among Devonian slates, and for many years it has been suspected that an unconformity exists here. Holl (1868), who first referred to such a possibility, envisaged a break between the Devonian and the Carboniferous. Ussher (1907 and earlier references) modified Holl's view and suggested that while there might be a break of this kind at Tamerton Foliot, nearby in west Devon, the interruption of the St. Mellion sequence falls within the Carboniferous, with "Middle Culm" resting on a highly irregular surface which includes outcrops of "Lower Culm".

In a recent examination of the ground, it has been found useful to distinguish the following elements in the geology :

1. A succession of slates with thin sandstones followed by Lower Carboniferous siliceous rocks, followed by turbidites and slates presumed to be of Carboniferous age. This sequence youngs northward and dips southward at a low angle : it is overturned.
2. A succession of feldspathic sandstones with subordinate shales, which lies unconformably on the overturned sequence.
3. Detached masses of Lower Carboniferous rock, including chert. These klippen are thrust over the feldspathic sandstone sequence and can be regarded as the highest part of the structural succession in this area.

The break in the succession is later than Ussher suspected. In order to recognise the unconformity, it is necessary to make a distinction between the turbidite sequence, with relatively thin sub-greywackes, and the later feldspathic sandstone sequence, whose units are thicker, rarely have sole-structures and do not necessarily have the sharply defined base which a turbidite displays. Some of the feldspathic beds contain mud-flakes and balled up masses of mud, and one especially thick bed has extraneous pebbles, whose dimensions are roughly one centimetre, and which are mainly of siliceous material. The base of this sandstone sequence has not yet been seen.

The overthrust masses of Lower Carboniferous rock assist in explaining the irregular occurrences of chert, high and low on the ground, which had puzzled Ussher. The northern limit of these St. Mellion outcrops of Carboniferous rock is along a fault which runs W.S.W.-E.N.E. through Callington Newbridge (SX 347679). Here the inverted turbidite sequence is brought against an inverted mass of slates and pillow lavas on the north : the major effect is that of reverse-faulting.

On the east, Carboniferous rocks strike toward the almost unrelieved outcrops of slate which occur in the Tamar Valley and in west Devon. Sedimentary structures in sandstones within the slates suggest that in west Devon the succession is normal. These ? Devonian rocks dip and young southward, and the Tamerton Foliot Lower Carboniferous rocks, mentioned above, may well follow in normal succession. The feldspathic sandstone group rests unconformably on the slates near Bere Alston. The inverted succession (with Carboniferous rocks) in east Cornwall appears to have been faulted against the normal succession of slates in west Devon. The fractures responsible are aligned north and south in the Tamar Valley and a major part of their activity may have preceded the deposition of the feldspathic sandstone succession (see also Matthews 1962). Implications of these proposals are :

1. That during the late Carboniferous, there was a sequence of events which included establishment of a large recumbent fold, with axial strike roughly E.-W., faulting of the fold along N.S. fractures to bring the normal and the inverted limb into apposition, deposition of the feldspathic sandstones, then finally emplacement of the detached Lower Carboniferous masses in east Cornwall.
2. That the post-orogenic history of this area has been such as to allow survival of some relatively high elements in the structural succession - the feldspathic sandstone sequence and the klippen.

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119. Facies changes in the Chert Formation (Lower Carboniferous) of North Devon : by J. E. Prentice.

The Chert Formation is a varied suite of rocks in which bedded chert is a major constituent, extending from the Tournaisian (Zones I/II) to the upper Visean (Zone IIIβ_7) outcrop in a series of plunging anticlines and synclines which lie to the north of a major east-west fault (the Brushford Fault) and are transected by a number of northeast-southwest and northwest-southeast wrench faults. The bedded cherts are of two main types : (a) a clastic type, consisting of silt-grade particles embedded in and replaced by chalcedony, and (b) a non-clastic type, consisting of abundant radiolarian tests in a chalcedonic matrix. The first type is found as a monotonous sequence of very regular bedding units, and overlies a uniform basement series of dark gray laminated mudstones. The second type is found interbedded with other rock types, and no basement series is present.

Type (a) chert displays a distinctive streaky lamination of dark and pale gray ; the streaks are laterally discontinuous, and sometimes show crumpling and overturned folds. Low-angle ripple drift bedding is sometimes found, and chert nodules indicate penecontemporaneous erosion. The tops of bedding units show an upwards grading to finer grain size. The fauna consists of the evolute, discoid prolecanites ; small proetid trilobites, isolated crinoid ossicles, rare solitary corals and small bryozoan colonies. Type (b) chert is generally unlaminated except at the top of a bedding unit, where carbonate fragments form distinct laminations, in which fairly strong ripple-drift bedding is developed. Interbedded with these latter cherts are found (i) black limestones, usually very fine grained, but where coarse showing graded bedding ; some cross lamination is also found ; (ii) limestone conglomerates, occupying erosional hollows, with angular fragments of limestone and chert ; (iii) black pyritic mudstones. The fauna of this association consists of globose goniatites, straight nautiloids, crinoid ossicles and small spinose brachiopods, together with fairly abundant *Posidonia.* Within the two associations there are many local variations ; in type (a) the variations are mainly of colour, which may vary from jet-black to pure white ; in type (b) there are changes in proportions of various lithologies, from one which is wholly calcareous mudstone to one in which chert, limestone and mudstone are in equal proportions.

Facies changes take place most frequently along structural lines. Thus type (a) chert traced from south of Barnstaple is abruptly replaced by type (b) association across the Landkey Fault ; type (b) association traced along the northern limb of the Swimbridge syncline passes into type (a) to the south of the axis. Approaching the Brushford Fault a rapid series of facies changes are observed along the strike. It is thus concluded that the same fundamental controls of present day structural trends were in operation at the time of deposition of the Chert Formation.

120. Tidal current fashioning of a basal bed : by R. H. Belderson and A. H. Stride.

The floor of the north eastern part of the Celtic Sea, with its bed transport paths converging from the Bristol and St. George's Channels and tidal currents of up to three knots, has been examined by means of Asdic and echo sounder, grab and corer. A basal shelly conglomerate marking the post-glacial transgression is now being buried except in the high current velocity regions at the heads of the bed transport paths. The bed transport paths may be divided into a series of five zones, each with features characteristic of present erosion, transport or deposition. There are zones of :

(1) erosion, where rock outcrops or boulder clay is subject to scour, which locally produces elongate erosion hollows ;

(2) sand ribbons, where sand is being transported over a coarser deposit :

(3) sand waves, which are expected to be associated with current-bedding ;

(4) a sheet of fine sand and silt completely covering the basal conglomerate ; and

(5) patches of present day sediments somewhat elongate parallel to the currents and only partially covering the basal conglomerate.

121. The stratigraphical distribution of kaolinite in the post Armorican formations of South-West England :
by M. E. Cosgrove and D. L. Salter.

As part of a wider investigation of the clay mineralogy and geochemistry of post-Armorican sediments, samples from Permian and succeeding formations have been collected from south coast localities in order to study the stratigraphical distribution of kaolinite. The samples are being investigated in the laboratory by standard X-ray diffraction procedures. To avoid the well-known difficulties of accurate quantitative analysis of clay mineral mixtures (Brown 1961) a semi-quantitative comparison of samples was effected by use of peak areas of basal reflections of the minerals encountered.

This report is a summary of progress and the results so far obtained are plotted in Figure 1. The presence of mixed-layer minerals (mainly illite-montmorillonite interstratifications) appears to bear some relationship to the degree of weathering of the samples used. For this reason illite, montmorillonite and mixed-layer minerals have been grouped together. The study was restricted to argillites because the clay mineral fractions of arenites are variable since diagenetic processes are probably more active in porous sediments (Weaver 1959, p.173).

The information obtained to date shows that the distribution of kaolinite follows a distinct trend. Kaolinite first appears in the White Lias and is then consistently present in beds of younger age, generally becoming more abundant. Chlorite is a constituent of argillites of all ages up to the Kimmeridgian ; thereafter it appears only in small quantity in some Tertiary clays. Illite is present in all samples.

Exceptions to this general pattern are provided by basal Permian sediments. The Watcombe Clay contains illite, mixed-layer minerals and kaolinite. The Crediton trough sediments, which are mainly arenaceous, contain in their clay fractions similar assemblages. The kaolinite in these rocks is probably derived from the breakdown of felspars originating from two sources - lavas of the Exeter Volcanics and from surface manifestations of the Cornubian Granite. Felspar from the latter source is very prominent in some of the Crediton trough sediments (Hutchins 1963).

Recent research by many workers (Weaver 1958 ; MacKenzie 1965 and others) has suggested that clay mineral assemblages of argillaceous sediments reflect the characters of the source rather than those of the depositional environment. The Cornubian Highlands must have been a prominent contributor to the post-Armorican sediments of the south-west, thus is might be expected that the distribution of kaolinite in these sediments would indicate the exposure of the granite.

Work carried out by Groves (1931) on heavy mineral suites from these rocks indicates that the granite was actively being eroded in Wealden times, but the evidence available suggested a probable earlier date for the unroofing of the main granite mass. Groves' investigations were confined to arenites, whereas a larger proportion of the sediments are argillites. Thus a study of the argillites permits a more thorough sampling of the strata.

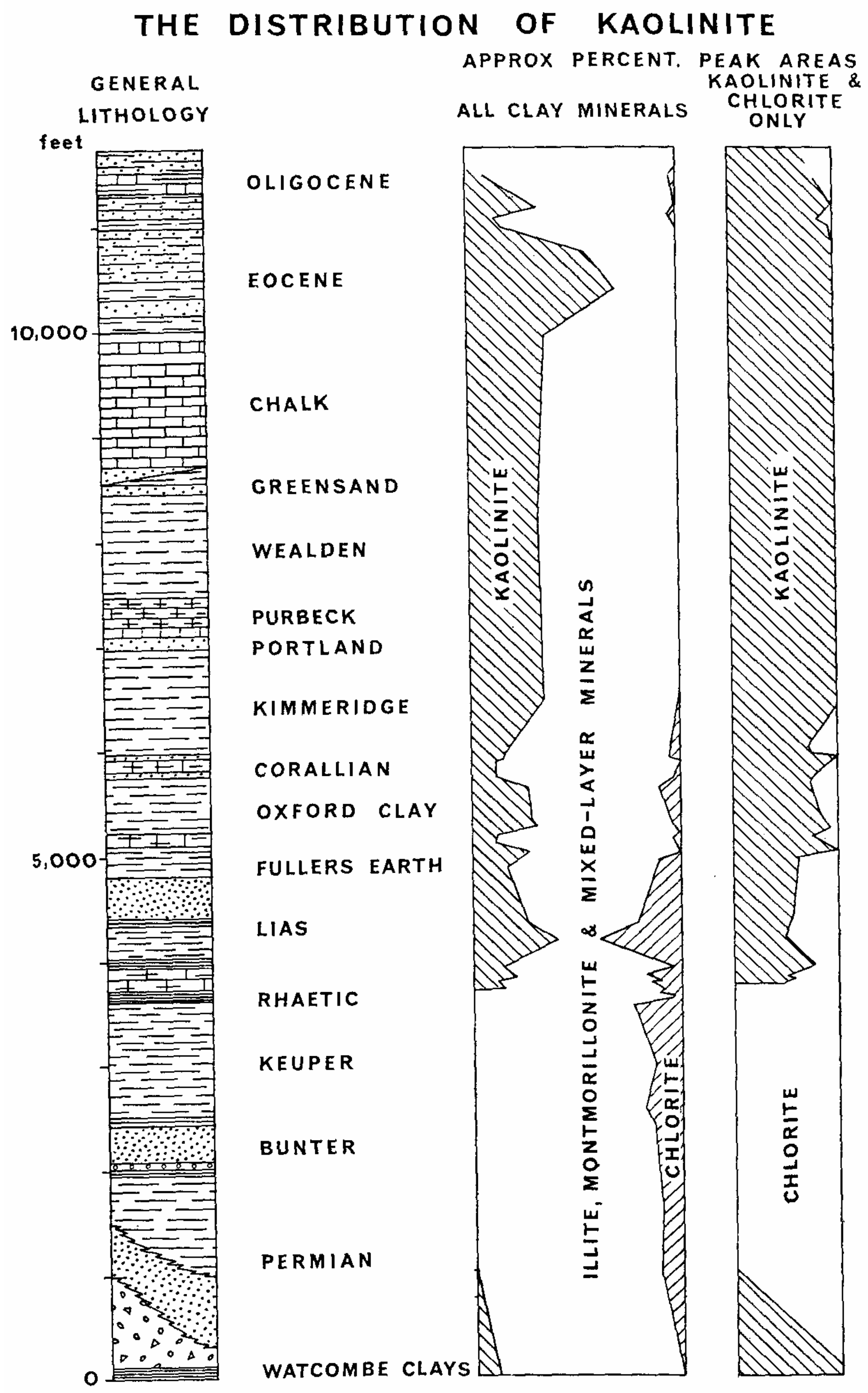
THE DISTRIBUTION OF KAOLINITE
GENERAL LITHOLOGY
feet
10,000
5,000
0
APPROX PERCENT. PEAK AREAS
ALL CLAY MINERALS
KAOLINITE & CHLORITE ONLY
OLIGOCENE
EOCENE
CHALK
GREENSAND
WEALDEN
PURBECK
PORTLAND
KIMMERIDGE
CORALLIAN
OXFORD CLAY
FULLERS EARTH
LIAS
RHAETIC
KEUPER
BUNTER
PERMIAN
WATCOMBE CLAYS
KAOLINITE
ILLITE, MONTMORILLONITE & MIXED-LAYER MINERALS
CHLORITE
KAOLINITE
CHLORITE

FIGURE 1.

One can infer from the first appearance of kaolinite in the White Lias that this would be the earliest date of unroofing of the granite. Consequent upon this, the geographical variation of clay mineralogy of selected argillaceous horizons might be expected to show increases in kaolinite content as the granite is approached.

Acknowledgements. We are obliged to Dr. D. Moore for reading the typescript. D. L. Salter was in receipt of a Science Research Council Fellowship during this investigation.

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122. Greenstone sills and metamorphic zoning in the Land's End aureole at Newlyn, Cornwall : by P. Floyd.

The object of this progress report is to outline the evidence for the existence of two major sills in the Mousehole-Newlyn part of the Land's End aureole and from a study of their mineralogy to demonstrate the presence of metamorphic zones.

1. Structure of the aureole between Mousehole and Newlyn. On the Geological Survey map (sheets 351 and 358) of this portion of coastline, only one sill of “meta-diabase” (“greenstone”) is considered present. The base is seen at Mousehole Harbour and the top at Penlee Point where a note on the map reads “slate overlying massive greenstone and baked at junction”. Recent mapping, however, reveals two major sills in this area and a number of much smaller ones, interbedded with pelitic meta-sediments as follows :

(5)	Pelitic hornfels (no. 3 horizon) …	...	>43'
(4)	Greenstone hornfels (Penlee sill)	…	89'- 112'
(3)	Pelitic hornfels (no. 2 horizon) …	…	276'- 328'
(2)	Greenstone hornfels (Gwavas sill)	…	230'- 276'
(1)	Pelitic hornfels (no. I horizon) …	…	>230'

The variation in vertical thickness indicated is only approximate, although some variability would be expected in an intrusive sheet. The Gwavas sill is the thickest of the two sills and shows a maximum at Gwavas quarry, Newlyn, where recent bore hole data indicates a thickness in excess of 276'. The excessive thickness in the quarry compared with the southern extension of the sill, may indicate that this is the site of the feeder pipe to the sills in the area. Unfortunately, there is no direct evidence for this suggestion.

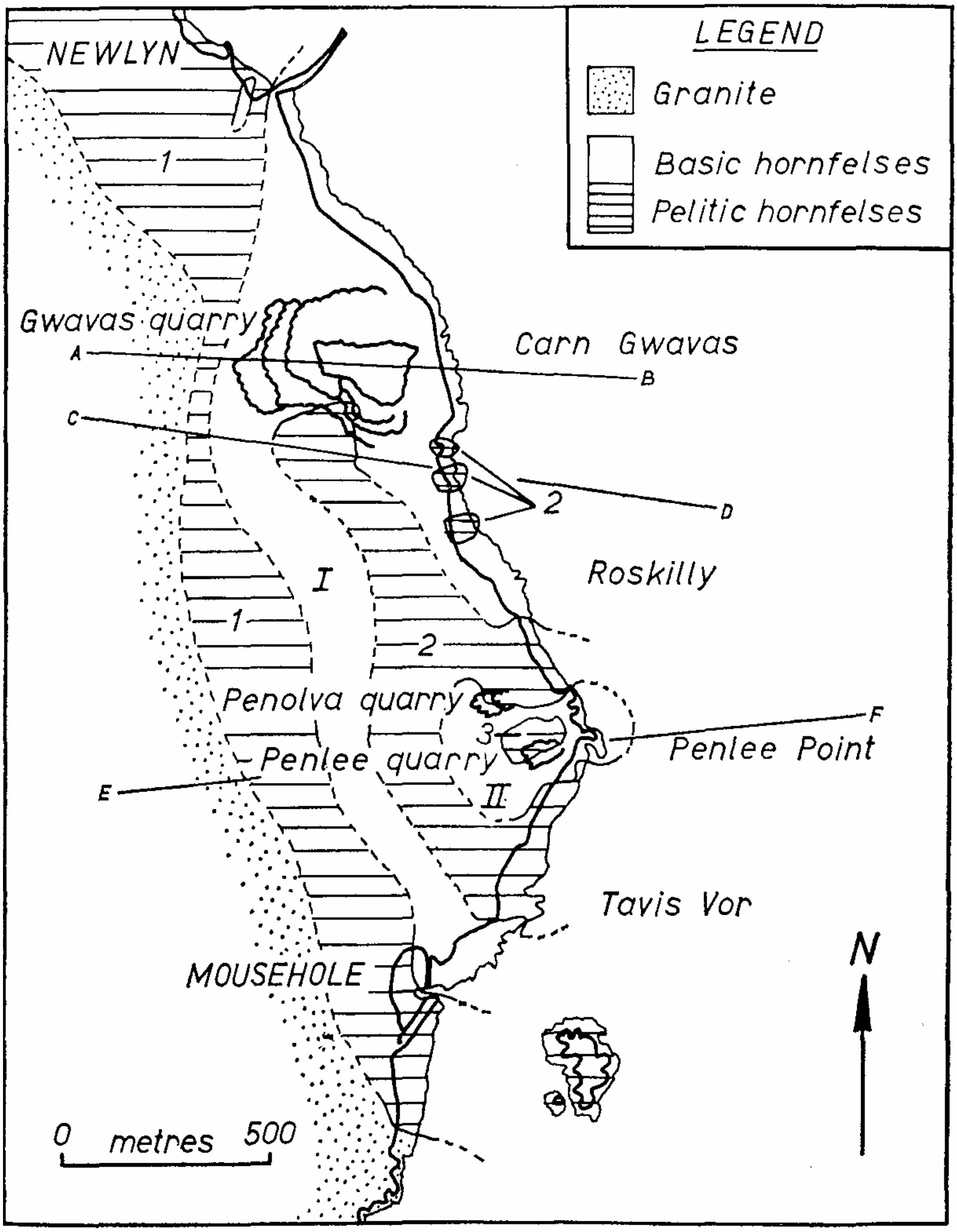

FIGURE 1. Geological map of the Land's End aureole between Mousehole and Newlyn, Cornwall, showing the Gwavas sill (I) and the Penlee sill (II). All rocks have an eastward dip.

As seen from the map (Fig. 1) the lowest pelitic horizon abuts against the granite. The only visible granite---sediment contact is seen near Mousehole harbour, where a spotted and laminated auartz-chlorite sericite hornfels (representing retrogressed cordierite-biotitc hornfels) dips off the granite at a shallow angle to the east. In a number of cases vertical contacts can be observed which probably represent stoping along pre-existing joints in the aureole sediments. Roughly similar distributions are seen between Doles to joint planes in pelitic hornfelses and poles to near vertical contact planes at this junction (Fig. 2). A better "fit" is obtained, however, by rotating Fig. 2 (b) about 15° to the west of north.

The meta-igneous rocks of the Gwavas sill are exposed at Mousehole harbour, south of Tavis Vor and also at Gwavas quarry and the Roskilly-Carn Gwavas foreshore. The junction between the south portion of the Gwavas sill and the no. 1 pelitic horizon lies hidden under the silt of the Mousehole harbour ; elsewhere it is covered by " Head " deposits. If the sill is relatively concordant and the dip of the sediments is taken into consideration, then the sill appears to lie on top of the pelitic horizon. The junction between the Gwavas sill and the next pelitic horizon (no. 2) is seen at Tavis Vor and represents the top of the sill. The brown biotitic pelites seen here rest on the dark green metadolerites and are separated from them by a hard porcellaneous adinole of variable thickness. From Tavis Vor, pelitic horizon no. 2 extends along the foreshore to just south of Penlee Point. These sediments are essentially biotite-rich laminated hornfelses and exhibit no obvious cordierite porphyroblasts or spotting, except at the Tavis Vor contact. The dominant foliation is considered to represent an original bedding feature. Any cleavage imprinted prior to intrusion of the Land's End granite is now largely obscured by the growth of micaceous minerals

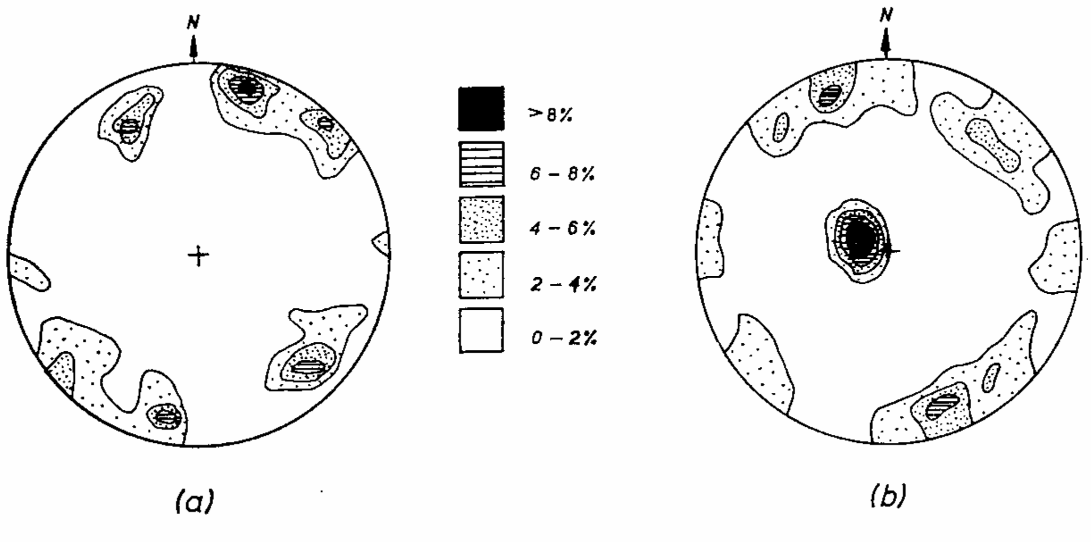

FIGURE 2. Stereographic plot of poles to planes for (a) joint planes in pelitic hornfelses and (b) pelitic hornfelses/granite contacts at Mousehole harbour.

during the retrogressive phase of contact metamorphism. Scattered throughout this horizon are a few thin (6' maximum) actinolite-bearing meta-igneous sills with the occasional attendant adinole.

Penlee Point shows a number of interesting contacts between the top "greenstone" sill (Penlee sill) and the pelitic horizons, nos. 2 and 3. This sill occupies the whole of the Point and also the high ground to landward. To the south of the Point, green meta-igneous hornfelses rest clearly on no. 2 pelitic horizon, while to the north a similar junction is seen. The gently seaward sloping plane of the contact continues up the cliffs and is visible in Penolva quarry (Fig. 1). It was probably due to the discovery of the sedi ments below the "greenstone" that this quarry was discontinued. In Penlee Quarry the top of the Penlee sill is overlain by pelitic hornfels horizon no. 3. An excellent pale-blue adinole is developed at the contact. Due to the rapidly increasing thickness of the sedimentary "overburden" as the quarry was worked landward it was soon discontinued. The Penlee sill, unlike the Gwavas sill, shows a gradation of grain size from a coarse "gabbroic" centre to thick, medium-grained margins and a thin, chilled, contact zone. The Gwavas sill, on the other hand, is relatively homogeneous throughout the maximum thickness exposed at Gwavas quarry. The rest of the foreshore to the north of Penlee Point (Roskilly to Newlyn) is composed of the Gwavas sill, although at least three small isolated erosion relicts of pelitic horizon no. 2 are observed resting on the "greenstone".

2. **Metamorphic zones.** Throughout this portion of the aureole, the sediments are essentially biotite-cordierite hornfelses and quartz-biotite hornfelses or their retrogressed products. Thus it is the basic hornfelses (the metamorphosed equivalents of the "greenstone" sills) that must be turned to for any indication of the progressive nature of thermal metamorphism in the aureole. The "greenstone-hornfelses" were originally ophitic dolerites composed of plagioclase, titan-augite and ilmenite. In a number of isolated exposures these rocks have undergone only mild thermal metamorphism as illustrated by partial uralization of the pyroxene and the presence of titan-augite relicts. They are still recognizably of doleritic parentage, although the original ophitic texture has been partially destroyed, Such sub-ophitic meta-dolerites are also seen at St. Ives Island in the north of the aureole. In the Mousehole-Newlyn portion, metadolerites are found at Mousehole harbour and also in the coarse centre of the Penlee sill at Life Boat House Cove, near Penlee Point. Such isolated pockets or relicts are enveloped by a plagioclaseactinolite hornfels "matrix" The amphibole-bearing hornfelses show the development of pale-green ragged matts of actinolite fibres which have totally replaced all the original pyroxene during metamorphism. The plagioclase is still albitic, shows little recrystallization and has retained its original igneous lath-form. The majority of the Penlee sill is composed of this hornfelsic type which belongs to the albite-epidote hornfels facies of contact metamorphism. Also at Penlee Point is the anomalous development of a cordierite-cummingtonite hornfels adjacent to a small raft of sediment caught up in the body of the igneous rock. Such an assemblage usually belongs to the hornblende hornfels facies of contact metamorphism, although instances have been recorded of cummingtonite occurring in the lower, greenschist facies. This development may represent a very local "hot

spot" generated by excess heat being trapped under the pelitic raft. The transition from the albite-epidote hornfels facies to the hornblende hornfels facies is marked by the simultaneous appearance of Ca-bearing plagioclase (andesine) and hornblende in place of albite and actinolite ± epidote. At Newlyn, however, although hornblende is now the dominant mafic of the Gwavas quarry hornfelses in place of actinolite, the plagioclase has remained albitic. Thus the rocks of the Gwavas sill in this area must represent a wide transition zone between the albiteepidote hornfels facies and the hornblende hornfels facies. Thus depending on the presence of the plagioclase-actinolite assemblage, with or without augite relicts and the plagioclase-hornblende assemblage, two tentative zones can be illustrated here. All the zones are essentially of very low grade and only in other parts of the aureole (e.g. Tater-du and Botallack) is the higher hornblende hornfels facies well developed.

The thermal metamorpsism of the Land's End aureole is typical of a high-level potassic granite, as illustrated by the wide zone of low temperature albite-epidote hornfels facies and narrow hornblende hornfels zone adjacent to the granite. Only in some xenoliths is the pyroxene hornfels facies attained.

123. Secondary tourmaline from the granitic rocks of S.W. England : by G. M. Power.

Two generations of tourmaline have long been recognised by petrologists in the granitic rocks of S.W. England, one being a widely distributed magmatic mineral often yellow in thin-section and the other a blue-green acicular mineral attributed to the action of post-magmatic hydrothermal fluids.

During the course of spectrographic analysis of fifty tourmaline samples from different localities in S.W. England a number of samples of undoubted secondary tourmaline have been analysed from such sources as luxullianite and quartz-tourmaline veins in china clay. In order to study the frequency distribution of the concentration of an element in the samples use was made of cumulative frequency plots on probability paper using the methods described by Tennant and White (1959). The frequency distribution plot for fluorine showed that there were two distinct populations of samples with log normal distributions. One contained the majority of samples whilst the other, lower in fluorine content, contained only the secondary tourmaline samples. Fluorine substitutes for the hydroxyl group in the crystal lattice of tourmaline and probably the competition from hydroxyl groups for acceptance into the lattice was greater in the hydrothermal fluid than under magmatic conditions.

Frequency distribution plots for iron, magnesium, manganese and calcium also yielded log normal distributions with the secondary tourmalines lower in iron and manganese and higher in magnesium and calcium than the general populations. The secondary tourmalines could be distinguished as separate populations on strontium and tin content, both being higher than the general level. Although distinct populations were not observed for V, Cr, Ni, Sc, Co, Zr and Ga there was a tendency for higher than average values to be obtained for secondary tourmalines for V, Cr, Ni and Sc. Hydrothermal tourmaline is therefore quite clearly distinguishable chemically from magmatic tourmaline. X-ray powder photographs and differential thermal analysis have however failed to detect any difference in the structures of these two types of tourmaline.

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126. Sedimentation on Instow beach, N. Devon : by J. M. Thomas.

The beach at Instow lies on the east bank of the river Torridge, a short distance before this north-flowing river joins the west-flowing river Taw to form their joint mouth into Bideford Bay. A brief survey of the beach has shown some features of interest in the study of the complete estuary complex. Seven profiles on the southern part of the beach have been accurately surveyed by staff of Bideford Borough Surveyor's office at regular intervals since 1959. These profiles show remarkable constancy, and suggest that the beach shape is stable. The only appreciable changes in shape during the survey were at the extreme southern tip, where a minor tidal channel appears to have gradually encroached on to the beach and been partially filled. Mechanical analyses showed the sand to be finegrained very well sorted sand, with a Trask sorting coefficient of 1.2 to 1.4, and never containing more than 14 per cent combined silt and clay.

The beach profile near high spring tide level is concave, being built-up against the sea wall, but there is a broad relatively flat middle zone between the high tide line and the steeper slopes of the low-water river channel. The steeper slopes of the margin of the main river channel are exposed at low spring tides, and show welldeveloped mega-ripples of sand, with heights of over one foot and wave lengths of more than five feet. These mega-ripples are asymmetrical, with a steep stoss side to the south and a more gently sloping lee side to the north bearing irregular current ripples. These asymmetrical structures suggest that a strong current flows southwards, i.e., up-river, on this eastern bank of the river Torridge, presumably during flood tides. The shapes of asymmetrical current ripples over the middle part of Instow beach also suggest up-river currents operate here.

At the extreme southern tip of the beach at low spring tide, south of the minor tidal channel, some mega-ripples were observed with steep stoss sides facing north. These suggest a strong down-river current, which does not seem to affect the main part of Instow beach. Symmetrical wave-formed ripples occurred only near high tide mark. A thin film of mud occurs in ripple troughs on parts of the beach almost to high tide level, suggesting that a moderately static water mass covers the beach near high tide, allowing clay settlement to take place. This thin film of clay is undisturbed in most places, and as the sedimentary structures apparently formed during flood tide are exposed unaltered at low tide, it appears that there is little current action over Instow beach during ebb tides, except for simple local drainage with falling water level. This contrasts with the flood tide current pattern, where strong up-river currents appear to be operative on this eastern bank of the Torridge.

The main tidal current entering the estuary during flood tide appears to be strong near the north bank of the joint estuary, west of Crow Point. One major tidal current seems to swing clockwise from here and flow southward towards Instow beach, flowing up-stream close to the eastern bank almost as far as the southern tip of Instow beach, before swinging clockwise again out towards the centre of the main river channel. During the ebb tide the major currents appear to keep to the west side of the river Torridge opposite the area of Instow beach.

127. D.PhiL and B.Sc. theses submitted at Oxford since 1950 on the geology of Devon and Cornwall : by M. R. House.

Inadvertently Professor Simpson was not supplied last year (p.199) with a list of theses at Oxford University. These are given here. It should perhaps be noted that the D.Phil. and B.Sc. degrees at Oxford are equivalent to the Ph.D. and M.Sc. degrees of other universities.

BOWLER, C. M. L. 1959. The distribution of the five alkali elements and fluorine in some granites and associated aureoles from the South-West of England. **D.Phil.**

DODSON, M. H. 1963. Isotopic ages from Southwest England. **D.Phil.**

EMBREY, P. G. 1951. The distribution of the elements in the New Consols Tin Mine, Cornwall ; and related problems. **B.Sc.**

EXLEY, C. S. 1955. A study of the process of alteration in the St. Austell granite. **D.Phil.**

GASKIN, A. R. J. 1953. Aspects of the mineralisation of the Pendeen district of Cornwall. **B.Sc.**

LOVELL, J. P. B. 1964. Stratigraphical, structural and sedimentological aspects of the Bude Sandstones from Bude to Widemouth, North Cornwall. **B.Sc.**

MONEY, N. J. 1966. Sedimentary petrography of sandstones in the Upper Carboniferous of North Devon. **B.Sc.**

MOORBATH, S. 1959. Isotopic composition of lead from British mineral occurrences and its geological significance. **D.Phil.**

SCRUTTON, C. T. 1965. Growth and variation studies in Devonian corals. **D.Phil.**

WALKER, R. G. 1964. Some aspects of the sedimentology of the Shale Grit and Grindslow Shales (Namurian R_1c, Derbyshire) and the Westward Ho ! and Northam Formations (Westphalian, North Devon). **D.Phil.**

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