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THE OLIGOCENE AND MIOCENE OUTLIERS OF WEST CORNWALL AND THEIR BEARING ON THE GEOMORPHOLOGICAL EVOLUTION OF OLDLAND BRITAIN

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[Plates 1 and 2]

CONTENTS

The Tertiary sediments preserved at St Agnes, Crousa Downs and Polcrebo Downs, Cornwall, are described in detail. The deposits at St Agnes have yielded two contrasting floras, one mid-Oligocene, the other Miocene in age. The latter appears to be the first recorded proven Miocene extant in the British landscape. Accordingly, it has become necessary to distinguish two discrete outliers at St Agnes: that termed the St Agnes Formation *sensu stricto* (Miocene) and the Beacon Cottage Farm Formation (Oligocene, the local equivalent of the Bovey Formation). A tripartite stratigraphy is proposed for the former, the upper and lower Members comprising wind-blown sands and the middle Member a colluvial slope-wash deposit; all were apparently formed under warm-temperate conditions.

The sediments at Crousa and Polcrebo remain undated; both preserve deep weathering profiles of tropical or subtropical type in the Palaeozoic floor below and are themselves much affected by *in situ* deep weathering.

Structurally, all four outliers appear to be simple erosional relics of once more widespread and, possibly, thicker sheets. No secondary structures have been identified. All four apparently survived as a result of their locations on prominent watersheds originating in at least mid- or even early Tertiary times.

The geomorphological relations of the four outliers are considered in detail. The sub-St Agnes Surface is shown to be the homologue of a planation surface that is widely developed in west Cornwall at an elevation of between *ca.* 75–131 m above sea level (ASL). The latter is redefined and termed the Reskajeage Surface. Its age is shown to be pre-Upper Miocene rather than Pleistocene, as was previously widely held. There is indirect evidence that it formed subaerially over a long period during mid-Tertiary times; essentially, it appears to be an etchplain of tropical and subtropical origins, now largely stripped of its former saprolitic cover. It is demonstrated that the grosser physiography of west Cornwall was established by the end of the Palaeogene at the latest and, also, that the area has probably never been inundated by Tertiary seas, except shallowly near to the end of that period (i.e. by the St Erth transgression).

The prolonged morphodynamic stability of the region, as established in this paper, has important consequences for the interpretation of landscape evolution elsewhere in areas of Oldland (i.e. post-Armorican) western Europe, especially where datable Tertiary deposits have yet to be recognized.

1. Introduction

(a) Objectives

Tertiary outliers occur as patches of unconsolidated sediments at a number of locations in southwest England; no doubt some owe their preservation to their location beyond the maximum limits of the Pleistocene ice sheets. Some of the West Country outliers, like the St Erth Beds and the sediments in the Bovey and Petrockstow Basins, have been the subject of detailed investigation concerning their stratigraphy and age in recent years (see, for example, Mitchell 1965; Mitchell *et al.* 1973; Freshney *et al.* 1982) but those cropping out at St Agnes, Polcrebo and Crousa Common have not previously been so rigorously investigated. Their age and depositional histories, however, are of interest not only in elucidating Tertiary stratigraphy but also as a result of their association with erosion surfaces in the area (see, for example, Balchin 1964; Brunsden *et al.* 1964; Everard 1977). This association clearly has important implications for the understanding of the geomorphological evolution of the 'Oldland' areas of western Britain (figure 1).

This paper reports the results of investigations into the West Cornish 'Tertiary Outliers' at St Agnes, Polcrebo and Crousa Common, mainly carried out by staff and students of The City University and Camborne School of Mines. Some of the preliminary findings were published by Atkinson *et al.* (1975) and Atkinson (1980) but new data, including the discovery of a Miocene flora at St Agnes, make necessary the present report on the extent, stratigraphy, age and sedimentary characteristics of these somewhat enigmatic deposits.

(b) Previous work

The dearth of detailed analytical data on the West Cornish 'Tertiary Outliers' has not prevented earlier workers from speculating about their ages and depositional histories.

Pryce (1778) was apparently the first to refer to the St Agnes Beds, followed in later reports by Boase (1832), Hawkins (1832) and Davies & Kitto (1878). De La Beche (1839) first classified the deposits as Tertiary, and Reid (1890) assigned them to 'Older Pliocene' times. Interest continued into this century with a summary of findings in Reid & Scrivenor (1906), and petrographical analysis and some particle-size data reported by Milner (1922) and Boswell (1923). Mitchell (1965) made brief reference to pollen extracted from a lignite sample originally collected by Dewey in 1932 (BGS sample MR10401) reportedly from the base of the St Agnes deposits at Beacon Cottage Farm (SW705501) that indicated an Oligocene age. Later, further examination of Dewey's sample led Atkinson *et al.* (1975) to report a Middle–Upper Oligocene

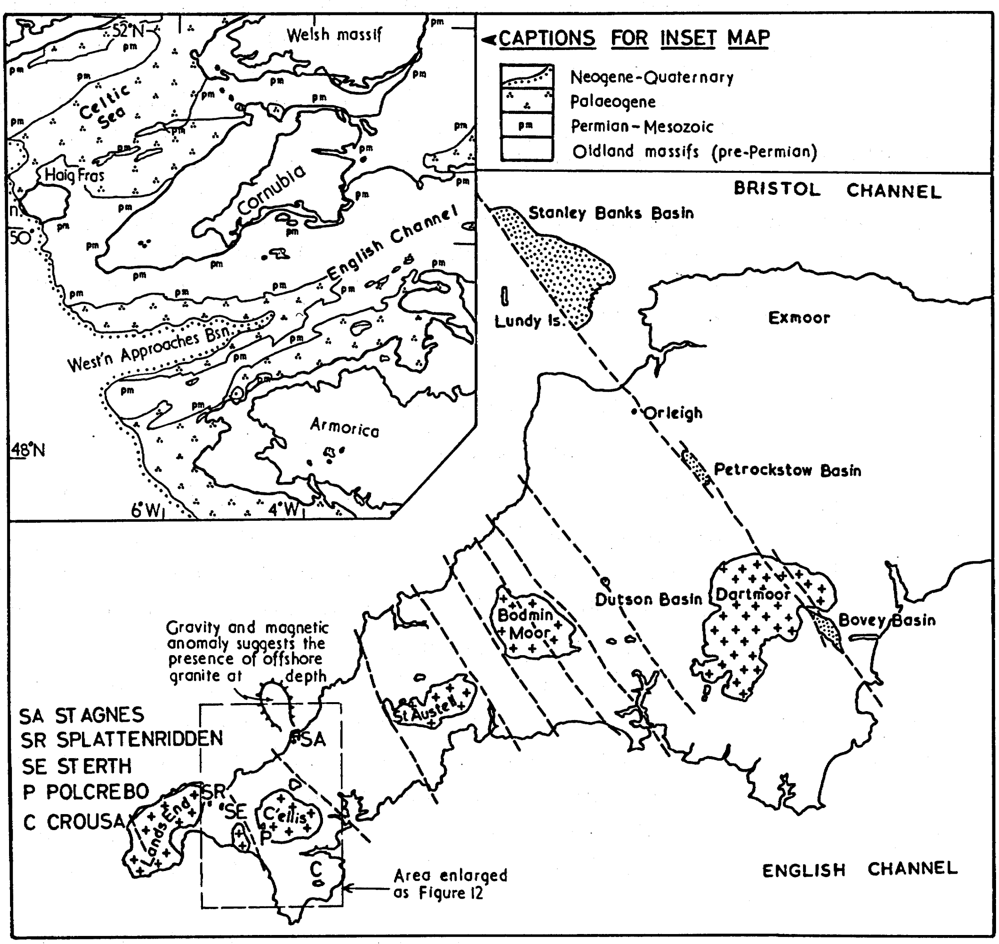

FIGURE 1. Maps showing location of the research area, location of Tertiary deposits in the west of England, Armorican Granite intrusions and some major transcurrent fault lines, and geology of the shelf areas around Cornubia. (Partly after BGS sources, Freshney *et al.* (1982), Dearman (1964) and others.)

age for the pollen. Wilson (1975) thought that the St Agnes Beds had undergone extensive marine erosion in the late Pliocene.

Explanations of the depositional history of the St Agnes Beds have ranged from marine to fluviatile and aeolian. An apparently 'shingle-worn' cliff face some 4.8 m high, formerly exposed in 1875 in mine workings east of the Beacon, a postulated sea stack and caves and hollows, led Reid & Scrivenor (1906) to favour a marine origin. Milner (1922) concurred with this view and considered the sand grains to show signs of marine abrasion. Boswell (1923) also considered a marine explanation as a possibility but in addition suggested a dune origin as an alternative hypothesis. In contrast, Hawkins (1832) and, more recently, Atkinson *et al.* (1975) favoured a fluviatile origin.

The deposits at Crousa Common have been subject to similarly diverse opinions as to their origin. There have been broadly two main schools of thought: one favouring a freshwater, the other a marine, depositional history. Hendricks (1923) belonged to the former school, regarding them as fluviatile, a view supported by Guilcher (1949). On the other hand, Flett & Hill (1912) regarded them as representative of a submarine gravel bank; Gullick (1936) and Everard (1977) concluded that they were a shoreline beach gravel. Milner (1922) considered that contortions in the upper beds were indicative of marine currents but Guilcher (1949) attributed these to periglacial action. In view of a lack of datable material associated with them, the Crousa Common deposits have generally been equated with other dated 'Tertiary outliers' in Cornwall and west Devon.

The deposits at Polcrebo, like those at Crousa Common, were investigated petrographically by Milner (1922), who noted little similarity in their heavy mineral assemblage when compared with the sediments at St Agnes, Crousa Common and St Erth. Later Gullick (1936) favoured a marine origin as did Everard (1977) although the latter acknowledged the possibility of a partial formation by fluviatile processes, which had been earlier advocated by Guilcher (1949). Like the Crousa Common deposits, those at Polcrebo are unfossiliferous, and various dates have been assigned to them. The sedimentary characteristics alone have led most authors to equate them with other 'Tertiary outliers' of the southwest Peninsula. Everard (1977) tentatively suggested an early Coralline Crag age.

(c) *Methods*

In addition to surveying abandoned and currently worked exposures, seismic and resistivity profiling, excavation of pits by mechanical digger and powered augering were undertaken where possible in an attempt to determine the extent and stratigraphical relations of the deposits. Identification of pollen and spores from lignitic clays retrieved from St Agnes was carried out by conventional methods (Wilkinson & Boulter 1980) and a variety of sedimentological techniques applied to the deposits. These techniques included particle-size analysis, X-ray diffraction of the clays and analysis of the surface textures of sand grains. The surface textures of 30 quartz grains from each of 10 samples of the 0.125–2 mm sand fraction were examined by using a Jeol JSM-35C scanning electron microscope (SEM) following standard pretreatment procedures (Krinsley & Doornkamp 1973). The presence or absence of 32 surface textures and characteristics was noted for each sand grain.

2. The St Agnes Outlier

(a) *General*

It has become necessary to regard the St Agnes deposits *sensu lato* (*s.l.*) as being composed of two distinct outliers: these are termed the St Agnes Outlier and the Beacon Cottage Farm Outlier. The St Agnes Outlier is the only one of the deposits to have been more or less continuously exposed in recent years; as it is better understood than the others, it is considered first.

The St Agnes deposits *sensu stricto* (*s.s.*) form a spread of mainly sands and clays on the east and north slopes of St Agnes Beacon (figure 2). The outcrop covers 1.6 km^2 and the residual volume of the deposits approximates 5×10^6 m^3 (figure 3). What is preserved seems to represent merely a small relic of a far more extensive and possibly much thicker sheet of sediment. The maximum residual thickness is about 10 m.

The only actively worked sections available at present are those of the New Downs Sandpits (SW706509) (also referred to as Doble's Sandpits). Examination of the discontinuous exposure here, supplemented by the evidence from auger holes made in adjacent fields, reveals a clear tripartite stratigraphy with two sandy divisions sandwiching clay. In modern terminology, the sediments should now be termed a formation (Atkinson *et al.* 1975); thus the three levels distinguished in the New Downs Pits have the status of members (table 1).

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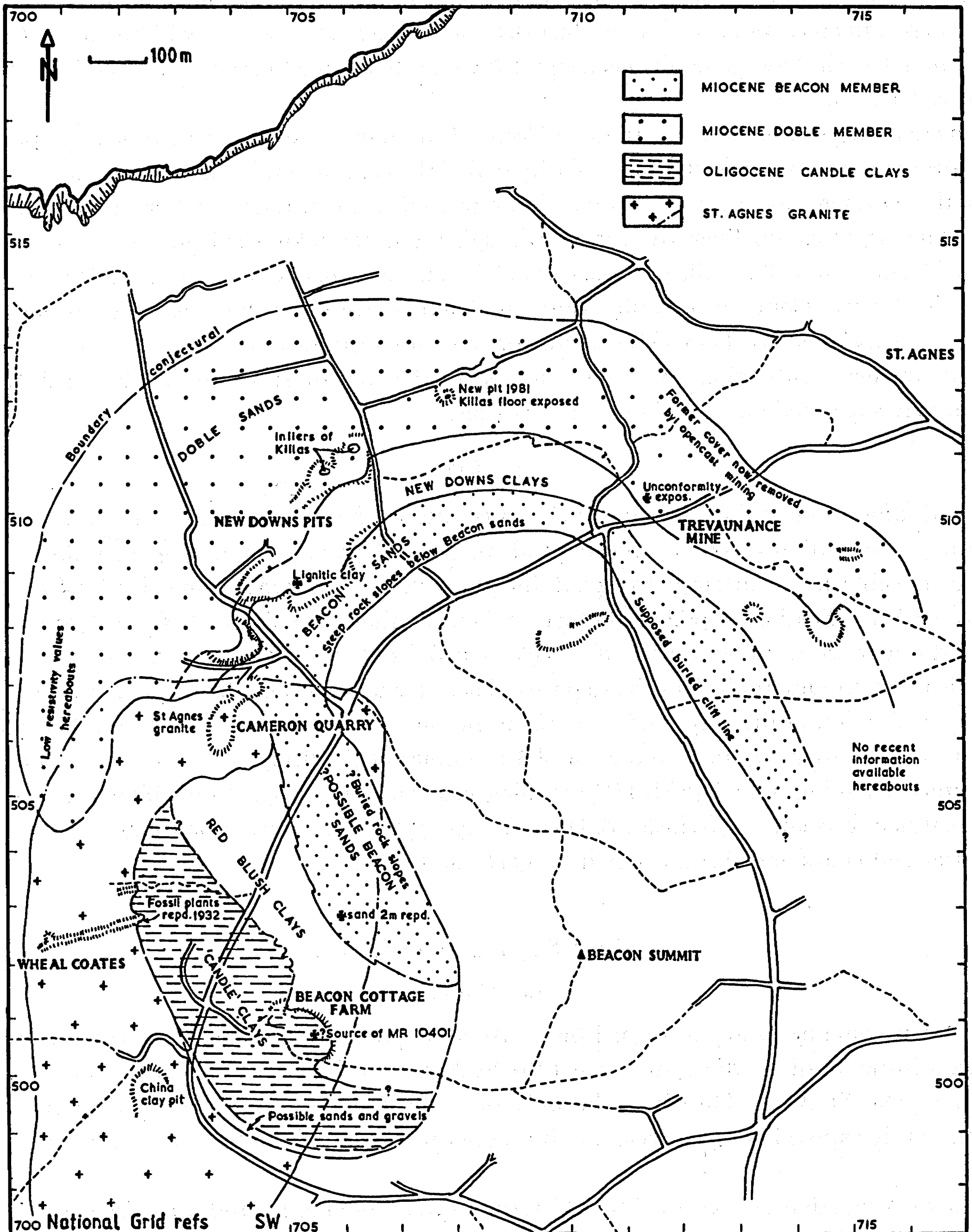

FIGURE 2. Geology of the St Agnes and Beacon Cottage Farm Outliers. The interpretation of the area between Cameron Quarry and the Beacon is problematical. Resistivity surveys indicate the presence of a thin cover of Tertiary sediments but thick overlying Head precluded augering.

(b) *The sub-St Agnes Formation Floor*

The St Agnes Formation is underlain by either Devonian slates ('killas') or the St Agnes granite (figures 2 and 8). In recent years the Palaeozoic floor has been exposed only in the lower levels of New Downs Pits and in the openworks of Trevaunance Mine (SW7121 5128). In the former, this floor appears to be sub-horizontal over an area of about 1000 m^2. To the

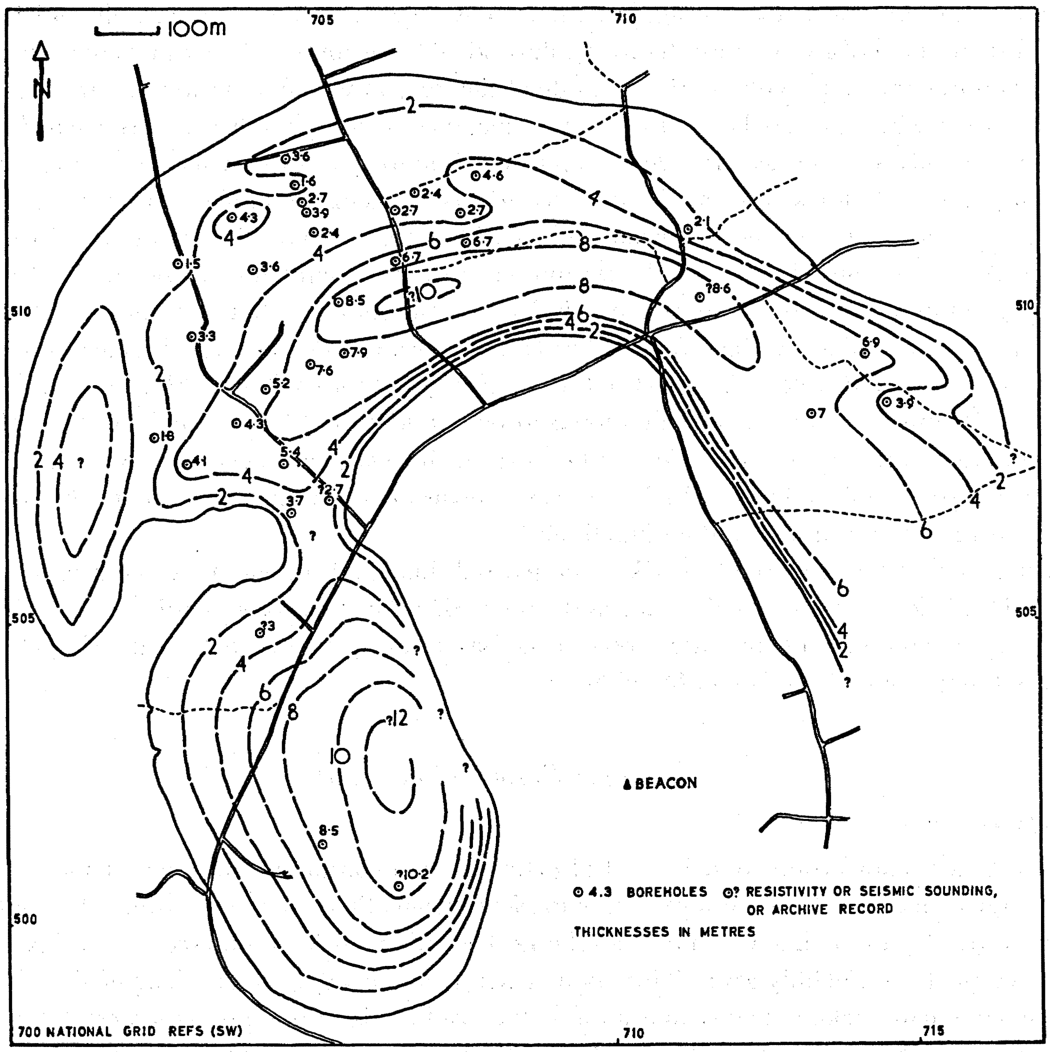

FIGURE 3. Isopachs of the combined Tertiary and Quaternary sediments that form the St Agnes and Beacon Cottage Farm Outliers. Depth-to-bedrock figures may be regarded as minimal, as the bedrock surface was seldom proved. Isopachs for the Beacon Cottage Farm Outlier are largely conjectural.

TABLE 1. PROPOSED STRATIGRAPHY FOR THE ST AGNES FORMATION (*s.s.*)

Upper Sands	Beacon Member	St Agnes Formation *sensu stricto*
Type Section	exposure in upper levels of New Downs Pits (SW7058 5107)	
Middle Clays	New Downs Member Borehole ND76/6 (SW7055 5103) (sediments contain a Miocene micro-flora)	
Lower Sands	Doble Member lower end of New Downs Pits (SW7056 5113)	

south, however, at the base of the slopes of the Beacon, augering has revealed that the successive layers of the formation wedge out against what is envisaged as a stepped rock wall, which has an overall gradient of 45° or more (figure 4). Beyond 200 m from New Downs Pits the evidence becomes unreliable, especially on the east side of the Beacon where no powered augering was possible. Even where powered augering was possible, the sub-St Agnes surface was reached with certainty on only a few occasions: elsewhere, penetration to bedrock may have been prevented by iron pan or cobbles within the Tertiary sediments. It seems probable that, in most cases, failure to penetrate deeper resulted from contact with the killas, but this cannot be confirmed.

The 4.8 m high 'buried sea cliff' (Davies and Kitto 1878) flanking the east side of the Beacon is of special interest. Its trend, approximately NNW–SSE, matches that of numerous 'Alpine' faults in the SW Peninsula (Shearman 1967; Dearman 1964). Further, the Tertiary Basins of Bovey (Edwards 1976), Petrockstow (Freshney *et al.* 1979), Stanley Banks (Fletcher 1975) and Dutson (Freshney *et al.* 1982) are all known to be bounded by 'Alpine' faults of this trend. Unfortunately, there is no fresh evidence bearing on this issue; however, in view of the clear evidence of rock cliffs and pinnacles in the New Downs area, the 'buried sea cliff' east of the Beacon is regarded as a non-faulted junction.

In the New Downs Pits the bedrock is stained red, lilac and orange, to a depth of at least 1 m with little loss of physical coherency in the rock. Since large clasts of identical stained killas occur occasionally in conglomerate layers in the basal sands, the bedrock weathering clearly preceded deposition of the Doble Member.

(*c*) *The St Agnes Formation* (*sensu stricto*)

(i) *The basal pan*

Reid & Scrivenor (1906) noted a bed of pebbles, often containing tinstone, at the base of the St Agnes deposits. No such layer exists in New Downs Pits, however; rather, the contact between St Agnes sediments and underlying Devonian rock is marked by a layer of iron-cemented, non-pebbly sand. This 'pan' extends for *ca.* 50 m in the floor of the pits; it averages 0.5 m in thickness and is ubiquitous in the east but discontinuous in the west. Its colour varies from black, through dark blue and brown to yellow. The iron content sometimes exceeds 10% by mass. Certain sections of pan contain isolated angular pieces of stained killas up to 100 mm long. Concentrations of tubular structures up to 2 m long and 0.3 m wide occur in the pan and contain unconsolidated yellow sand (Atkinson *et al.* 1974). The majority of the tubes are subhorizontal and trend 35–215°.

(ii) *The Doble Member*

In New Downs Pits, the Doble Member is 5–6 m thick. The dominant lithology is a yellow or buff, fine-grained silty sand (5 YR 6/10 is a typical colour). The upper levels become pale yellow and the junction with the overlying clays of the New Downs Member is gradational.

Unfortunately, the sections are not currently being worked and are deteriorating rapidly. Epsilon-type planar cross bedding is ubiquitous, although individual units vary much in size, reaching about 1 m in thickness, but being mostly smaller. Palaeocurrent indicators in the New Downs Pit sections suggest that the sediment source of the Doble sands lay to the northwest; however, the foreset bedding in the sands of the New Pit indicates palaeocurrent flow from

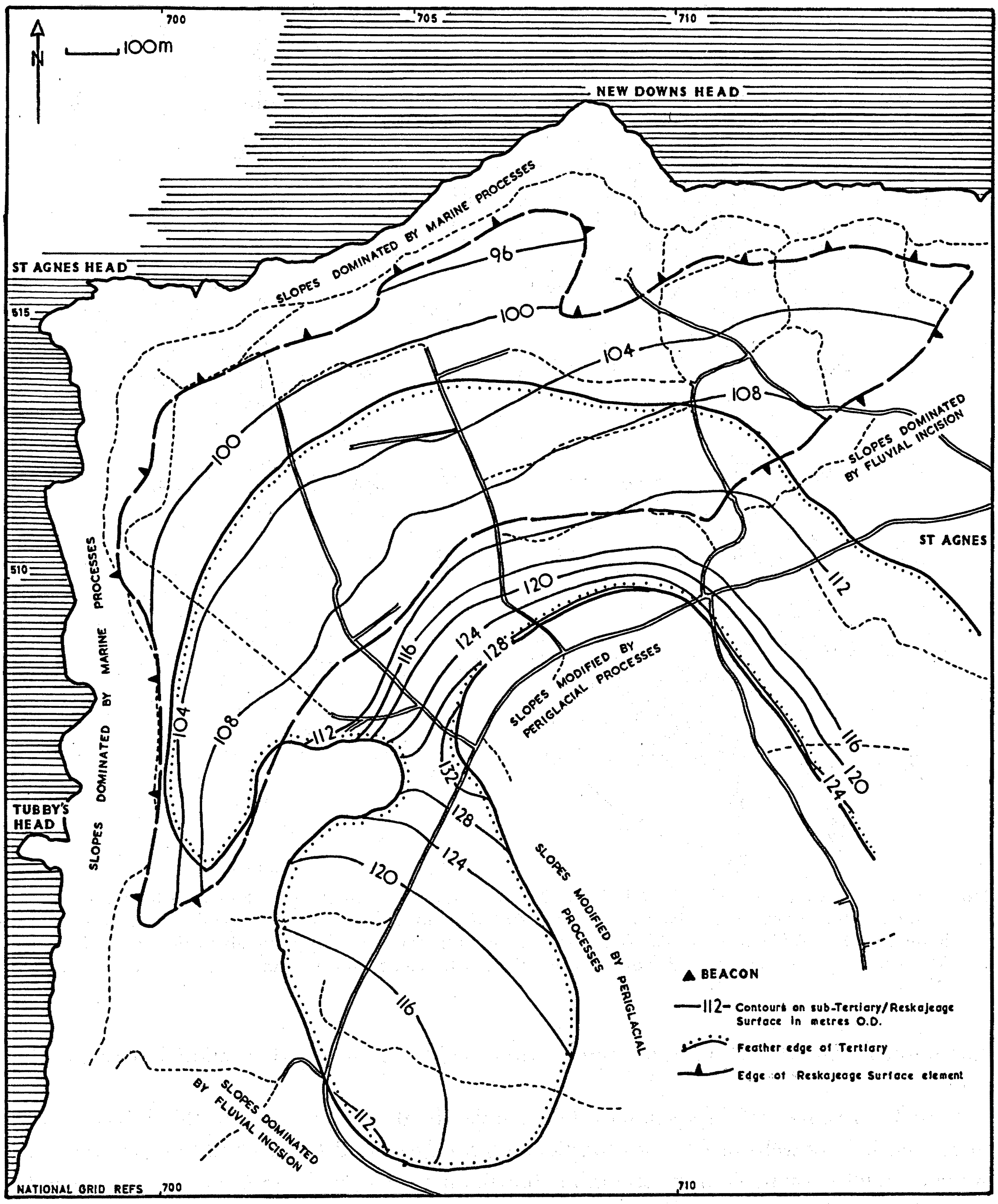

FIGURE 4. Form of the sub-Tertiary–Reskajeage erosion surface at St Agnes. The representation of the fragment of the Reskajeage Surface is based on interpretation of aerial photographic stereomodels. Bedrock contours for the Beacon Cottage Farm Outlier are largely conjectural.

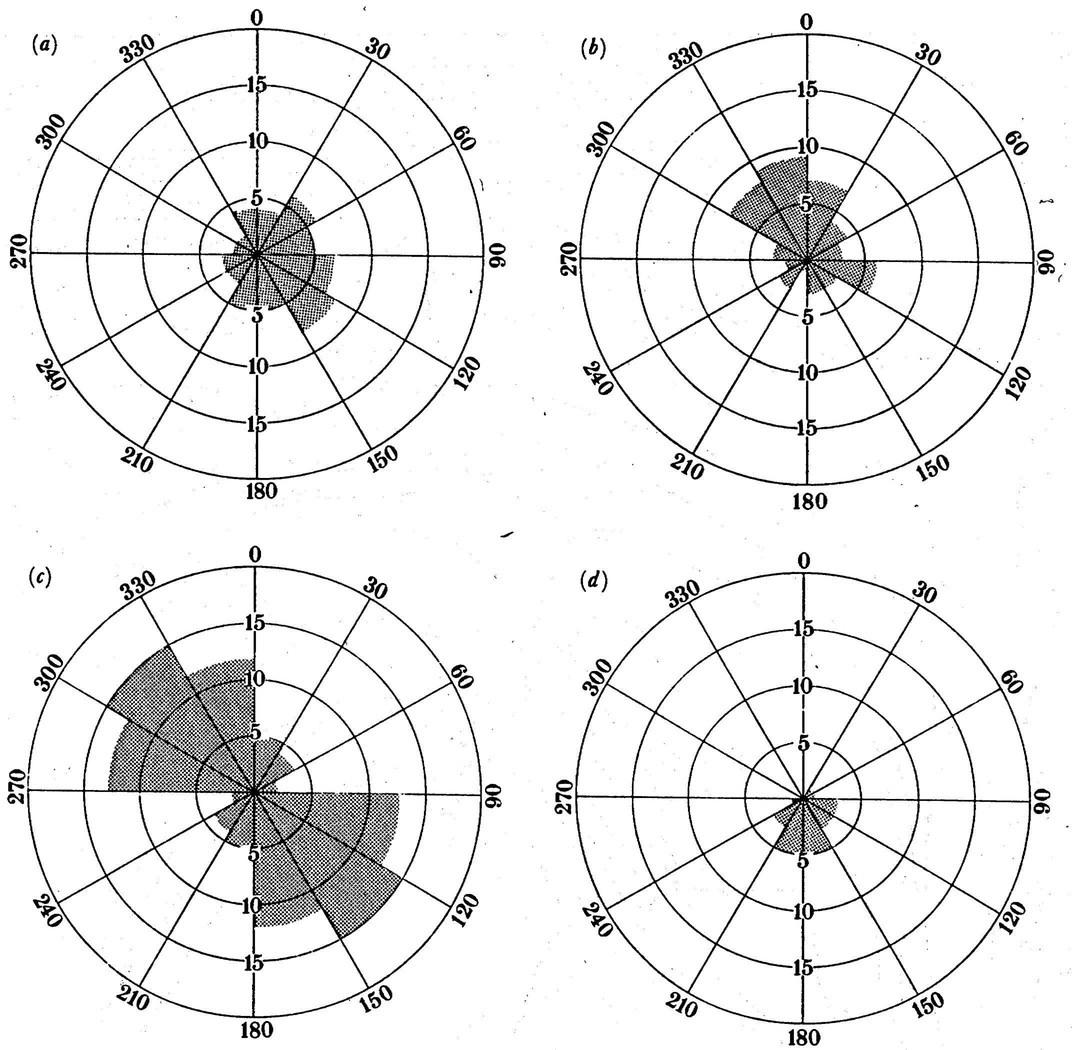

FIGURE 5. Palaeocurrent indicators from the Doble Member, St Agnes Formation. (*a*) Foreset inclinations of Doble Member sediments exposed in New Downs Pits. (*b*) Foreset inclinations of Doble Member sediments exposed in the New Pit (SW707513). (*c*) Pebble long-axis trends from rudaceous layer 2 m above the base of the Doble Member in New Downs Pits. (*d*) Foreset inclinations of Beacon Member sediments exposed in New Downs Pits.

the southeast (figure 5). This is not thought to be evidence for post-depositional folding in this area.

Particle-size curves of three samples of the Doble Member (figure 6) show that it is composed almost entirely of well-sorted sands, particularly samples DOB 1 and DOB 3, which recorded more than 90% by mass in the size grade 0.2–0.6 mm. Sample DOB 5, taken 5 m above the base of the sands, is somewhat less well-sorted as a result of the inclusion of silt (less than 15%) and a small proportion of coarse sand (more than 0.6 mm). Overall, the mineral content is dominated by quartz (more than 90 %).

The heavy-mineral assemblage of the Doble Member sands includes haematite, tourmaline, zircon, rutile, kyanite, andalusite, topaz and cassiterite, all of which could be locally derived (Reid & Scrivenor 1906; Milner 1922; Boswell 1923).

Three samples of Doble Member sand from different levels were subjected to SEM analysis.

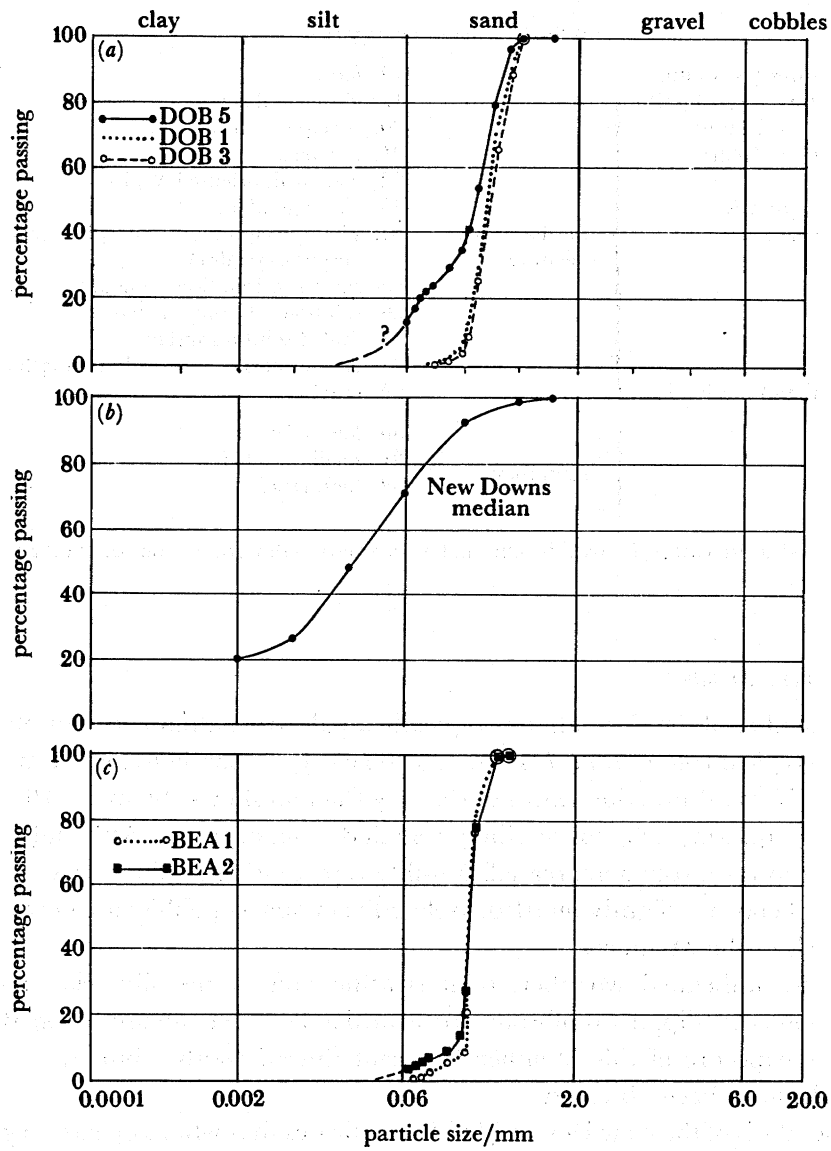

FIGURE 6. Particle-size curves of samples from the sediments of the St Agnes Outlier.

The results are represented in figure 7*b* as a mean percentage frequency of the surface textures observed. The combination of low-medium relief, mainly subrounded and rounded grains and dish-shaped concavities (63%) is strongly indicative of an aeolian transport history. Because of the degree of post-depositional chemical alteration of the surfaces of the grains, any other less frequent surface textures that might have elucidated the transport history have been obliterated.

About 1.8 m above the base of the Formation there is currently exposed a 100 mm thick band of pebbles and cobbles. The clasts show various states of rounding, from large, angular, stained fragments of killas, which are presumably very locally derived, to small, well-rounded pebbles of vein quartz and sandstone. Long-axis trend analysis for 107 elongate pebbles and cobbles from this layer revealed a clear preferred alignment NW–SE (figure 5).

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(*a*) Surface feature categories

1. large conchoidal fractures (> 15 μm) 2. small conchoidal fractures (< 15 μm) 3. large breakage blocks (> 15 μm) 4. small breakage blocks (< 15 μm) 5. arc-shaped steps 6. random scratches and grooves 7. oriented scratches and grooves 8. parallel steps 9. non-oriented, V-pits 10. meandering ridges 11. dish-shaped concavities 12. upturned plates 13. microblocks (chemical and mechanical)	mechanical features	18. facet 19. cleavage flake 20. precipitation platelet 21. carapace 22. chemical, oriented V-pits 23. cleavage plane 24. silica precipitation (amorphous and cryptocrystalline) 25. silica precipitation (euhedral) 26. solution pits and hollows 27. dulled solution surface 28. chattermarks (chemical and mechanical) 29. cracks	chemical features
14. rounded outline 15. subrounded outline 16. subangular outline 17. angular outline	roundness	30. low relief 31. medium relief 32. high relief	relief

FIGURE 7. (*a*) Surface-feature categories used in SEM analysis of quartz sand grains from the St Agnes Formation.

(iii) *The New Downs Member*

The middle member of the Formation is typically a pale grey, almost structureless silty clay with some sand (typical colour 7.5Y 7/1) that, as revealed by boreholes, is 3.4 m thick in the New Downs Pits. X-ray diffraction (XRD) of the clay fraction shows (by mass) 19% kaolinite; 36% mica; 22% quartz; 7% tourmaline; remainder amorphous. Although the base is transitional, the top is sharply demarcated, possibly representing a minor erosion surface, for the upper layers of clay are slightly mottled. Isolated vein quartz pebbles are occasionally seen in the upper levels of the Member.

In an otherwise unbedded Member, faint stratification in the silty clay horizons can occasionally be observed, dipping uniformly northward at 3–8° over an area of *ca*. 1000 m^2 (i.e. the extent of the exposure of this Member in recent times). Neither burrow structures nor desiccation cracks have been observed.

Particle-size analysis of the New Downs Member indicates that what appears megascopically to be a predominantly argillaceous sediment is, in fact, composed of mainly silt (51.1%) and sand (28.3%), with a relatively small clay fraction (20.6%). The poorly sorted nature of the sample is indicated by the form of the particle-size curve (figure 6*b*), which contrasts markedly with those for the well-sorted sands of the Doble and Beacon Members.

SEM analysis of three samples of sand grains from this Member revealed a more heterogeneous combination of textures than those from the Doble Member. In addition to grains characteristic of the latter, grains from the middle Member also included angular and subangular, medium-high relief grains, some displaying severe chemical alteration. Apart from slight edge abrasion on some grains (cf. Goudie & Bull 1984) (a characteristic not noted grain by grain in the original analysis), signs of mechanical alteration of grains otherwise typical of source rock were absent (figure 7).

There have been persistent reports of the presence of carbonaceous sediments in the New Downs Pits, some as early as 1832 (Hawkins). Dewey, in his 1932 field notes, wrote of 'dark grey, current-bedded drab clays...(with) numerous remains of plants, carbonaceous stems, leaves and twigs, but not determinable'. A patch of dark-grey and brownish lignitic clay

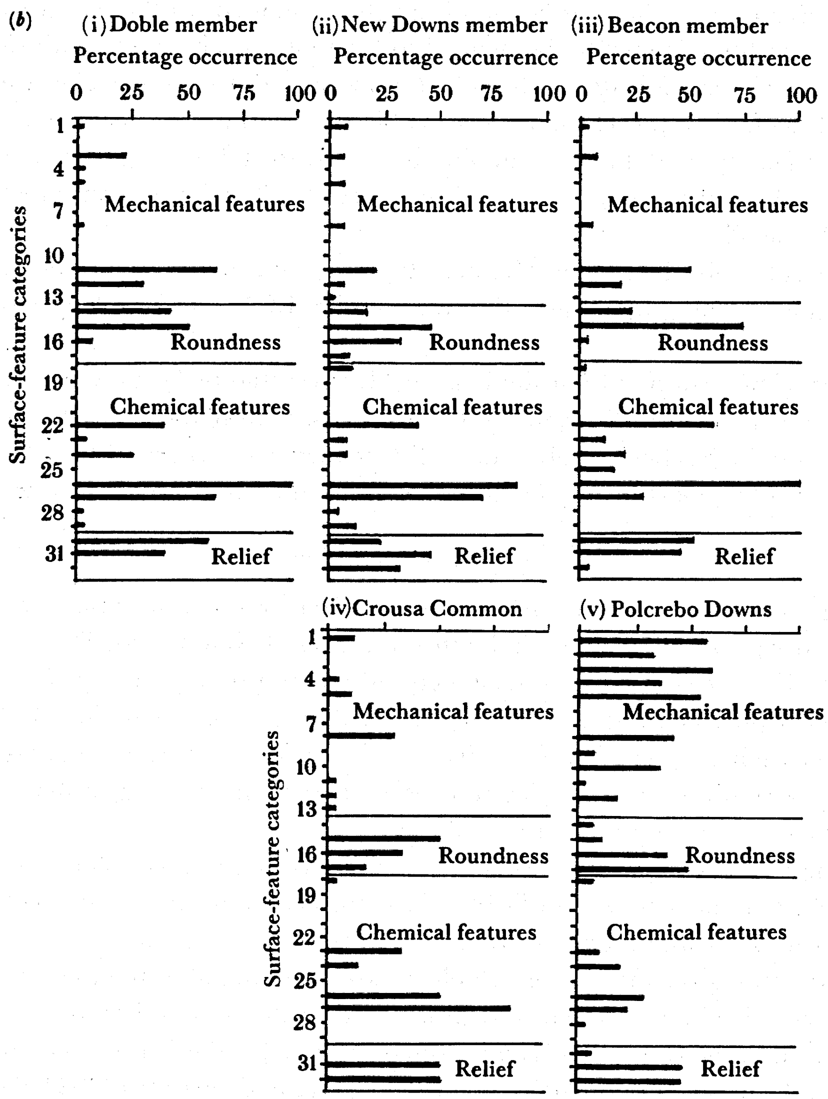

FIGURE 7. (*b*) Relative abundance of surface features on quartz sand grains from the St Agnes Formation (see figure 7*a*) for key to categories).

(10YR 3/1) at least 120 m² in extent has been exposed in recent years about 20 m SE of the drying plant (SW7049 5088). This body, 220 mm thick, is intermittently exposed in the sides of a small drainage channel; the exposure is not clear enough to determine its exact relations with non-carbonaceous clays, except that it undoubtedly occurs in the upper half of the Member. The lignitic clay lies about 1.3 m below the former level of the Beacon Member base (W. Doble, personal communication).

(iv) *The Beacon Member*

In New Downs Pits, the Beacon Member is represented by about 3 m of cross-bedded fine- to medium-grained yellow and orange sands (7.5YR 6/10), in many respects similar to those of the Doble Member. Some of the sands are very weakly cemented by iron compounds, especially above silty layers. Irregular lenses of greenish silty sand have been observed in some sections. The sections have been much affected by periglacial freeze–thaw processes and, together with the overlying Head cover, the stratification is much convoluted. In the relatively undisturbed sections, foreset bedding is invariably inclined to the south-southeast or south (figure 5).

Geophysical evidence indicates perhaps 2–3 m more of Beacon sands beneath Head north of St Agnes Beacon. The power auger was unable to penetrate the coarse Head here. Field notes made by Dewey in 1932 show the Beacon Sands to 'tail off' against 'a steadily rising floor of killas'. Macfadyen (1970) recorded up to 24 ft (7.3 m) of Beacon-type 'brown sand' in the New Downs Pit.

Particle-size curves for the Beacon Member (figure 6) show that it comprises very well sorted sands accounting for 90% by mass of the two samples, BEA 1 and BEA 2, between 0.2 and 0.6 mm.

SEM analysis of two samples from the Beacon Member (figure 7) showed an assemblage of surface textures similar to those from the Doble Sands, with mainly rounded to subrounded grains, medium to high relief and ubiquitous dish-shaped concavities (50%). As for the Doble Sands, an aeolian transport history for the Beacon Member is clearly indicated.

(*d*) *Lateral variations*

The St Agnes Formation *sensu stricto* is characterized by rapid variations in thickness and facies. Detailed logs of some 35 boreholes in the region of New Downs Pits and southeast of Trevaunance Mine are contained in the undergraduate project reports of J. C. Whittaker (no. 960), D. A. Pearson (no. 950) T. A. Smith (no. 1065) and S. J. Tite (no. 1066), all of the Department of Civil Engineering, The City University, where these reports are available for inspection. Nineteenth century detailed records are of some help in unravelling the variations, although the loci of some data remain doubtful.

Facies changes are abrupt, with boreholes only a few metres apart showing great changes of colour and grain size. Away from Doble's Pits, correlation is somewhat perplexing, at least on a bed-by-bed basis, and the old records are of little assistance here.

Even before mining operations, the Doble Sands were probably the most restricted of the three members. They were evidently deposited in localized rock basins. Certainly, recent augering shows that the Doble Sands have been overlapped at the south end of the New Downs Pits. Likewise, the mass of granite now exposed at Cameron Quarry (SW7038 5065) must have projected through the sheet of Doble Sands, assuming they were once present south of there. The nature of the Member is difficult to reconstruct but there are numerous reports that it is pebbly on the east side of the Beacon. The New Downs 'clays' appear to be the most persistent sediments, and, apart from the small lignitic lens in New Downs Pits, no major variations have been discerned by the present authors. Davies & Kitto (1878) recorded that a 'candle clay'† could be distinguished from a 'fireclay'; the fireclay was said to be restricted to the north and west of the outcrop, and, where both clays were present, 'it is the fireclay which is uppermost'. They also reported candle clay sandwiching a sand layer 1.5 m thick southeast of Polberro Mine. Boase (1832) reported that in some pits the 'intermediate stratum of clay is absent'. The character of the Beacon Member east and west of the New Downs Pits is not known in detail, but is thought to overlap older sediments against the rising floor of the killas (figure 8).

The nature of the former 'outer' boundary of the New Downs and Beacon Member sediments

† 'Candle clay' is a particularly unctuous clay that was sold by past owners of the Beacon Cottage Farm Pits (Balandeeze Mine) to the mines of Cornwall, particularly those of the Camborne–Redruth area, for fixing candles to the underground mine walls and also the brims of miners' hats. The trade gradually declined and died out about 1940.

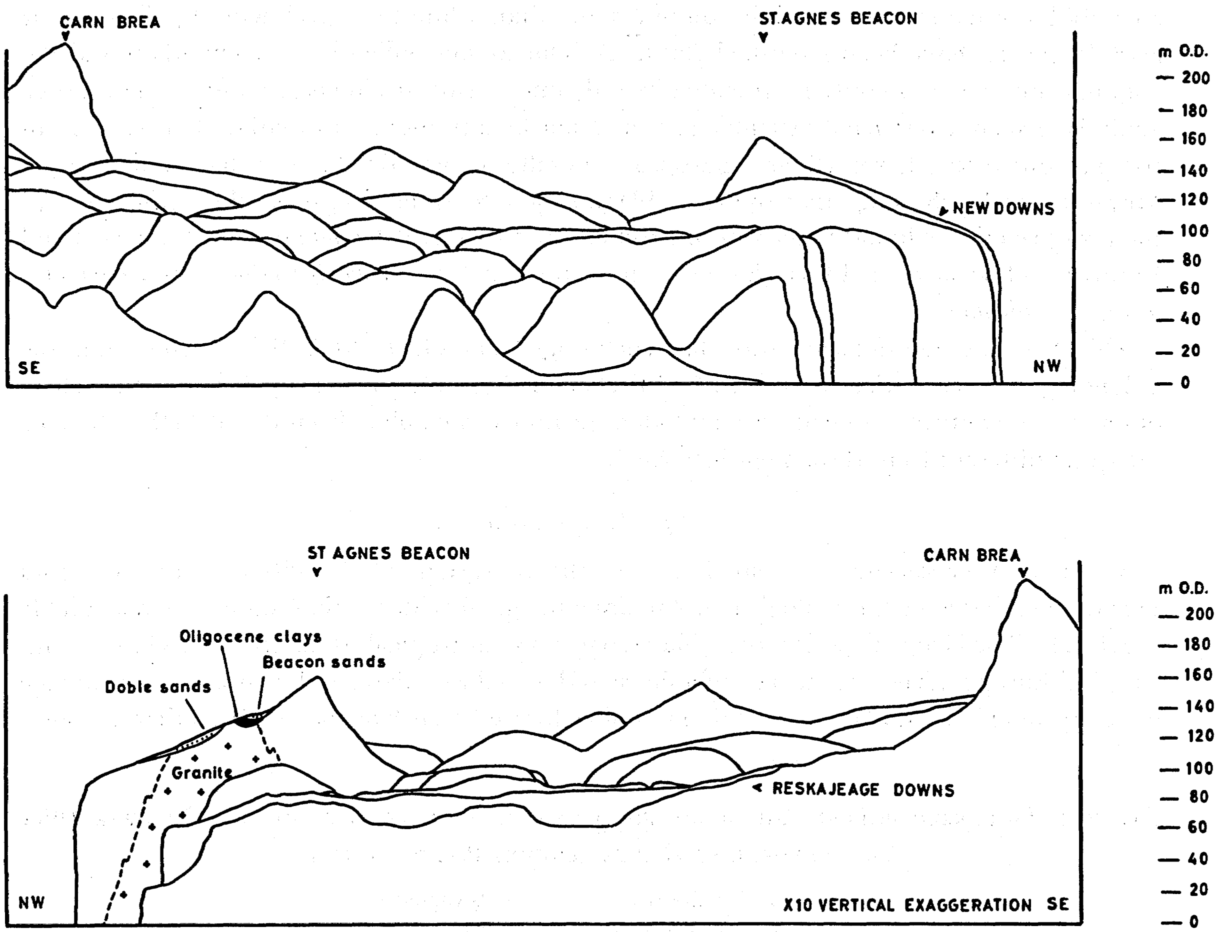

FIGURE 8. Twenty-two projected profiles viewing SW (in upper figure) and NE (lower), transverse to the North Cornish coast between Portreath and Perranporth. The profiles were taken diagonally at the intersections of 1 km Ordnance Survey Grid reference easting and northings. The Profiles are thus *ca.* 700 m apart. Geological relations at St Agnes also summarized.

is completely conjectural. The report of 2 m (or more) of sand in a temporary exposure in the fields between Beacon Cottage Farm and the Beacon itself may indicate that a tongue of Beacon Sands extends onto the Oligocene in this area (figures 2 and 8).

(*e*) *Palynology*

Samples have been obtained from the carbonaceous clays of the New Downs Member about once a year since 1972. Each has been macerated for pollen analysis. On the first seven occasions they yielded nothing but fragments of indeterminable carbonaceous debris about 10–40 μm in size (plate 2, figure 21). The eighth sample, collected in April 1983, yielded, apart from this usual black debris, recognizable fragments of leaf cuticle and brown-wood tracheids, pollen and spores (plate 2, figure 20). Later sampling in October 1983 yielded a similar assemblage, but subsequent sampling has again proved to be barren of all but the black palynodebris.

Four microscope slides from the April and October 1983 samples are deposited at the British Geological Survey (BGS), Keyworth, Nottinghamshire, and are all that remains of that set of productive samples. The preparations are mounted in glycerine jelly and are unstained, making photography for plates 1 and 2 difficult. Furthermore, many of the specimens of pollen contain air bubbles. Each microscope slide contains more than a hundred specimens of pollen and at least 19 species have been identified (table 2). The conifer pollen is most abundant and the angiosperm taxa are mainly represented by only one or two specimens, so a fully quantitative analysis of such a restricted assemblage would not be any more informative. It is clear from comparisons with other northwest European microfloras (van der Brelie 1967; Boulter 1971; Meyer 1980; Koch 1984) that the assemblage is of a Neogene age, most likely Miocene. All the taxa present are found in terrestrial sediments of this age. Palaeogene forms are absent and European Pliocene assemblages do not contain taxa such as *Monocolpopollenites* and *Porocolpopollenites vestibulum*.

This Neogene age determination has encouraged one of us (M.C.B.) to re-examine the palynological preparations described by Mitchell (1965) from the nearby St Erth Beds. These observations confirm Mitchell's original identifications; the pollen from the St Erth sediments are quite different from those identified here.

(*f*) *Interpretation*

The new interpretation presented here of the conditions of deposition of the St Agnes Formation is based on palynological and sedimentological evidence that has not been available previously. The Neogene pollen assemblage suggests a subtropical Mediterranean climate with a typical European vegetation of conifer forest and mixed woodland and shrub. The assemblage listed in table 2 is similar to the inland conifer forest (*Pinus*-like species, Taxodiaceae, etc.)

TABLE 2. DISPERSED POLLEN AND SPORE FORM GENERA IDENTIFIED FROM THE OCTOBER 1983 SAMPLE FROM NEW DOWNS PIT, ST AGNES

Stereisporites stereoides	bryophytes
Laevigatosporites haardti	ferns
Pinus haploxylon-type *Pinus* sylvestris-type *Tsugaepollenites* canadensis-type *Cedruspollenites* *Abiespollenites* *Sciadopityspollenites serratus* *Sequoiapollenites* *Inaperturopollenites dubius*	conifers
Tricolpopollenites liblarensis *T. microhenrici* *T. henrici* *T. ipilensis* *Trivestibulopollenites betuloides*	deciduous forest–mixed woodland
Polyvestibulopollenites versus *Triporopollenites* *Porocolpopollenites vestibulum* *Ericipites*	shrub-heath

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DESCRIPTION OF PLATE 1

PLATE 1. Gymnosperm pollen from the Miocene St Agnes Formation sample at New Downs Pit. All photographs are magn. ×1000 except figures 5 and 6, which are magn. ×750. Figures 1 and 2, *Tsugaepollenites*; figures 3 and 4, *Pityosporites* sylvestris-type; figures 5 and 6, *Abiespollenites*; figure 7, *Pityosporites* haploxylon-type; figures 8–11, *Sequoiapollenites*; figures 12–19, *Inaperturopollenites*; figure 20, *Cycadopites*.

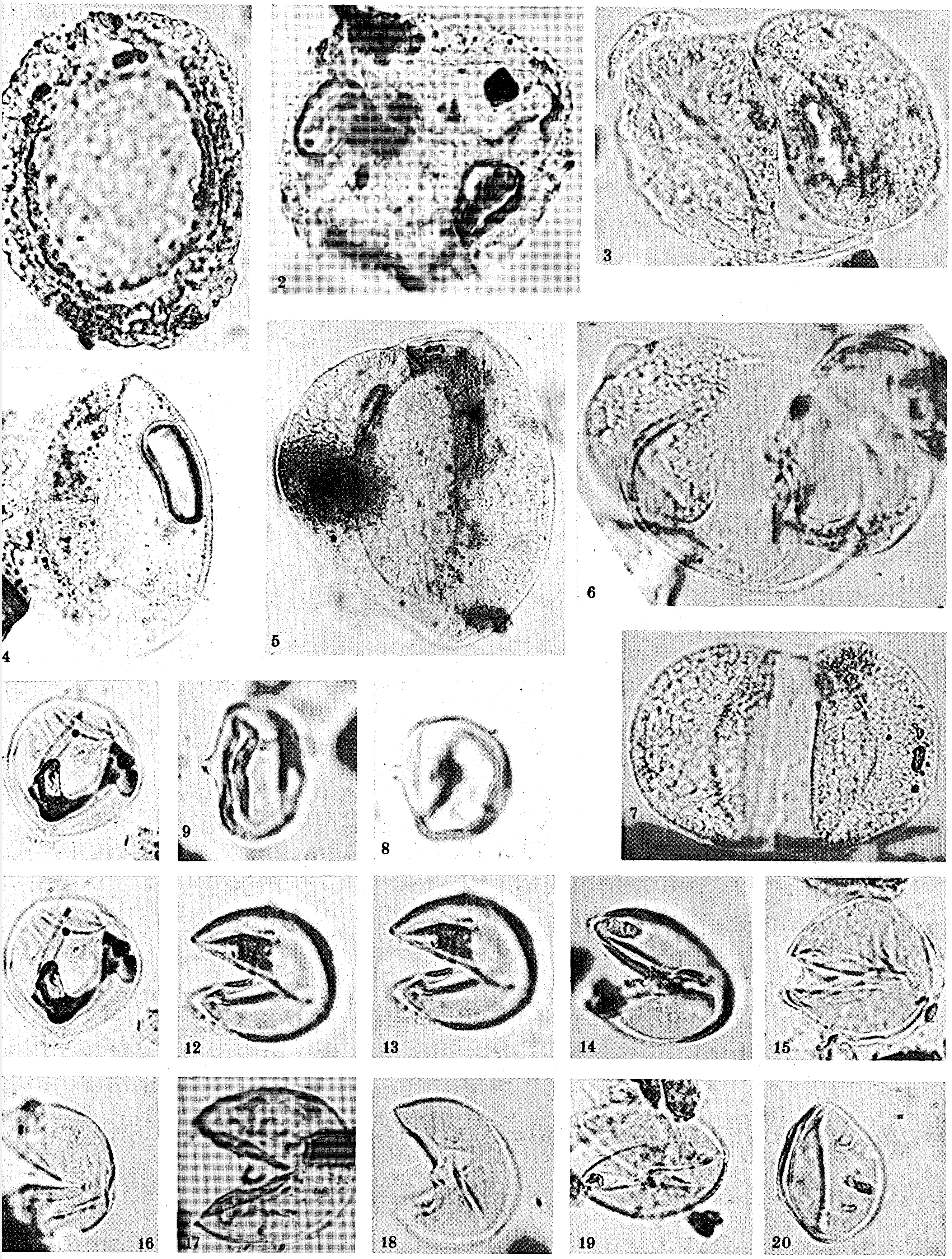

PLATE 1. For description see opposite.

(*Facing p.* 226)

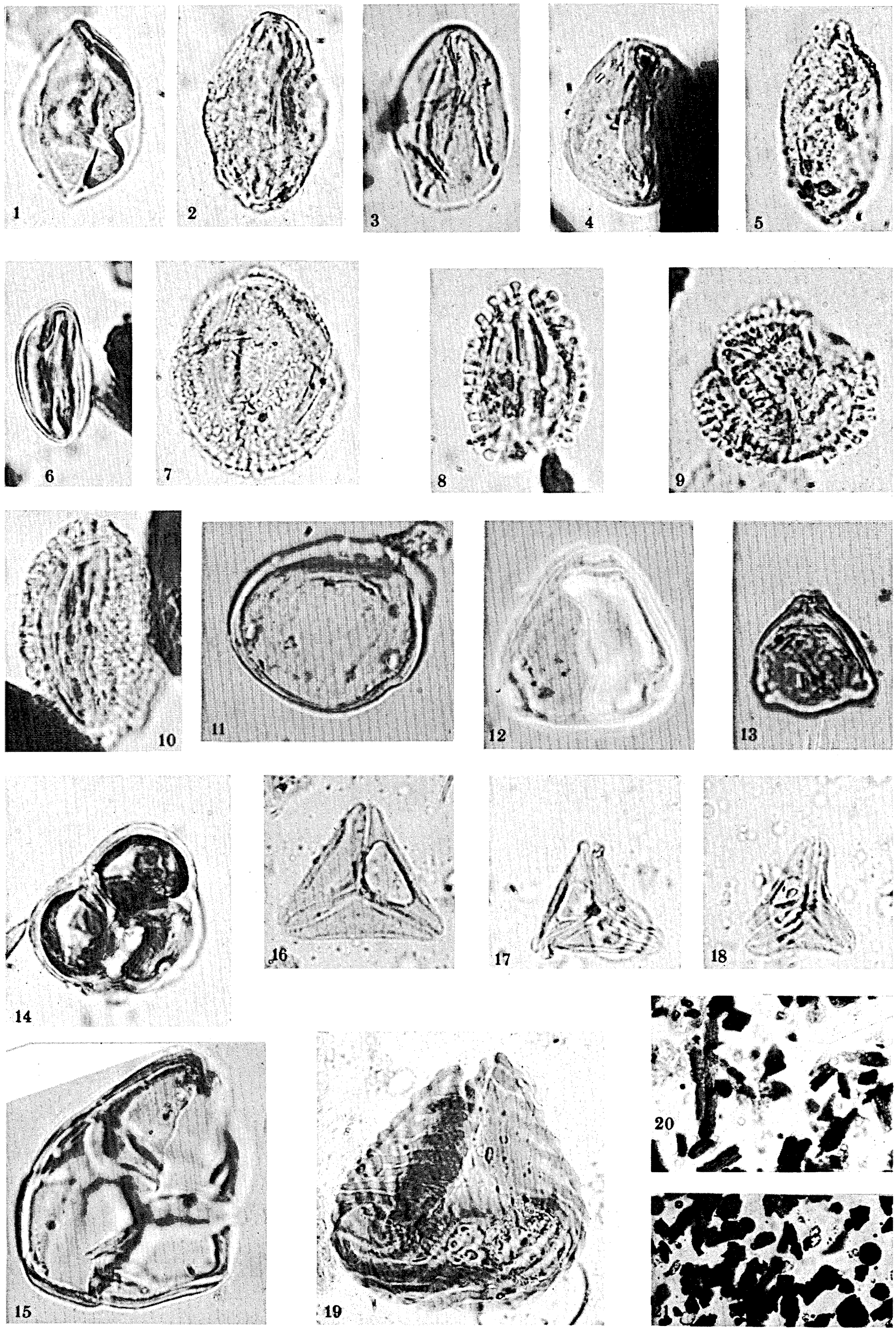

Plate 2. For description see opposite.

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from upland vegetation and mixed angiosperm and conifer forest perhaps from less elevated surfaces (tricolpates and conifers). In addition, shrubland and heathland type vegetation may be represented by forms such as *P. vestibulum*, *P. versus* and *Erecipites*. This is much in line with the classic work of Teichmuller & Teichmuller (1968) and others who have based their similar conclusions on different parameters (Boulter 1971; Koch 1984).

The absence of palm pollen may mean that winter temperatures fell below 0 °C, and the absence of dinocysts confirms that marine influences were absent. The palynodebris is present in all the samples studied that are otherwise lacking plant fossils. It consists mainly of very abundant black debris (Boulter & Riddick 1987) that is 10–40 μm in diameter and angularly fragmented. It is suggested that the pollen was deposited in lenses at the edge of rapidly formed sediments, in which the heavier black debris was evenly deposited away from these sheltered lenses. This may account for the absence of pollen in most of the Doble's Pit samples that have been examined for palynological evidence.

As regards the depositional environment at St Agnes, three models must be considered: that the sequence of sediments there was formed by (1) marine action, (2) fluviatile action, or (3) aeolian processes interrupted by a colluvial phase.

Considering the first hypothesis, there are several features about the sediments and their location that suggest deposition under marine conditions. Among these are the 'buried cliff' on the east side of the Beacon (Davies & Kitto 1878), the basal gravels (possible beach deposits), the situation of the deposits on a supposed 'marine' planation surface (Balchin 1964; Everard 1977) and the sand–clay transition, which might be viewed as a typical coastal dune–estuarine sequence. However, none of these features is in itself diagnostic, and none of the quartz sand grains from any sample shows surface textures normally associated with marine action. Moreover, the lignitic clay in the New Downs Member is clearly of terrestrial origin.

A fluviatile origin for the St Agnes Formation was proposed as recently as a decade ago by some of the persons who now co-author the present work (Atkinson *et al.* 1975), before much of the sedimentological research on the St Agnes samples reported here had been completed. This hypothesis would explain the sand–clay–sand sequence in terms of different degrees of fluvial energy; indeed, it is difficult to explain the presence of the basal cobble beds east of the Beacon and the pebble band in the Doble Member north of the Beacon except by invoking a fluviatile agency for the transport of these sediments. But most of the sediment now constituting the St Agnes deposits would appear not to have been formed in this way for the following reasons. First, the quartz grain surface textures from the sand samples give no indication of fluvial transport (although it is just possible that the small diagnostic textures may have suffered too much diagenetic alteration for them now to be distinguishable); second,

Description of plate 2

Plate 2. Figures 1–15 are of pollen from the Miocene St Agnes Formation at New Downs Pit. (Magn. × 1000.) Figures 16–19 are from Dewey's sample MR10401 thought to be from the Beacon Cottage Farm claypits. (Magn. × 1000.) Figures 20 and 21 are of palynodebris from the Miocene St Agnes Formation at New Downs Pit. (Magn. × 50.) Figure 1, *Cycadopites*; figures 2 and 3, *Tricolpopollenites*; figure 4, *Monocolpopollenites*; figure 5, *Tricolpopollenites*; figures 6 and 7, *Tricolporopollenites* spp.; figures 8–10, *Ilexpollenites*; figure 11, *Subtriporopollenites*; figure 12, *Porocolpopollenites vestibulum*; figure 13, *Momipites*; figures 14–15, *Erecipites*; figures 16–18, *Boehlensipollis hohli*; figure 19, *Cicatricosisporites paradorogensis*; figure 20, black debris, transparent debris made up of tracheid cells and leaf cuticle, and pollen, from the 19 samples; figure 21, black debris from one of the unproductive samples collected at other times, and transparent debris and pollen are completely absent.

particle-size analysis reveals the New Downs 'clays' to be quite untypical of floodplain deposits. Third, to interpret the St Agnes sediments as alluvial sediments would require a complicated post-Miocene physiographic inversion, for which there is no structural evidence (see §6*c*).

In our opinion, the most satisfactory explanation of the conditions of deposition is the third one (i.e. an aeolian–colluvial origin), which, with respect to the sands, was first suggested by Boswell (1923). With the exception of the pebble bands mentioned above, the two sandy members of the St Agnes Formation are regarded as aeolian, whereas the New Downs Member is regarded as a colluvial slope-wash deposit. The SEM observations clearly indicate such a depositional history: the grains from the sands show clear evidence of aeolian action, whereas the New Downs 'clays' show a mixture of aeolian-type grains, together with grains showing source-rock characteristics with edge abrasion, which is quite consistent with the hypothesis of weathering followed by restricted downslope movement. The particle-size analysis of the New Downs sediment reveals it to have a degree of sorting closely comparable with that of modern subtropical colluvia (Goudie & Bull 1984); that for the sandy members shows them to be well-sorted and typical of modern aeolian sediments.

Most problematical are the rudaceous bands in the Doble Member. Although no lithology has yet been reported that indicates a far-travelled provenance, they clearly cannot be aeolian. It is suggested tentatively that they represent fluviatile incursions into the aeolian dune belt; conceivably, they may have been derived from local pre-existing alluvial or even marine deposits.

Although novel in the context of the St Agnes deposits, this aeolian–colluvial hypothesis seems to offer the simplest explanation. It does not require tectonic action in the explanation of the structures, nor does a radical change in the physiography of the local area need to be envisaged. Moreover, such a sequence of deposits is not uncommon in present-day subtropical environments with seasonal rainfall, as might be envisaged for western Britain in the Miocene.

3. The Beacon Cottage Farm Outlier

(*a*) *General*

Until the discovery of the Neogene flora in the New Downs Pits, the deposits at Beacon Cottage were assumed by us and others (see, for example, BGS 1:50000 sheet 346, Newquay) to be both contiguous and coeval with those to the north of the Beacon, the thick grey 'clay' beds in the middle of both sections seeming to indicate a common identity. It now seems appropriate, however, to regard the Beacon Cottage deposits as discrete. Indeed, Davies & Kitto (1878) had earlier reported that the Beacon Cottage sediments occupy a discrete circular basin, 300 m in diameter and centred on Beacon Cottage Farm.

(*b*) *Stratigraphy*

Regrettably, no current exposures of the Beacon Cottage sediments exist and our knowledge of their stratigraphy is derived from nineteenth century publications, field notes of H. Dewey (by courtesy of the BGS) and recent augering around the old candle clay excavations (figure 9).

A tripartite stratigraphy, reflecting that of the St Agnes Formation *sensu stricto* is discernible. However, apart from the floral evidence, there are significant differences: the basal sandy beds are thinner than those in the New Downs section, and little sand overlies the grey clays of the middle levels. Clearly, our knowledge of the Beacon Cottage profile is at present too limited to propose a member-by-member terminology.

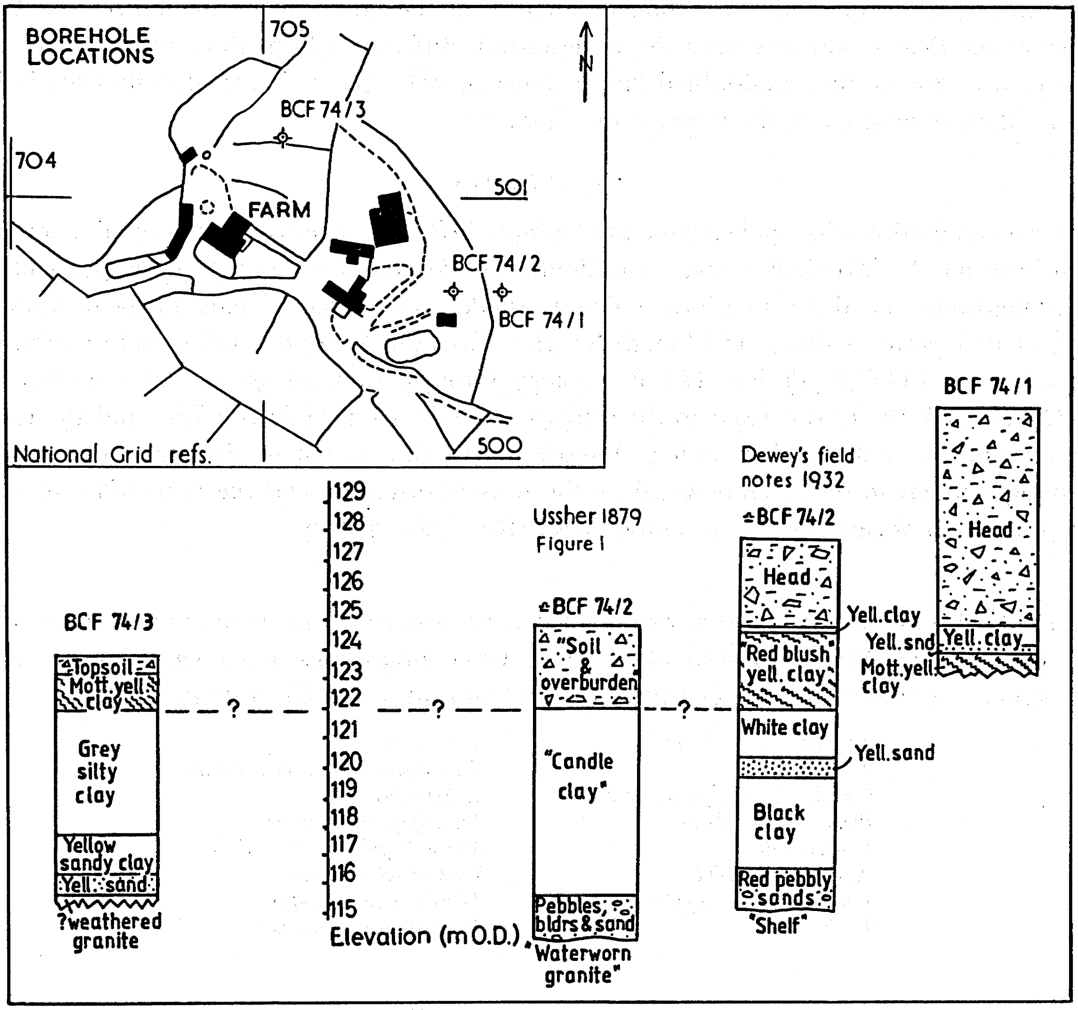

Figure 9. Stratigraphy of the Oligocene sediments adjacent to Beacon Cottage Farm, St Agnes. Borehole BCF 74/2, sunk in September 1974, met with resistance to penetration at 118.2 m o.d., which was assumed at the time to represent the Granite bedrock. However, it is considered that most, if not all of this sounding of depth 6.4 m is in made ground, and it now seems likely that the auger was stopped by stony Head backfill.

The main interest of the Beacon Cottage sediments undoubtedly lies in the intermittent reports of carbonaceous material, apparently located in the lower half of the 'candle clay' beds. Davies & Kitto (1878), reported no fossils but found 'a black substance in pellets a little larger than peas'. Dewey noted the presence of 'black clays' in the lower levels of the Farm excavations and also, in the openworks of Wheal Coates Mine, 'a bed of laminated clay with obscure remains of plants'. Until 1965, when G. F. Mitchell reported the preliminary analyses of the BGS sample (MR10401), no-one had suggested that the Beacon Cottage sediments were older than Pliocene. Most accepted that these sediments rested on the 'Pliocene Platform' and that the basal gravelly sediments encountered in the St Agnes deposits (*s.l.*) were formed in Pliocene marine conditions. The derivation of specimen MR10401, supposedly collected by Dewey at the Farm in 1932, is therefore crucial to the geological history proposed here. Scrutiny of Dewey's notebook, consideration of the likelihood of mislabelling at the Geological Museum in Kensington and a re-examination of the pollen led us initially to doubt the authenticity of the sample and the validity of the results.

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However, no error in the sampling or analysis of the flora can be demonstrated. Thus, whereas the Beacon Cottage flora shows significant differences from those in the Bovey and Petrockstow Basins, their undoubted Palaeogene age (*vide infra*) indicates that they are in fact the local representative of the Bovey Formation.

(*c*) *Palynology*

A re-examination of the pollen content of sample MR10401 confirms the original taxonomic identifications by Mitchell (1965) and Boulter (Atkinson *et al.* 1975) (table 3), and the mid-Oligocene age determination, which is reinforced by recent palynological work on Oligocene deposits at Bovey and Lough Neagh (Wilkinson & Boulter 1980, and unpublished work by the I.G.C.P. Project 124 Palynology Group). *Cicatricosisporites paradorogensis* and *Boehlensipollis hohli* are restricted to the Oligocene in the western British Isles and the rest of the assemblage confirms that dating. A more precise date is not possible from one sample. Although similar to the assemblages from the Bovey Formation and the Lough Neagh clays, the proportion of each species in sample MR10401 differs greatly.

TABLE 3. DISPERSED POLLEN AND SPORE FORM TAXA IDENTIFIED FROM NEW PREPARATIONS OF BGS SAMPLE MR10401 AND MITCHELL'S 1965 MICROSCOPE SLIDE PREPARATION FROM SAMPLE PURPORTEDLY TAKEN FROM BEACON COTTAGE FARM CLAYPIT IN 1932

Laevigatosporites haardti	*T. coryloides*
L. discordatus	*Intratriporopollenites indubitabilis*
Cicatricosisporites paradorogensis	*I. instructus*
Pityosporites labdacus	*Porocolpopollenites verus*
P. microalatus	*Monocolpopollenites tranquillis*
Boehlensipollis hohli	*Tricolpopollenites* spp.
Triatriopollenites coryphaeus	*Tricolporopollenites* spp.
T. plicatus	*Tetradopollenites callidus*

(*d*) *Conditions of deposition*

The Oligocene Beacon Cottage assemblage contains palm pollen, *Monocolpopollenites tranquillis*, suggesting frost-free winters. These results match closely those in the Bovey and Lough Neagh Oligocene deposits (Wilkinson & Boulter 1980), which have been shown by Hubbard & Boulter (1983) to reflect a cooling climate with a lowland mean annual temperature of *ca.* 12 °C. Marine microfossils were not found, and dispersed plant parts within the lignitic clay (i.e. leaf cuticle and wood cells in significant quantities and structureless amorphous matter, possibly of freshwater algae origin) suggest low-energy deposition. Besides marine influences, such characteristics usually indicate lake deposits, and the good preservation of all fossil material confirms a low-energy depositional environment. The colour is uniform and there is no evidence of reworking of the material.

4. THE CROUSA COMMON OUTLIER

(*a*) *Setting and field relations*

Crousa Common covers most of the so-called 'Lizard Platform' that lies above the 100 m O.D. level. The 'gravel' outcrop is roughly ovate, about 2 km long and 0.5 km wide, and overlies the Gabbro–Troctolite of the Lizard Series.

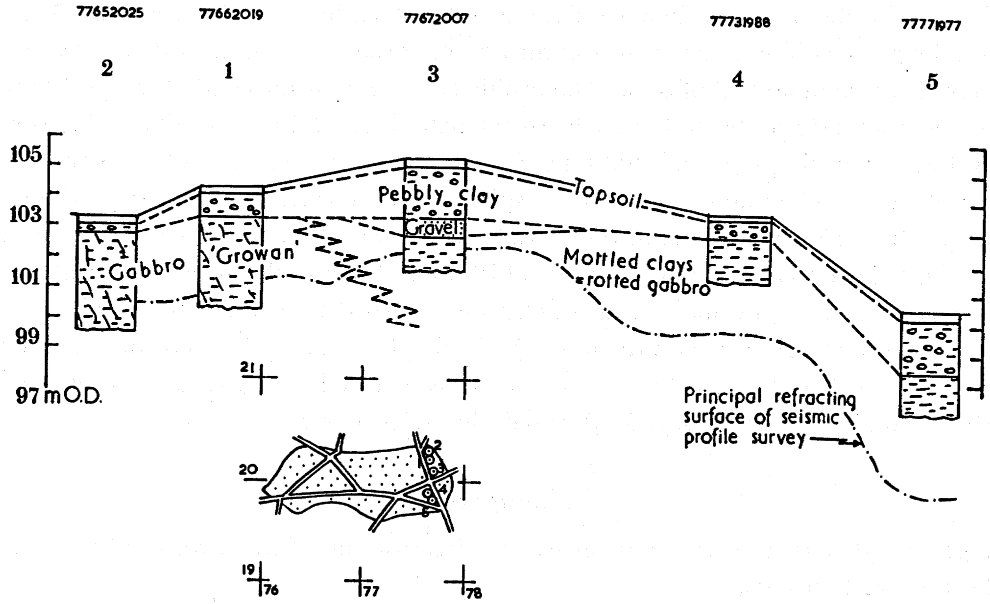

FIGURE 10. Profile across the eastern end of the Crousa Common Outlier, based on the results of trial pits excavated in September 1981 (partly after BGS sources).

The relevant BGS map (sheet 359) shows a thin capping of 'Pliocene Crousa Gravels' on the broad summit. This leads to the view that the gravels are an erosional remnant of a possibly once more-widespread covering.

The Gabbro outcrop is marked by rough common land with numerous large surface boulders presumably derived from bedrock weathering. Earlier mapping of the Gabbro probably relied on these boulders for its delimitation; by contrast, the Gravel outcrop supports pasture land and woodland (Flett & Hill 1912).

The present investigations have principally sought to determine the form of the sub-gravel surface and the stratigraphy and composition of the sediments. Because of the lack of undisturbed exposures, much reliance has been placed on trial pits and a complementary seismic survey.

(b) *Trial pits*

Five pits were dug with a JCB 3D excavator to provide a representative transect across the eastern end of the outlier (figure 10), where attempts at seismic profiling had previously been made (the latter determined by constraints of access). 'Gabbroic bedrock' was reached in all holes although it was always very decomposed, being a growan-like rotten rock (pits 1 and 2) or a highly mottled clay with relic crystal structures (for the remaining holes). A clear-cut junction between 'Gabbro' and 'Crousa gravel' was not discerned. As a result, 'bedrock' was assumed to correspond to the lowest level at which isolated quartz pebbles were present, with either the gabbro–growan or at least 1 m of pebble-free clay below. Only in pit 3 were traces of stratification evident and here the 'Tertiary' comprises a two-layered structure.

2. Pale grey or greenish-grey (5GY 8/2) stiff clay, bearing numerous, but isolated water-rounded quartz pebbles and cobbles of maximum diameter 120 mm. Much of this layer was mottled yellow and red; 1.9 m.

1. Light-brown or orange (10YR 6/10) fine gravel in which clasts of vein quartz, typically 3–5 mm in diameter, are dominant. Silty clay matrix; 0.7 m.

In Pits 1–4 the 'bedrock' surface lies close to 103 m O.D., but is 4 m lower in pit 5. Possibly, therefore, the pit 5 sediments are stratigraphically older than those in the other holes, although they resemble those in layer 2 of pit 3. The profile across the eastern end of the outlier broadly confirms the boundary on BGS sheet 359. In the field, layer 2 appears to be a clay-dominant sediment but wet sieving revealed that only 51 % by mass was clay and silt (less than 63 μm). Most of the Crousa Common sand grains displayed source rock characteristics when viewed with the SEM (figure 7). Half the sample grains, however, were subrounded and it is conceivable that this resulted from some sort of a transport history, although substantial chemical alteration of the surfaces of such grains make it impossible for further diagnostic features to be identified. No edge abrasion was observed on the less chemically altered, angular and subangular grains. By XRD, the mineralogy of typical layer 2 sediments is revealed to be (by mass) kaolinite, 19 %; mica, 19 %; quartz, 28 %; felspar, 5 %; remainder amorphous.

(c) *Interpretation*

Data presented here broadly confirm earlier descriptions of the Crousa Outlier (see, for example, Flett & Hill 1912).

Clearly, the Crousa deposit is not a true gravel and is better classified as a gravelly clay, the whole sediment having been subjected to considerable post-depositional weathering. This view is supported by (1) the mixed and laterally highly variable particle size range, and (2) the source-rock characteristics of many of the quartz sand grains.

Previous workers have maintained that the sediment was derived from the north, which is not contradicted by the results presented here. The nearest source of quartz pebbles would appear to be the Gramscatho-type conglomerates, located 4 km to the north. Most workers, however, have favoured a more distant origin, usually the Carnmenellis granite, a probable source of the granite pebbles reported by Flett & Hill (1912). It is possible that the clay has been derived largely from post-depositional rotting of gabbro pebbles, the gabbro : non-gabbro clasts ratio being similar, perhaps, to those preserved in the little-rotted Eocene interbasaltic sediments of Hamera and Osdale, Skye (Anderson & Dunham 1966). Such an hypothesis explains (1) the poor stratigraphy of the Crousa deposits, (2) the ubiquitous mottling, (3) the scattered distribution of quartz pebbles in the gravel–clay fabric, and (4) their dispersed orientation.

From the present results, the sub-Crousa and the Lizard surfaces can be regarded as homologues: any extensive erosion of the latter would have removed the unconsolidated Crousa sediments. The present location of the Crousa sediments on the modern Lizard watershed suggests that they represent the best-protected remnant of a once much more extensive, relatively easily eroded cover.

(d) *Age*

Evidence bearing on the age of the Crousa sediments is circumstantial, and interpretations are somewhat circular. They seem to have a similar association in the Cornish landscape in terms of height and state of preservation as the St Agnes deposits (*s.s*). Even if the erosion surfaces beneath them are contemporaneous, however, the deposition of the two masses may well not be synchronous.

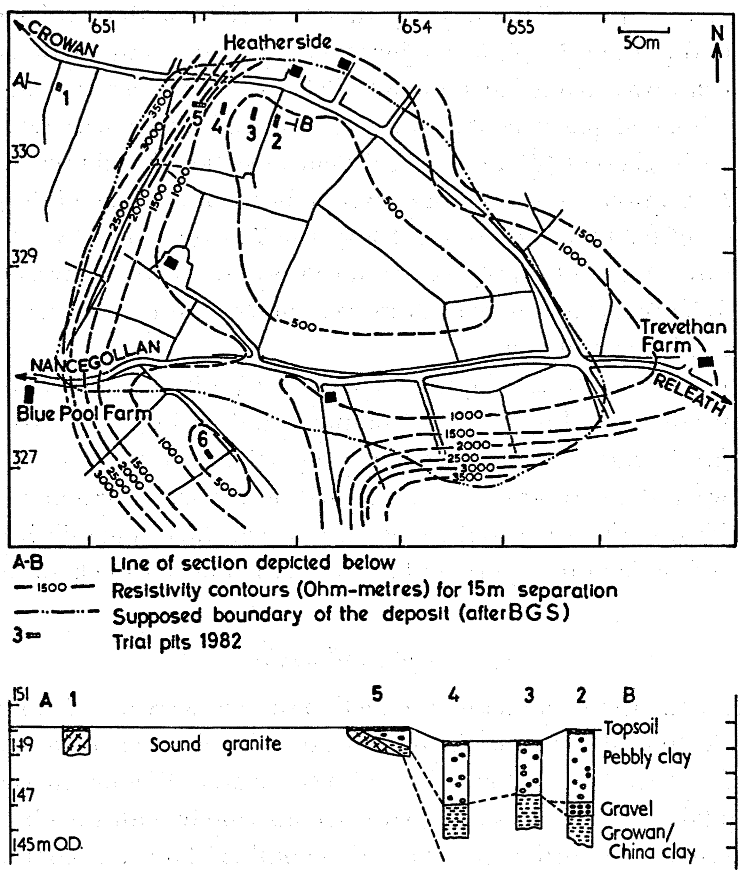

FIGURE 11. (*a*) Profile of the northwest corner of the Polcrebo Downs Outlier, based on trial pits excavated in September 1982. (*b*) Resistivity contours derived from a 15 m separation Wenner survey. Pit 6 proved only Growan–China clay to a depth of 3 m (partly after BGS sources).

5. The Polcrebo Downs Outlier

(*a*) *Setting and field relations*

At Polcrebo Downs, on a bench-like feature on the southwestern margins of the Carnmenellis Granite, further 'Tertiary Gravel' occurs at *ca.* 150 m O.D. On BGS sheet 352 it is shown to crop out over 10 ha (figure 11). Like the Crousa gravel, the Polcrebo gravel body can be regarded as an erosional remnant. Everard (1977) regarded its survival as dependent on its watershed location.

No permanent exposures of the 'Gravel' exist, nor can the underlying bedrock surface be seen, but this presumably comprises Granite. Neither field examination nor air photography indicates the margins of the 'Gravel', Geological Survey mapping presumably having been based on augering and trial pits.

(*b*) *Trial pits*

Within the scope of the limited funds available, a line of pits was dug by mechanical excavator across the northwestern corner of the outlier, where previous electrical resistivity surveying had indicated a well-defined junction of two contrasting rock types (figure 11).

At the northwestern corner of the outcrop the 'Gravel' boundary coincides with that of underlying kaolinized granite. In pit 5, the junction of sound granite with Tertiary sediment and growan–china clay was inclined at about 30° ESE. Where present, the base of the 'Gravel', taken as the deepest isolated quartz pebble in any pit (succeeded by at least 60 cm of non-pebbly material), appears to level off at 147 m O.D. for the entire section. Maximum 'Gravel' thickness was 3.3 m (in pit 2). Stratification was absent except for tonal banding of the grey clay matrix and ill-defined lines of pebbles (e.g. at 146.4 and 146.7 m O.D. in pit 2). As for the Crousa deposit, the term 'Gravel' is misleading because it comprises a greyish-white (10Y 8/1) pebbly, clayey, coarse sand. Very few non-quartz clasts were noted; most clasts were less than 50 mm in length, the longest being 150 mm.

Sand grains observed with the SEM from the Polcrebo deposits were substantially larger than those from the other deposits. Like Crousa Common sand grains, source-rock characteristics predominated (figure 7), but with relatively high proportions of mechanically formed features: this difference between the two samples is attributed to the size variation rather than to any transport history. Two grains were well-rounded, but with high magnification no diagnostic features indicative of mode of transport could be discerned owing to chemical alteration.

(c) *Geophysical results*

Detailed electrical resistivity and seismic refraction surveys were unable to define clearly the sub-Gravel surface with evidence from the trial pits showing little correlation with geophysical depth soundings. The 1500 Ωm contour of the 15 m separation Wenner survey, however, with its associated steep fall in resistivity values, corresponds closely with the observed junction of 'Gravel' and Granite in the northwest corner of the outlier. Thus this contour may be taken provisionally as the northern and western gravel boundaries (figure 11). To the south, this contour more likely indicates the junction of heavily kaolinized granite with sound granite.

(d) *Interpretation*

At Polcrebo, (unlike St Agnes and Crousa), there is no large associated erosion remnant although a bench-like feature beneath parts at least of the 'Gravel' appears to be present. As the outlier lies on an isolated spur, however, the possible former extent of this bench cannot now be determined. A supposedly horizontal bench would impinge on the present Carnmenellis upland (the Boquio ridge) about 1.5 km to the north, but to the south and east it could have been widespread.

The coincident wedging-out of Tertiary sediment and rotten granite against a steeply rising slope in sound granite (pit 5) suggests that the basin of deposition may have originally been excavated from kaolinized granite. As at Crousa, however, the 'Gravel' fabric and SEM results confirm that considerable post-depositional rotting of the sediments must also have taken place. Whether the pre- and post-depositional rotting phases were broadly contemporaneous, with brief interruption for the deposition of the sands and gravels, cannot be determined for the present.

(e) *Age*

Presumably no-one would regard the Polcrebo sediments as Mesozoic, although theoretically they could be of any post-Armorican age. The kaolinitic nature of the clay sediments suggests an affinity with the other Tertiary sediments elsewhere in Devon and Cornwall. The degree of post-depositional alteration of the Polcrebo sediments and those at Crousa is similar, leading to the view that they are of similar age.

6. The geomorphological significance of the outliers

(a) *Introduction*

To assess the significance of the present results, it is first necessary to establish the chief features of the modern Cornish landscape; second, the interrelations of the four outliers; third, the relationship of the outliers to the modern physiography; fourth, the significance of the new data in a regional context; and, finally, a wider context for the regional evolutionary model.

(b) *Modern Cornish landscape features*

There are six primary geomorphological elements in the west-central Cornish landscape.

(i) *A near-level rock-based offshore platform up to 25 km wide, mostly submerged, the shoreward extension of which appears to coincide with the modern intertidal wave cut platform*

Wood (1974) regarded this platform as an ancient feature related to stable sea level throughout late Tertiary times. As the surface transgresses large faults that throw Mesozoic against Devonian outcrops on the sea bed, Wood reasoned that the surface originated in the Miocene. Donovan & Stride (1975, figure 2) recorded the presence of a −49 m submerged cliff about 25 km NNW of St Agnes Head.

(ii) *Steep sea cliffs, resulting at least partly from recent active marine attack, up to about 120 m high*

Little is known of the speed of coastal recession. The widely-occurring, comparatively small 'interglacial' (possibly Ipswichian) raised platforms and associated beaches around the whole of the southwest Peninsula suggest slow rates of erosion under temperate and/or periglacial conditions. Donovan & Stride (op.cit.) believed that the offshore submerged clifflines of Cornwall and Devon formed over 'millions of years'.

(iii) *A complex network of steep-sided valleys with convex side slopes the courses of which are apparently strongly directed by structural features in the Palaeozoic floor* (*Everard* 1977)

Everard presented evidence that the valleys pre-existed the Pliocene transgression when the St Erth deposits were laid down in the St Ives–Mounts Bay depression. The valleys are evidently graded to sea levels much lower than that of the present.

(iv) *One or more bench-like erosion surfaces, from which the modern stream courses originated, ranging in height from about 75 to 131 m ASL*

The surfaces are best recognized as interfluve flats of very limited width (figure 12) but, occasionally, plateaux of many hundreds of hectares are preserved in the Cornish landscape, as in the Lizard and at Nancekuke and Perranporth on the north side of the Peninsula. The erosion surfaces mostly transect Devonian metasediments but also occasionally granite boundaries to the extent of several hectometres.

Various attempts have been made to contour a single generalized surface (figure 12 for our own conceptual model; compare, for example, figure 14 in Everard 1977). Computer analysis of altitudinal data (Everard 1977) suggests that this very spectacular erosion surface in fact comprises several delicately arranged steps, rarely actually discernible in landscape vistas.

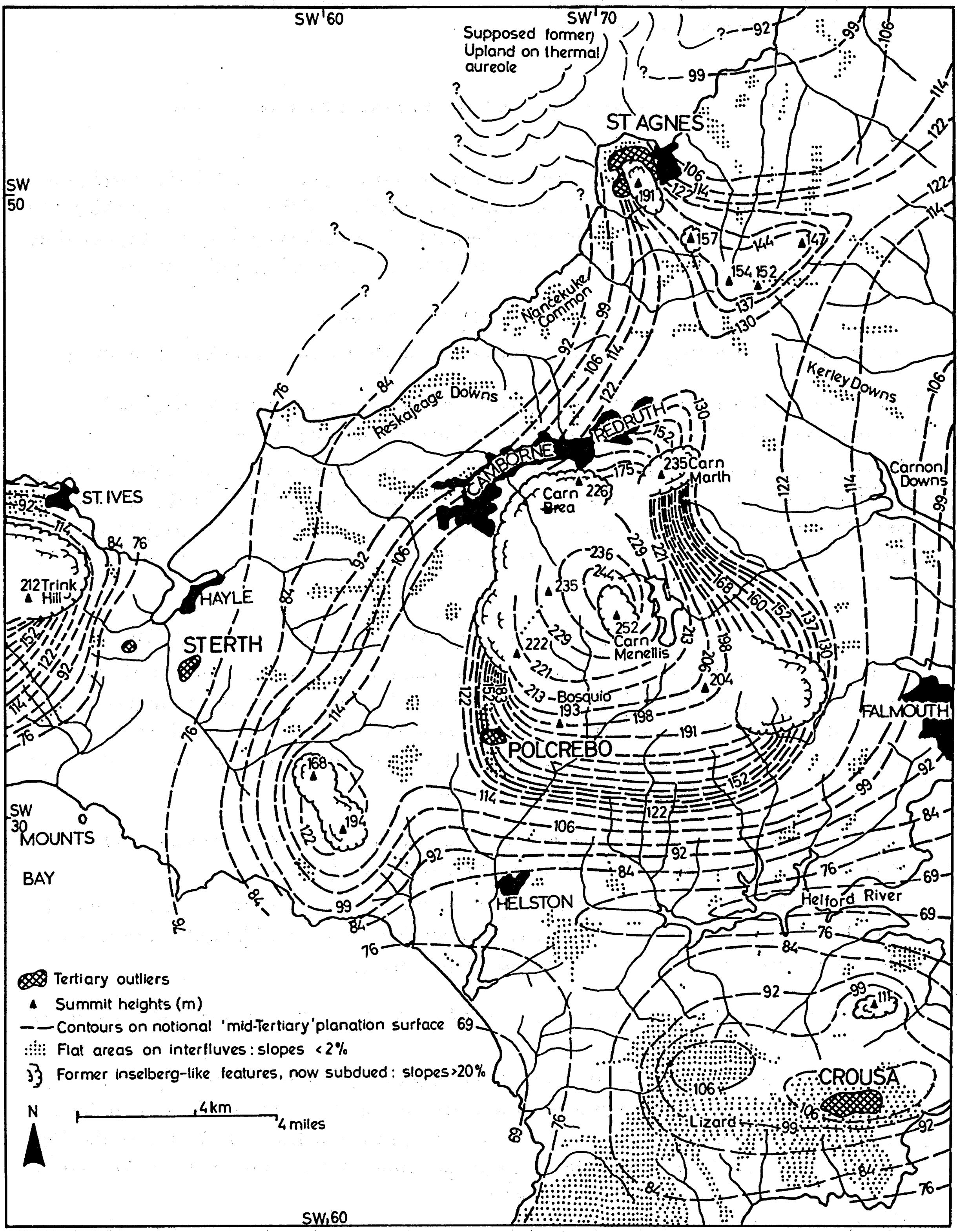

FIGURE 12. Notional form of the 'mid-Tertiary' (Reskajeage) planation surface and its relation to the Oligocene and Miocene outliers. Localities mentioned in the text are shown.

Some of the interfluve flats radial to the Carnmenellis upland are remarkably flat. The spur of Kerly Downs–Carnon Downs, for example, has an overall gradient of only 1:200 over 6 km. A similar gradient is present on the notional surface that intersects the interfluves over a wide area east of St Agnes and Perranporth on the north side of the peninsula.

The spur between Redruth and Reskajeage Downs is even flatter, sloping seawards at only 8 m in 5 km. The Lizard has vast areas that slope at less than 1:50. Virtually every age from Triassic (Fryer 1958) to Pleistocene (a general attribution) has been suggested for the age of this landscape feature.

Because this surface is obviously important in the landscape evolution of western Britain, whatever its origins, it should be accorded a new, non-genetic name. Terms previously applied to it such as 'Coastal Bench', 'Pliocene Platform', '90–131 m surface' and '121 m surface' are all now clearly misleading for different reasons. At Reskajeage Downs, the planation is as well developed as anywhere in the area, and this landscape component figures prominently in many vistas of Cornish landscape, whether viewed to the southwest from St Agnes Beacon or to the northeast from Lands End (figure 8). Therefore it is suggested that the term 'Reskajeage Surface' be applied; that this term should relate only to the areas of west and central Cornwall; and that it relate to the macromorphic planation surface landform broadly between 75 and 131 m ASL.

(v) *Prominences lying above the Reskajeage Surface*

Above the Reskajeage Surface, slopes generally steepen and the uplands (culminating on Carnmenellis at 252 m ASL) often have cliff-like marginal slopes (the slopes below Carn Brea and the cliff line along the north side of the Lands End Promontory being the best examples). The bases of the supposed cliff lines often coincide with the granite boundaries, but are otherwise independent of Armorican structure. These cliff lines have been regarded as the products of marine erosion; such is the interpretation given on the recently published BGS sheet 351/358 (1984), the spur-profile bench along the north side of the Lands End Promontory being regarded as the product of erosion 'at high sea levels'. Several writers claim to distinguish small higher-level plateau remnants in these areas, most recently Griffin & Gilmour (1981).

(vi) *The broad lowland of the St Ives–Mounts Bay depression, which contains on its flanks a number of Pliocene outliers* (*Mitchell et al.* 1973; *BGS sheet* 351/358)

The Pliocene deposits are undoubtedly marine (Mitchell *et al.* 1973), and on faunal grounds are considered to have formed in water about 10 m deep (Jenkins 1982). This would imply that this depression was once flooded to at least as high as the present 50 m ASL mark. There seems to be general agreement that the deposits of St Erth were formed in a pre-existing depression, which became a strait at the time of the Pliocene transgression. Some writers have argued that, at its maximum, the Pliocene transgression also cut the '122 m' (Reskajeage) Surface that flanks the depression (Wilson 1975).

(*c*) *The structure and physiographic setting of the outliers*

As discussed previously in §2*e*, non-horizontal stratification in the St Agnes (*s.s.*) sediments can adequately be accounted for as primary depositional structures. No inclined structures, whether primary or secondary, have been observed in any of the other outliers. Such disturbance as has been observed clearly results from Pleistocene freeze–thaw activity as has been reported in the Tertiary sediments of other West Country Palaeogene basins (Dinely 1963; Jenkins and Vincent 1981).

Everard's (1977) conclusion that the Polcrebo and Crousa deposits have survived because of their watershed location is supported here; the same conclusion for the survival of the outliers at St Agnes seems inescapable (figure 12). By inference, in view of their 'perched' position on major watersheds, the original extent of sediment could have been large. If, as hypothesized in this paper, the Reskajeage Surface has altered little since the deposition of the four outliers, the remnant deposits must represent merely the attentuated margins of sheets that, in the Tertiary Plains beyond, may have reached several decametres or even hectometres in thickness.

Certainly, there is some indirect evidence that mid-Tertiary sedimentation occurred away from the uplands. For instance, gravels, of presumed Tertiary age, have been recorded by Edmonds *et al.* (1969) at Pendarves, south of Camborne. Stained and rotted surfaces resembling those of the sub-St Agnes and sub-Crousa are found elsewhere in the modern Cornish landscape; for example, the deeply-stained slates recently exposed in cuttings on the A390 between Chiverton Cross and Truro and on the A30 Camborne to Hayle roads. Possibly such features are widespread and simply await discovery on unexposed ground. All these features and, indeed, the four outliers themselves, owe their discovery to chance intersections during mining and engineering work; there remains, therefore, the possibility that further occurrences will yet emerge.

If, on the other hand, it is postulated that the sediments preserved in the form of the four outliers were never much more widespread than now, and that they owe their existence to a number of narrow upwarps (NNW–SSE in the case of the St Agnes outliers; roughly E–W in the cases of Polcrebo and Crousa) along what were sedimentary traps in the mid-Tertiary (i.e. there has been a physiographic inversion in all three cases), it would be very difficult to produce positive evidence to refute this.

Unfortunately, recent structural studies of the southwest Peninsula and adjacent Continental Shelf, as discussed below, are, at best, somewhat unhelpful in resolving this issue. There seems to be general agreement that large dextral transcurrent faults were active in early and mid-Tertiary times in Devon; we are well aware of the parallelism of these features with the Chiverton Cross–St Agnes Beacon–St Agnes Head ridge. The Devon faults have influenced significantly the alignment of the modern drainage in the area, and they also appear to have functioned as the margins of crustal downsags in which Palaeogene fluvial and lacustrine sediments were trapped (figure 1). Although traps were small in area, they are surprisingly deep, over 600 m at Petrockstow (Freshney *et al.* 1979) and over 1300 m at Bovey (Edwards 1976) and some of the NW–SE faults can be shown to have vertical displacements measurable in decametres; according to Shearman (1967) they are associated with fault scarps, which displace erosion surfaces comparable with those described in this paper. Dearman (1964) implies that the fault lines may still be active, albeit at a reduced level. The Tertiary basin at Dutson, east Cornwall, is fault bounded; by implication the faults are post-Upper Eocene in age. In the Bovey Basin, the sub-Eocene surface lies at −1300 m, whereas only a few kilometres to the west on Dartmoor, it lies at least 2000 m higher. The question then arises as to whether western-central Cornwall escaped such disturbance.

On the other hand, recent research into the Tertiary structure of the Western Approaches offers a somewhat contradictory picture of structural events in the Tertiary. For example, Evans & Hughes (1984) could discern no 'Alpine' tectonic event in the mid- to late Tertiary sequences that floor the area southwest of the Scilly Isles, nor any post-mid-Miocene faulting of any kind. Evans & Hughes (1984) infer a post-Oligocene history for the Cornubian Peninsula similar to that of the shelf area southwest of the Scillies, any crustal distortion here being 'of an epeirogenic nature of very broad extent'.

(*d*) *The relation of the Tertiary outliers to the modern physiography*

Numerous writers (for example Freshney *et al.* 1982) have recognized that the physiography of the Cornubian Peninsula was more or less in its present form as early as the Eocene, except, perhaps, that coastal erosion has reduced its width since then. Certainly this view of landscape stability since the early Tertiary is supported by the evidence presented in this paper from western and central Cornwall. If the Beacon Cottage sediments are accepted as of Oligocene age, and the contiguous St Agnes sediments as Miocene, then landscape evolution in this area clearly must have been extremely slow; moreover, by extrapolation, landscape elements, in particular the Reskajeage Surface, developed over a long period and were persistent. However, rather than viewing the persistence of the Reskajeage Surface in such terms, many previous workers have regarded its 'freshness' as indicative of geological youthfulness.

As far as we are aware, no marine deposits have ever been found on any part of the Surface, yet there has been a persistent tendency to regard the surface as having a marine origin. It is surely timely to demolish this concept once and for all; firstly, as pointed out by Stephens (1980) (following King 1963), such a surface would be wider by a several-fold factor than any known modern shoreline wave-cut bench. Secondly, in our view, it is absurd to think that a marine agency that was capable of wide surface across hard Devonian metasediments and forming steep slopes in granite at Carn Brea was not apparently able to remove the Tertiary sands and clays at the exposed northern end of St Agnes Beacon. The same general relation holds for the Crousa deposits and the cutting of the Lizard surface. Plainly, the Reskajeage Surface, whatever its origins, must have existed essentially in its present form *before* the accumulation of the Miocene at St Agnes and the undated sediment at Crousa.

Accepting that the Miocene sediments have never been covered by the sea, the same must be true of the mid-Oligocene Beacon Cottage Farm outlier at a similar altitude. Thus, the sub-St Agnes surface, which is evidently older than the late Miocene, could not have been formed by a marine agency in the period between then and the mid-Oligocene. Marine transgression, if it played any part in fashioning the landscape of western central Cornwall, must have been at a level lower than the Reskajeage Surface or was pre-mid-Oligocene in age. The simplest hypothesis is of course that the area has never been inundated by the sea, except shallowly, near the close of the Tertiary, by the St Erth transgression (which, significantly, seems not to have left any obvious bevel in the landscape when at its maximum). Figure 12 shows the generalized contours on the Reskajeage Surface. Clearly, the area between New Downs Pits and the modern cliff edge at St Agnes Head is part of this surface; also, the 'inner' edge of the Surface coincides almost exactly with the bedrock break of slope on the north side of St Agnes Beacon (figures 4 and 8). The gradient of the sub-St Agnes floor beneath the New Downs Pits and adjacent fields to the north continues beyond the veneer of Miocene sediment virtually unchanged. The same general relation applies at Crousa Downs.

The conclusion is inescapable: the Reskajeage Surface is the homologue of the sub-St Agnes surface. There is, of course, no suggestion that this surface was everywhere once covered by

Miocene sediment; rather that, locally, where topographic or when climatic conditions were favourable, a spread of Miocene sediment blanketed the mid-Tertiary landscape.

In the present authors' opinion, the Reskajeage Surface was substantially formed between the mid-Oligocene and the late-Miocene. The relation of the Surface to the Beacon Cottage Outlier is unfortunately not clear, for hereabouts both have been degraded by post-Reskajeage valley incision. If, as is implied in figure 2, a tongue of Beacon Sands overlaps the Oligocene in the area northeast of Beacon Cottage Farm, it is possible that the 'Red Blush' clays (Dewey's description) represent stained, deeply-weathered soils of mid-Tertiary age that underlie the sub-Miocene unconformity. Such investigations were beyond the resources of the present survey and they remain an intriguing subject for future study; clearly additional borehole data into the Palaeozoic floor under the Beacon Cottage Farm Outlier would greatly have assisted interpretation.

Thus, far from being a surface of marine planation, the Reskajeage Surface is more properly to be regarded as having been produced subaerially and the prominences of the Spine uplands such as Carn Brea, Carn Marth, Godolphin Hill and St Agnes Beacon are to be regarded as now-degraded inselbergs. The modern Reskajeage Surface, even now deeply stained in places, is then to be regarded as an exposed basal weathering surface, much of the associated thick mid-Tertiary weathering residues (as still preserved beneath the Polcrebo and Crousa Outliers) presumably being removed chiefly during the Pleistocene periglacial phases. The deposits of St Agnes and elsewhere may then be recognized, at least in part, as the wind-redistributed and colluviated slope sediments derived from the mid-Tertiary weathering profiles of tropical or subtropical type.

(*e*) *The relation of the outliers to other Tertiary deposits in the west of England*

There is good reason to believe that, eventually, the Oligocene deposits at Beacon Cottage Farm will be correlated with Bovey Formation sediments elsewhere in the West Country. The mid-Oligocene dating for the Museum sample invites a possible correlation with the Abbrook Clay Member of the Bovey Basin succession (Edwards 1976). According to Edwards, the Abbrook Clay was deposited at a time of overlap onto the flanks of a hitherto fault-controlled trough.

Possibly the onset of sedimentation at Beacon Cottage and the overlap of the Abbrook Clay were triggered by the same regional influence.

With regard to the deposits at Crousa and Polcrebo, attention is drawn to the many similarities of these deposits with those at Orleigh Court in North Devon (Rogers & Simpson 1937; Edmonds *et al.* 1979), all three being dominated by gravelly deposits that have suffered a great deal of chemical weathering. Edmonds *et al.* (1979) regarded the Orleigh Court sediments as Eocene in age and possibly derived from a nearby cover of Cretaceous Chalk.

Deep chemical weathering, commonly attributed to Tertiary tropical or subtropical processes, is also well known at numerous other localities in the west of England (Bristow 1968, 1977; Fookes *et al.* 1971; Eden & Green 1971; Sheppard 1977; Isaac 1981, 1983). Isaac regarded the so-called 'Plateau Deposits' of East Devon as a residual complex of early-Tertiary deep weathering profiles of lateritic type, developed on the Cretaceous Chalk by deep weathering in early Tertiary times. Bristow (1968) concluded that the sediments of the Petrockstow Basin were derived from the deeply weathered Upper Palaeozoic outcrops surrounding the Basin and that a weathering mantle similar to that preserved beneath the

Palaeogene sediments in the Basin was once widespread in southwest England. Freshney *et al.* (1982) regarded the Oligocene clay mineral suite in the Dutson Basin as having been derived from an immature subtropical weathering profile.

(*f*) *The west Cornish Outliers and Reskajeage Surface considered in a wider context*

The broad interpretation of the evolution of the west Cornish landscape, as proposed here, matches closely that suggested recently for the Welsh landscape by Battiau-Queney (1984), who believes that the latter is explicable in terms of a single widespread polygenetic planation surface, the original constituent landforms having been shaped in a tropical or subtropical environment with associated typical weathering products. Large-scale altitudinal variations are attributed to late Tertiary warping along relatively few major structural lines, whereas smaller-scale upstanding rock masses are regarded as 'true inselbergs', recognized, for example, on the St Davids and Goodwick promontories in Dyfed (Battiau-Queney 1984, p. 234, figure 1). The physiographic similarities of this area with west Cornwall are striking.

In south Dyfed a similar, if slightly lower, counterpart of the Reskajeage Surface cuts across tightly folded Upper Palaeozoics. It is associated with kaolinitic clays at Flimston, which appear to be piped into the Carboniferous Limestone foundation. The clays remain undated but the presence of carbonaceous sediment, as recorded by Murchison (1839), suggests an Oligocene age.

In southern Ireland, the preservation of Cretaceous (Walsh 1966) and Tertiary (Walsh 1965) outliers in mid-Kerry and of Palaeogene at Ballymacadam, Tipperary (Watts 1957), points here to a broadly similar landscape evolution.

Effective comparisons may also be made of the present study with results from elsewhere in northwest Europe where the permanence of landscape features outside the post-Armorican Basins has been stressed. Emphasis has been laid on the slow subaerial evolution under, probably, a wide range of morphoclimatic régimes; the inheritance of macroforms in the landscape from remote times and the dominance of vertical structural effects in the determination of physiographic contrasts. In southeast England, for example, Jones (1980) relates the landscape to the dominance of a sub-Palaeogene surface 'developed in a permanent structural instability but with spatial variation in the balance between erosion and deposition'. Klein (1975) proposes a similar model for Brittany, terming the fundamental landscape feature there the 'Peneplaine de l'ouest de la France'. The extreme case, perhaps, is that of Watson (1985) who presents evidence that the grosser upland morphology of the northern Scottish Highlands is essentially one inherited from a sub-Devonian land surface.

In view of the similarities in the landscape evolution for the Tertiary period across much of northwest Europe, there would now appear to be a case for an overview of events in this period, at least for the Celtic Sea area, as has already been done for the Pleistocene period (Mitchell 1976).

7. Summary and conclusions

The main conclusions arising from the results presented in this paper concern: (*a*) the age and origin of the Tertiary outliers; and (*b*) the implications of the results for the long-term geomorphological evolution of west-central Cornwall.

(*a*) Although it has not been possible to determine the precise relation between the two formations, the deposits from Beacon Cottage Farm and New Downs Pits near St Agnes can no longer be regarded as coeval, and a new classification of them is proposed. A mid-Oligocene age of the flora in the BGS sample MR10401, thought to have been collected from the Beacon Cottage Farm sediments in 1932, is confirmed. Palynological evidence indicates that the sediments there formed under a subtropical climate, partly, if not wholly in a lacustrine environment. These sediments are regarded as the equivalents of the Bovey Formation of Devon (i.e. Palaeogene in age).

The sediments in the New Downs Pits, by contrast, contain lignitic material that has yielded a poor although distinctive pollen assemblage indicative of a Miocene age. This appears to be the first proven Miocene extant in the British landscape. These sediments are reclassified into a formation termed the St Agnes Formation (*sensu stricto*) and comprise Doble, New Downs and Beacon Members. Evidence is presented that suggests strongly that the St Agnes Formation (*s.s.*) formed as aeolian and colluvial sediments, probably under warm temperate conditions. Previous interpretations of their origin as marine or fluvial sediments are shown to be no longer tenable. Both the St Agnes and Beacon Cottage Farm outliers appear to comprise simple primary structures. Their residual bulk appears to reflect merely the vicissitudes of later erosion.

No fossils have yet been found in the Crousa Common and Polcrebo Downs deposits. On the basis of their sedimentological properties and geomorphological associations, they are thought to postdate the planation of the Armorican foundation with which they are unconformable, and to be Palaeogene in age. The sub-Tertiary surface in both cases comprises deeply weathered bedrock.

TABLE 4. SUMMARY OF TERTIARY EVENTS IN WEST/CENTRAL CORNWALL

Pleistocene	removal of much surviving Tertiary sediments and weathered zones under fluvial and periglacial conditions regional uplift	—
Pliocene	deposition of St Erth deposits St Erth transgression cutting of offshore platform by marine processes; attenuation of SW Peninsula by marine attack. Valley incision through Reskajeage Surface	—
Miocene	regional uplift deposition of St Agnes Formation (*s.s.*) sediments cutting of Reskajeage Surface under subaerial conditions	↑ Crousa and Polcrebo sediments could have formed at any time in this interval
Oligocene	deposition of Beacon Cottage Farm sediments	│
Eocene		↓

(*b*) It is suggested that the prominent, dissected planation surface present throughout much of west central Cornwall and lying between *ca.* 75 and 131 m be termed the Reskajeage Surface. The sub-St Agnes surface is regarded as part of this feature. It is concluded that sea level never reached this height range throughout mid- and late Tertiary and Pleistocene times, thus excluding the widely held view that the feature formed through marine activity. Instead it is suggested that the Reskajeage Surface represents a tropical or sub-tropical etchplain, formerly mantled by saprolite of varying thickness and with upstanding inselbergs, and formed over a long period before late Miocene times. Valley incision would have taken place in late Tertiary times following regional uplift during the late Miocene or early Pliocene.

The present study supports the view that the Cornish landscape has changed little at the macro-scale since the early Tertiary; the main exceptions to this picture of prolonged morphodynamic stability would seem to be cliff erosion leading to a narrowing of the Peninsula, valley incision and redistribution of Tertiary weathering products, together with some freshly weathered rock, mainly through Pleistocene periglacial activity.

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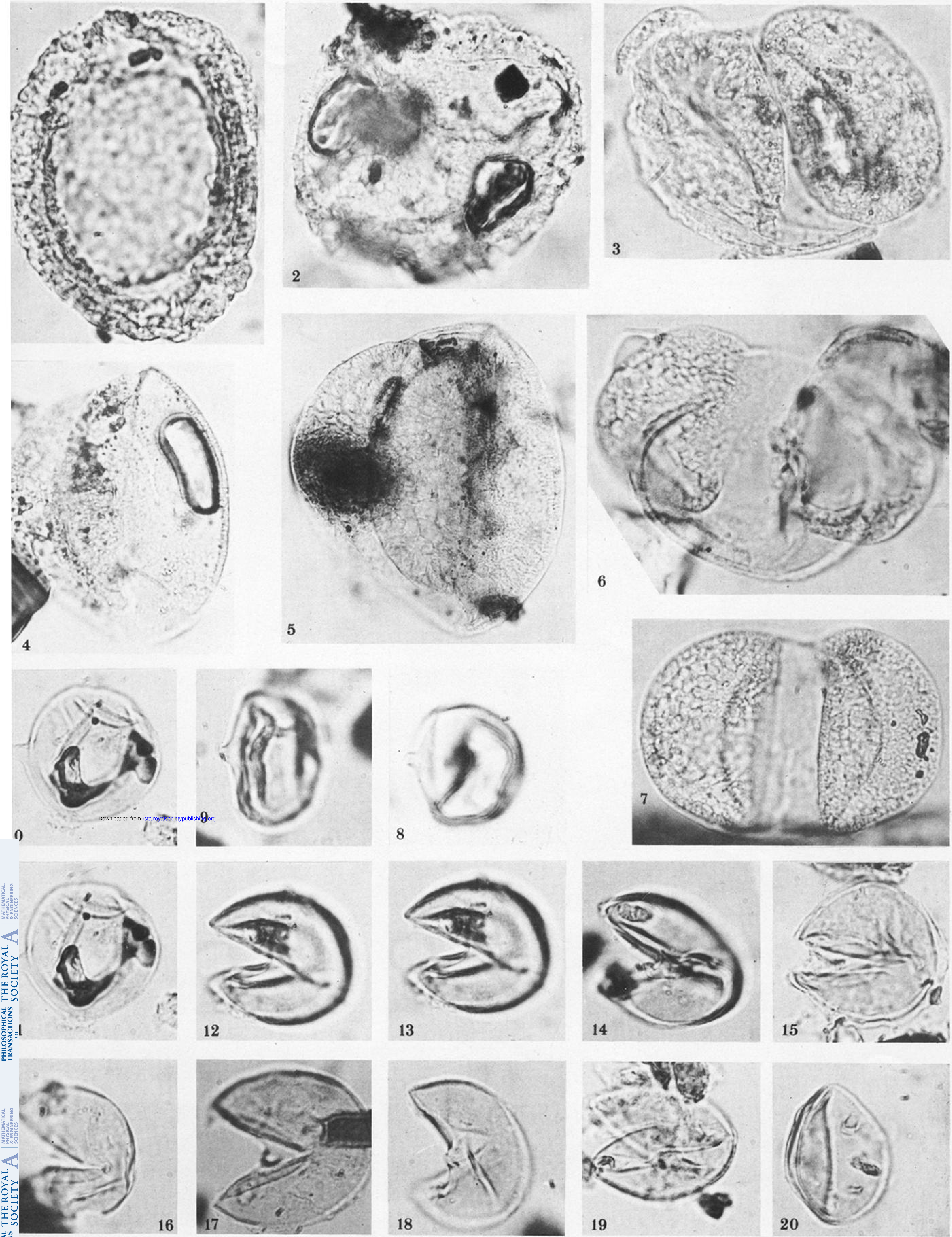

Plate 1. Gymnosperm pollen from the Miocene St Agnes Formation sample at New Downs Pit. All photographs are magn. × 1000 except figures 5 and 6, which are magn. × 750. Figures 1 and 2, *Tsugaepollenites*; figures 3 and 4, *Pityosporites* sylvestris-type; figures 5 and 6, *Abiespollenites*; figure 7, *Pityosporites* haploxylon-type; figures 8–11, *Sequoiapollenites*; figures 12–19, *Inaperturopollenites*; figure 20, *Cycadopites*.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

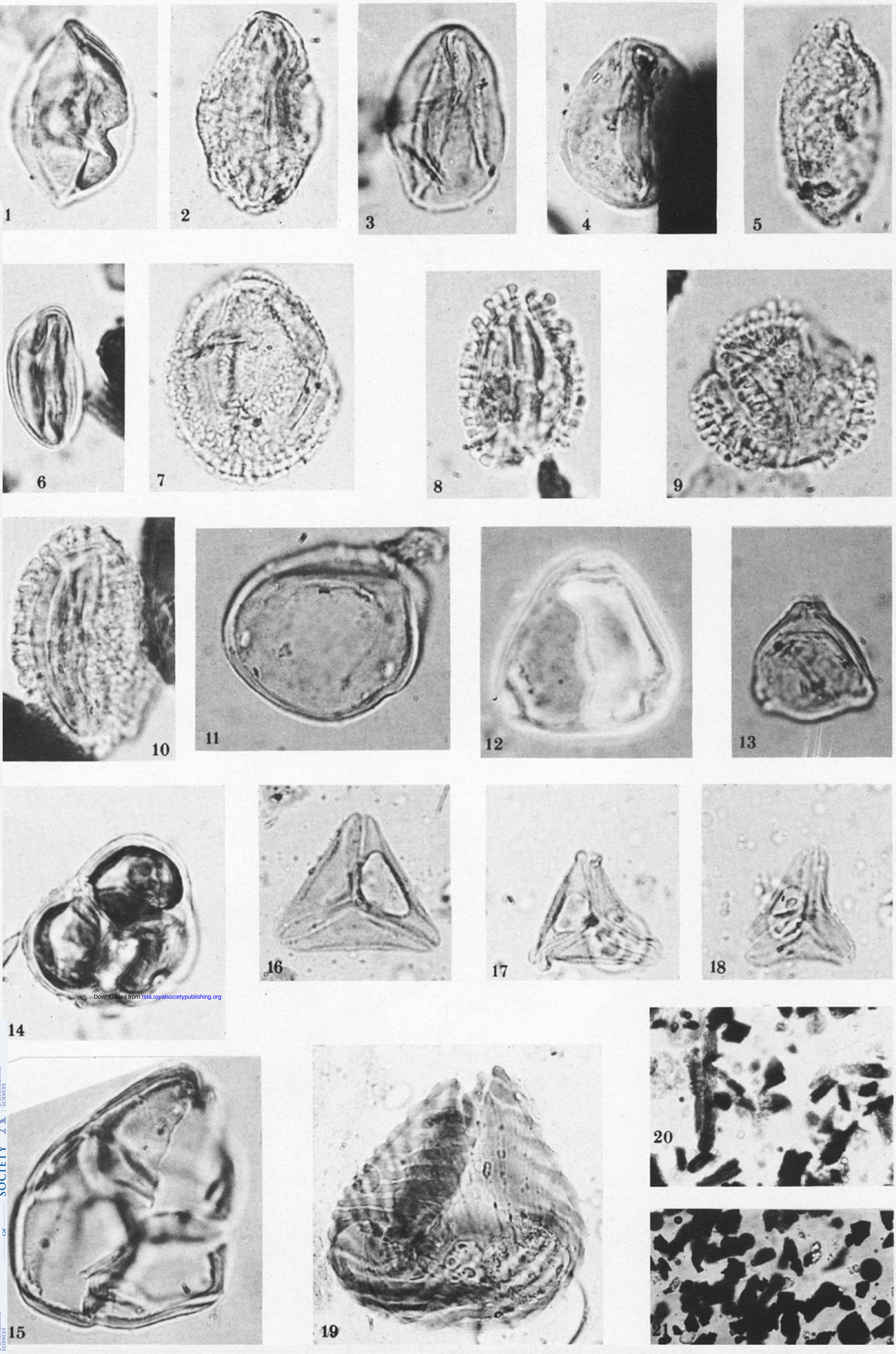

Plate 2. Figures 1–15 are of pollen from the Miocene St Agnes Formation at New Downs Pit. (Magn. × 1000.) Figures 16–19 are from Dewey's sample MR10401 thought to be from the Beacon Cottage Farm claypits. (Magn. × 1000.) Figures 20 and 21 are of palynodebris from the Miocene St Agnes Formation at New Downs Pit. (Magn. × 50.) Figure 1, *Cycadopites*; figures 2 and 3, *Tricolpopollenites*; figure 4, *Monocolpopollenites*; figure 5, *Tricolpopollenites*; figures 6 and 7, *Tricolporopollenites* spp.; figures 8–10, *Ilexpollenites*; figure 11, *Subtriporopollenites*; figure 12, *Porocolpopollenites vestibulum*; figure 13, *Momipites*; figures 14–15, *Erecipites*; figures 16–18, *Boehlensipollis hohli*; figure 19, *Cicatricosisporites paradorogensis*; figure 20, black debris, transparent debris made up of tracheid cells and leaf cuticle, and pollen, from the 19 samples; figure 21, black debris from one of the unproductive samples collected at other times, and transparent debris and pollen are completely absent.