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Periglacial features in the Bovey Basin, south Devon

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Spectacular periglacial features have been observed in a recently unheaded ball clay quarry in the Bovey Basin. The structures extend to a depth of 13m below the ground surface and are 20-25m in diameter. Previous authors have inferred a periglacial origin for the structures and that suggestion is supported and developed. Three factors have been identified as being important in the formation of the features: 1) An interaction with the gravel heading. 2) Variation in moisture content and permeability between lignitic strata and the clays. 3) The dip of the sequence.
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Introduction

The term "ball clay" is applied to plastic sedimentary clays which have a high content of kaolinite and which possess white-firing properties and high green strength (Mitchell and Stentiford 1973). The name "ball clay", however, is not derived from any specific property of the clay but from the original method of production (Scott 1929), In open pits, the clay was cut into cubes, the sides of which were approximately 22 to 25cm and each weighed 14 to 16kg. The plastic nature of the clays allowed the rounding of the comers and edges as it was handled and hence the production of a “ball”. The true ball clays are won from three deposits in the south-west of England, namely an area in Dorset, the Petrockstow Basin and the Bovey Basin. It is with structures found in the Bovey Basin that this paper is concerned.

The Geology of the Bovey Basin

The Bovey Basin (11km x 8km) is situated east of the Dartmoor Granite in south Devon (Fig 1). This basin together with the Petrockstow Basin lies within the Sticklepath Fault System which acted as a sedimentary trap during the early Tertiary. It was in subsiding areas along this fault system that the disordered kaolinite, derived from the weathering of the country rocks, as well as ordered kaolinite derived from hydrothermal "china clay" deposits within the Dartmoor Granite, collected (Vincent 1974).

The Basin has been worked for ball-clays for 300 years and the excavations have largely been confined to the eastern outcrop (as they still are at the time of writing). The commercial seams in the western part of the Basin are covered by the more recent unconformable Bovey Formation sediments. Scott (1929) recognised a two-way division which he identified as "stoneware clay" and "ball-clay', the outcrops of which stretched from Chudleigh Knighton in the north to Newton Abbot in the south, the latter type overlying the former. Edwards (1970) identified the Abbrook Member, clays and sands with little carbonaceous matter approximating to Scott's "stoneware clays", and the Southacre Member, clays and lignites passing downwards into mainly lignitic material (approximating to Scott's "ball clays"). Study of the Southacre Member to the north shows a diminution of the lignite content, which becomes virtually nil to the north of the A38 trunk road in Chudleigh Knighton Quarry (SX 841771). Towards Bovey Tracey increasing occurrence of sand limits further working. Vincent (1974) attributes this pattern to outwash fan, lacustrine and back-swamp facies. This outcrop pattern is summarised in Fig. 1.

The structures which are the subject of this paper occur in Clay Lane Quarry (SX 844768), immediately south of the A38 trunk road near Chudleigh Knighton. This pit was opened during the latter part of 1978 to replace eventually the production from Chudleigh Knighton Quarry. The initial stage of development was the removal of "overburden", which largely consists of alluvial gravel. The pebbles in this gravel include granite and aureole rocks, Devonian limestones and intrusives, as well as flints. Clay Lane Quarry, although only 200m south-east of Chudleigh Knighton Quarry, does contain thin lignitic bands which increase towards the south-east. As quarry development progressed, it became obvious (June 1979) that the straight line interpretations based upon the limited number of boreholes bore little resemblance to the structures which were being uncovered in the upper part of the quarry.

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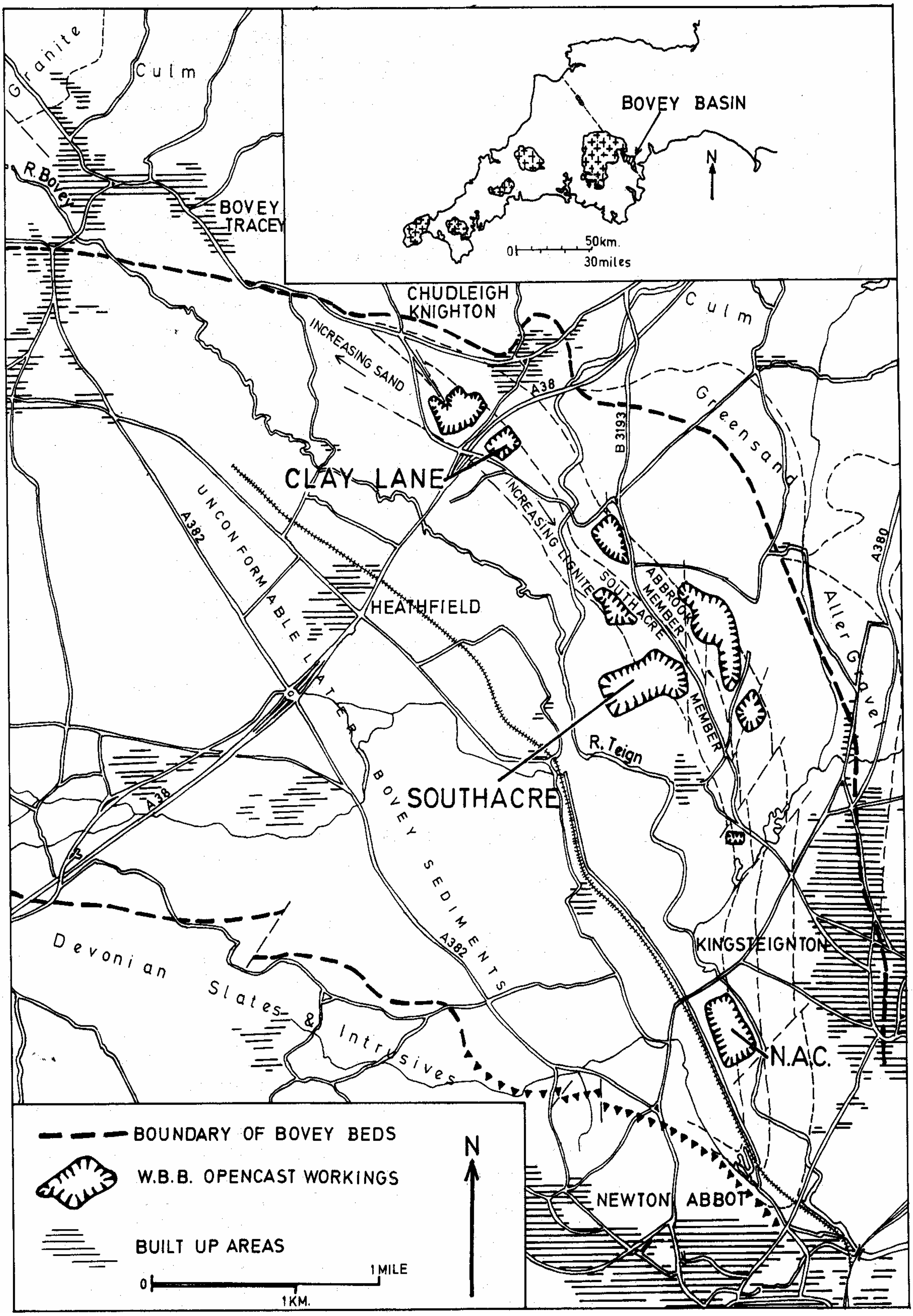

Figure 1. The geology of part of the Bovey Basin. The inset shows the location of the Bovey Basin in south-west England. (W.B.B. = Watts Blake Bearne & Co. P.L.C.)

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Description of the structures

The first impression gained, as the gravels were being removed, was of deep channels traversing the uncovered area. Further exposure, however, revealed that the deeper gravel pockets were circular or elliptical in shape, with upward projection of clay between the gravel pockets. As the first working bench progressed it became apparent that there was a considerable amount of contortion. The anticipated structure, based upon borehole interpretations and adjacent workings, was of a plane dip of 1 in 4 to the south-west, with a recognisable seam classification based upon clay property parameters. The structures seen in the upper part of Clay Lane Quarry, however, included sharp anticlines, vertical seams, dips to all points of the compass, and rupture and mixing of the normal seam boundaries.

At this stage it was realised that the structures were similar to those described by Dineley (1963) and discussed by Gouldstone (1975). Over the period 1951-1959, Dineley observed, in detail, nine similar structures as the faces in Southacre Quarry (SX 854755) were worked for clay (Fig. 2). A periglacial origin was attributed to the contortions observed.

The contortions seen at Clay Lane (Fig. 3) appear to be more extreme than those observed by Dineley, but a periglacial origin for the features appears to be most likely. The gravel pockets are 20-25m in diameter at the surface and penetrate to a depth of 12 to 13m from the original surface. The clay "anticlines" between the gravel pockets appear almost to reach the surface in some areas. The boulders and pebbles in the gravel have an imbricate structure and are aligned parallel to the sides of the gravel pocket, as indeed are the finer-grained horizons. The latter feature is considered to indicate bodily downward movement at the centre of the pocket. Minor features which occasionally occur include the downward migration of pebbles into the clay below (from which hard rock is normally totally absent), and some ice wedging. The contortions occur in all vertical planes and do not appear to be orientated in any particular direction, except that the longest axes of two of the elliptical gravel pockets are parallel to the strike.

The origin of the structures

Dineley (1963) recognised the contortions which occur in the clays and lignitic bands, but did not comment on the structure of the overlying gravels. Dineley's model for the possible origin of the anticlinal disturbance is shown on Fig. 4. The areas marked A are regions of expanding permafrost, and the arrows denote directions of growth of frozen ground. C is a stratum of pale ball clay subjected to pressure from overburden and/or the permafrost of regions A. C rests upon D, a sub-stratum of comparatively unyielding, perhaps frozen, darker clay. Point B is a region of pressure release due perhaps either to i) difference in weight or strength of overburden, or ii) absence of permafrost (or a combination of both). Therefore, at E plastic clay accumulates in laccolitic form by flow from surrounding areas C. The depth of Dineley's section is approximately 6 metres.

Dineley's model is considered to explain the essential origin of the contortions in the clay but does not take into account the intimate relationship of the gravels to the features, or the dip which must have existed before periglaciation. Dineley did, however, recognise the importance of lignitic materials in the formation of the contortions. The spectacular features which occur at Clay Lane Quarry are not found in the low-carbon Abbrook Member quarries, and perhaps more significantly, are not found in the same, but low-carbon clay sequence at Chudleigh Knighton Quarry, a mere 200m to the north. The reason for this is perhaps the higher permeability and higher moisture content of the lignitic materials. Best and Fookes (1970) demonstrated the ball clays to be overconsolidated. Vincent (1974) showed that the moisture contents of the clays (on dry weight basis) were much lower than their Plastic Limits. When the ball clays are referred to commercially as being “very plastic” the statement refers to a reconstituted property rather than their condition in the ground. The actual moisture content of the clays generally varies with the proportions of kaolinite, quartz and carbon. Table 1 shows the variation of moisture content in a range of clays. Although the results used in Table 1 were collected for a different purpose and only sample 3 is from the Chudleigh Knighton Area (and would not be considered typical), the general indications are considered to be relevant. Siliceous clay of low carbon content is represented by sample 4, which has 11.6% moisture. Clayey silts of higher SiO_2 content have less than 10% moisture. As the carbon content of the clay increases (as demonstrated by the loss-on-ignition) so also the moisture content increases. Samples 1 and 2 are carbonaceous ball clays and show moisture contents of 25-26%. The most carbonaceous saleable ball clays have loss-on-ignition values of 20-22% and moisture contents of around 30%. In the range investigated, there is a straight line relationship between loss-on-ignition and

Table 1

Sample	%SiO_2	% Loss-on-Ignition	% Moisture dry Weight basis	Plastic Limit
1	45.3	17.8	26	32
2	45.7	17.1	25	36
3	56.8	9.4	18	26
4	66.6	6.5	11.6	18

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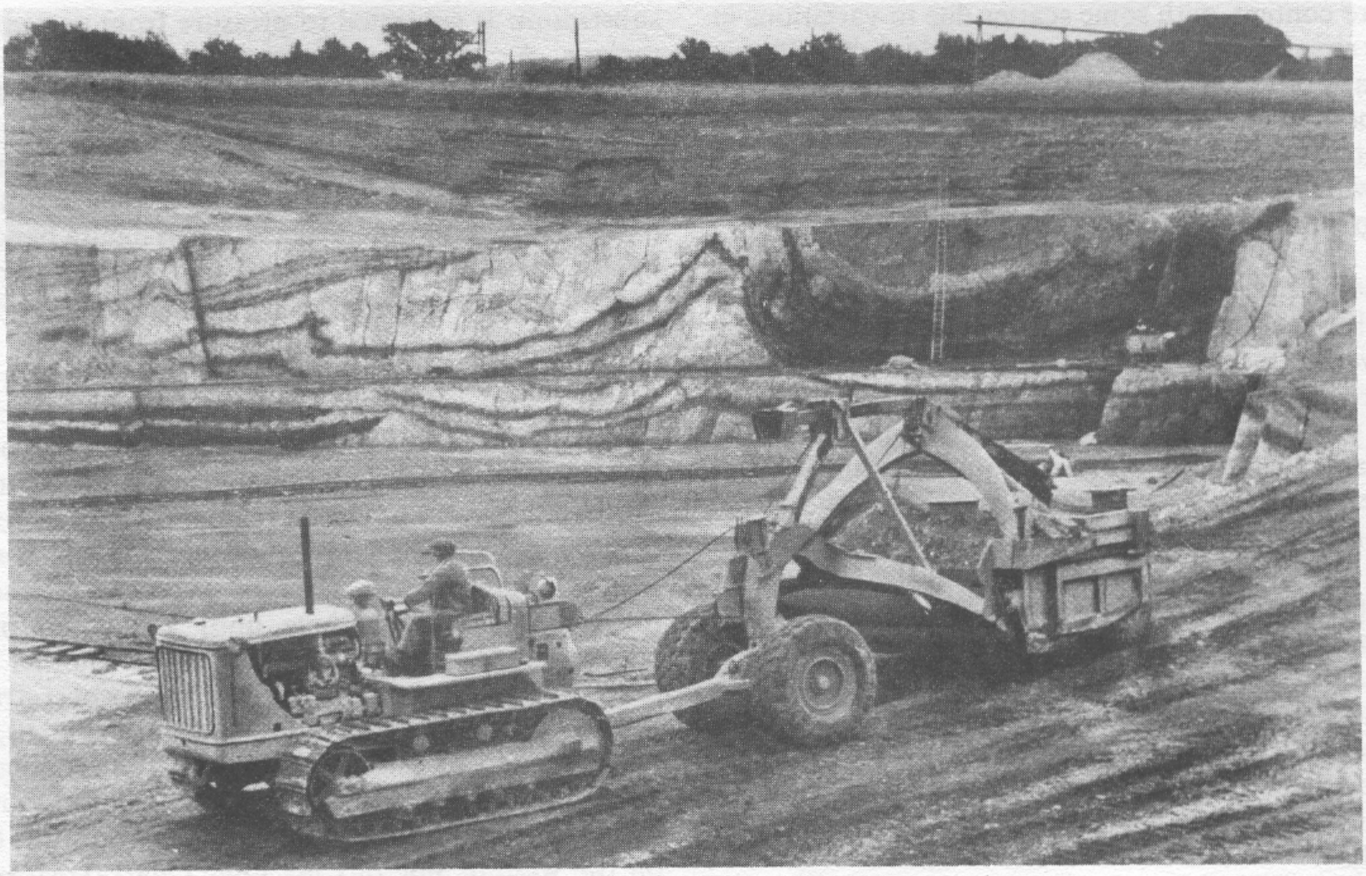

Figure 2. Periglacial contortions in Southacre Quarry, c.1955.

Figure 3. Periglacial contortions in Clay Lane Quarry, January 1981.

moisture content, with some scatter due to variations in particle size distribution and clay mineralogy. The Plastic Limits and other such parameters vary in accordance with the same criteria (Vincent 1974). Clay and lignite are end members and most lignitic materials are admixtures, albeit with moisture contents of more than 40% and a much greater permeability than the clays.

The model to explain the Clay Lane structures is probably much more complex than that suggested by Dineley. Firstly the sequence of clays would have various moisture contents and the lignitic horizons would have greater permeability. Secondly, there is an inclination of the beds, so that exactly the same sequence would be in an unfrozen state down dip. The moisture in clays exists in pores on surfaces, and around the edges of the particles. Clay *in situ* has little plasticity without the addition of water and work, and it is difficult to visualise the material reacting to pressure by flowing. In the frozen state, however, the ice formed on particle surfaces and edges would tend to push the particles apart and facilitate their movement relative to each other, so that a frozen ball clay subjected to pressure would tend to flow. Frozen ball clay has been observed to swell and assume greater apparent plasticity.

The trigger mechanism for the structures is suggested by Dineley to be either a difference in weight, or strength, of the overburden, or absence of permafrost in certain areas. The normal hollows and swells which form the erosive base of the gravels in conjunction with the outcrop position of the permeable lignite bands may well provide the initiation of the structures, A model as shown in Fig. 5 is suggested. As in Dineley's model, the substratum is subjected to pressure from permafrost at regions A, which are gravel-filled hollows in the impermeable clay where the water could collect. Point B is a region of pressure release due to i) being a high point on the gravel/clay interface and ii) being a point where drainage was enhanced due to the presence of a lignite band intersecting the interface. Most lignite bands have lignitic clays on either side, so that pressure would be exerted on the clays both above and below by the freezing of the relatively great amount of water in the lignitic bands. The pressure would act at right angles to the bedding planes. Consequently, clay above the lignitic horizon :would be subjected to a downward pressure (from region Al) and an oblique upward pressure from the lignitic band. The clay at region X would therefore be between the opposing forces and tend to flow away from point X towards an area of pressure release. The movement would continue until a zone of pressure release was reached such as point B (i.e. another lignitic band) or point Z. In the latter case, the highest stratum is extremely siliceous with a low moisture content, which would tend to act as a resistant block. The bedding planes would be forced into a vertical position but little contortion would take place (these features can be seen on the western side of Clay Lane Quarry). Meanwhile, below the lignitic band, a further pressure regime would have existed. The two sources of pressure, the lignitic band and region A2, would have tended to supplement each other in a downward direction, until the effect of the resistant block of non-frozen ground would have turned the pressure back towards the lignitic band. At point Y, the clay would tend to flow towards the lignitic band, which, because material has migrated from point X,

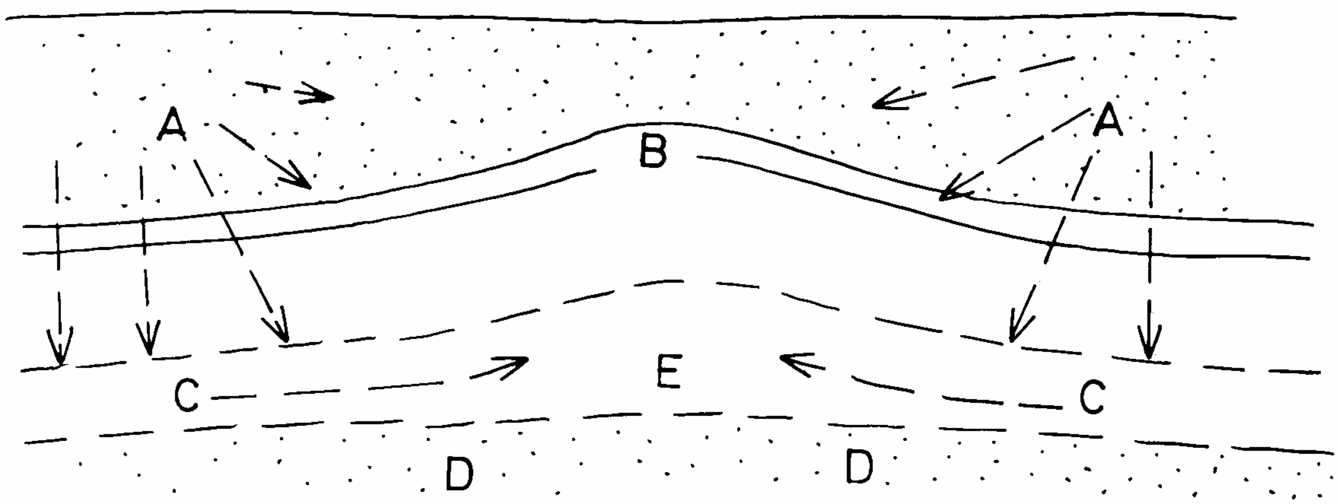

Figure 4. Possible origin of contortions in the Bovey Formation (after Dineley 1963). See text for explanation.

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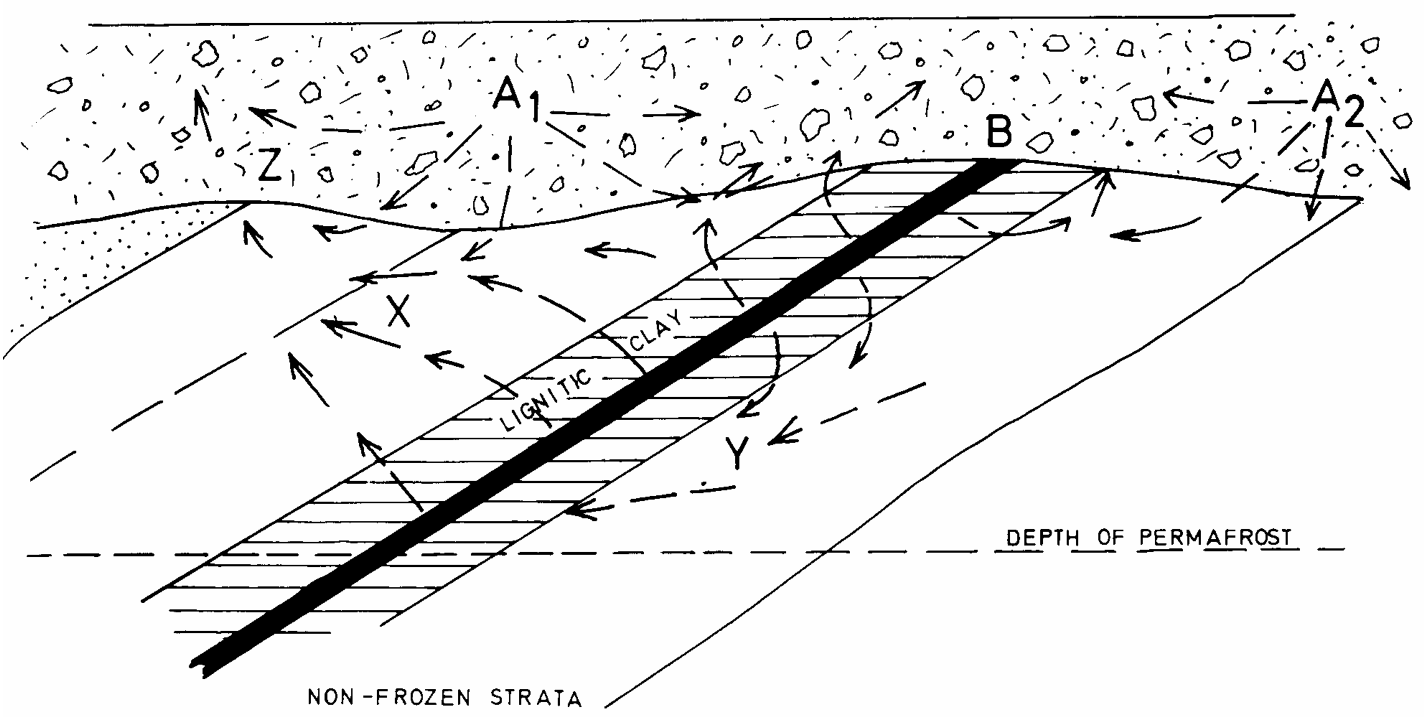

Figure 5. Possible origin of the contortions in a dipping lignitic sequence. See text for explanation.

would itself be moved towards point X. As the cycle of freeze and thaw continues, the lignitic band at point Y would tend to move to point Z. An occasional feature is the eruption of the lower seam through the lignitic band into the clay seam above, caused either by greater localised pressure occurring under the lignitic band, or by holes in the lignitic band appearing during stretching.

Under regions A, the hollow would become accentuated by each freeze and thaw. After each thaw, the gravels would slump into the enlarged hollow with contributions from points B and Z, where the clay was rising and displacing the gravel. The latter could well explain the imbricate structure in the gravels towards the base and the more irregular arrangement in the centre of the gravel pocket.

Conclusions

The structures observed by Dineley in Southacre Quarry and those observed more recently in Clay Lane Quarry are similar and are of periglacial origin. The features are 20-25m in diameter and extend to a depth of 12-13m below the present surface. The features developed under permafrost conditions and are the result of a freeze-thaw interaction between the overlying alluvial gravels and a day sequence containing lignitic bands. The structures have therefore only been observed in the Southacre Member Quarries where lignitic material also occurs. At the southern end of the Bovey Basin, a further quarry, at Newton Abbot Clays (SX 860730), is being worked in the Southacre Member. N.A.C. Quarry, however, only contains minor periglacial features, yet is probably the most lignitic of the W.B.B. workings. It is possible that the greater drainage through the lignites has had its effect, but more likely it was due to the absence of a gravel cover. Gouldstone (1975) concluded that the features were formed under periglacial conditions during the Wolstonian glaciations and that the superficial deposits at the N.A.C. quarry were later in age. (Gouldstone showed that the basal gravels and muds were Flandrian in age, whilst the upper part contained Bronze Age relics). If the gravels were absent over the N.A.C. area during the periglaciation, then the spectacular structures found at Clay Lane would not have occurred.

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