Beer Quarry

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Highlights

One of the best exposures of clay-filled chalk 'pipes' in Britain, Beer Quarry provides important evidence for interpreting solutional processes operating in chalk landscapes, and shows a classic example of the controversial 'clay-with-flints'. Recent evidence suggests that the pipes may have formed largely as the result of solutional processes which accompanied lateritic (tropical) weathering in the Palaeocene.

Introduction

Beer Quarry exposes important evidence for longterm, including pre-Pleistocene, landscape evolution in South-West England. A superb series of 'pipes' here was probably formed by chalk solution in the Tertiary: an infill of 'clay-with-flints' may be the product of dissolution of Upper Cretaceous rocks. Described in detail for the first time here, the features at Beer Quarry have a major bearing on reconstructions of the Tertiary palaeoenvironment of east Devon: these have formerly been adduced from weathering profiles and lithostratigraphic evidence found elsewhere in the plateau deposits of the region (e.g. Woodward and Ussher, 1911; Green, 1974a; Isaac, 1979, 1981, 1983a, 1983b). Little agreement exists as to the origins of solutional cavities and associated infill materials in general: Beer Quarry provides important evidence for both, and adds to the growing belief that these features are probably polygenetic and have formed at different times.

Description

Beer Quarry [SY 215 895], one mile west of Beer in Devon, is noted for the famous Beer Freestone, worked here for centuries, and for an extensive network of caves cut into the Chalk during its extraction. The main area of caves, excavated as early as Roman times (Perkins, 1971), lies to the south of Quarry Lane, and is now a visitors' centre. The current workings, including the GCR site, lie to the north of Quarry Lane and consist of a large disused face between *c.* [SY 213 896] and [SY 215 896]. Present freestone workings are restricted to a small area at the extreme eastern end of the face, and other beds in the Middle Chalk are now worked for agricultural lime in the south-eastern part of the quarry. The quarry floor is occupied by plant and buildings and, in its deepest part, excavated caverns run north for about a quarter of a mile into a large chamber supported by chalk pillars (De la Beche, 1826; Ager and Smith, 1965). These adits underlie the main disused face (Figure 3.2) and were used as ammunition stores during thy Second World War.

Jukes-Browne (1903) recorded a succession of Middle Chalk up to 24 m thick overlying Cenomanian limestone at Beer Quarry. The Beer Freestone, some 4 m thick, is the basal part of the Middle Chalk and is itself overlain by a series of more highly jointed, flinty, nodular and brecciated chalk beds (Jukes-Browne, 1903). These less coherent beds are penetrated from the top by solution cavities, here conveniently referred to as 'pipes'. Details of the pipe structures found in the northern quarry face are shown in (Figure 3.2). These sediment-filled pipes are well exposed along the entire 200 m-long section ((Figure 3.2); section A–C), and merge upwards into an extremely poorly sorted, flinty gravel which forms a continuous layer, some 2 m thick, at the top of the sections. Individual pipes are commonly 2–3 m deep by 2–3 m wide at the top; most, although not all, taper with depth. The pattern of piping, however, is extremely irregular. Many small pipes (< 1 m wide by 1 m deep) occur, in addition to several much larger examples (at 25, 120 and 155 m along the section; (Figure 3.2)). Features at 25 m and 155 m extend beneath the base of the exposed face and therefore exceed 15 m in depth. Some pipes are narrow, others much wider (e.g. those at *c.* 120 m and 155 m); between *c.* 90 and 115 m along the section, the Chalk has been replaced/dissolved over a broad area now occupied by flinty gravel at least 3.5 m in depth.

Similar pipes also occur elsewhere in the quarry, but are generally less frequent and less well developed. An extremely large, clay- and gravel-filled pipe occurs, however, at the easternmost end of the quarry. One example ((Figure 3.2); section B–C) shows the infill material to occur beneath an *in situ* 'shelf' of unaltered chalk. In several pipes, the clay-with-flints is completely surrounded by unaltered chalk.

Most of the pipes show a rapid transition from chalk to infill (Figure 3.3) and (Figure 3.4). The latter consists almost entirely of whole and broken flints in a black, chocolate-brown or red clay-rich matrix: clay-with-flints is an apt description for these mostly structureless, unbedded and undifferentiated deposits. Material infilling the pipes is visually strongly similar to the capping layer: there is some suggestion that flints are more densely packed towards the base of pipes where, as a result, the deposit is almost clast-supported. Variations in the colour of the infill material do, however, occur. Generally it is reddest towards the top of the sections and dark chocolate-brown or black towards the base. Along pipe margins, the infill is frequently colour-zoned with a blackened band, almost 0.5 m wide, occurring next to the Chalk (Figure 3.3) and (Figure 3.4). Elsewhere, the different colours are abruptly juxtaposed without apparent pattern, perhaps having been disrupted by frost.

Interpretation

Details of the petrography and sedimentology of the deposits filling the pipe structures at Beer are not available, although the pipe structures were recorded by Ager and Smith (1965) and Perkins (1971). However, much information regarding the nature and origin of the infill can be gleaned from published studies of adjacent plateau deposits in east Devon (e.g. Woodward and Ussher, 1911; Waters, 1960d, 1960e; Hamblin, 1968, 1973a, 1973b, 1974a, 1974b; Edwards, 1973; Brunsden *et al.,* 1976; Isaac, 1979, 1981, 1983a, 1983b). The formation of the solutional cavities or 'pipes' may also be related to work on comparable karstic structures and associated infills found elsewhere in southern England and northern France (e.g. Osborne White, 1903; Kirkaldy, 1950; Avery *et al.,* 1959; Hodgson *et al.,* 1967; Mathieu, 1971; Thorez *et al.,* 1971; Pepper, 1973; Walsh *et al.,* 1973; Chartres and Whalley, 1975; Brunsden *et al.,* 1976).

The Tertiary plateau deposits of east Devon were first mapped and described in detail by Woodward and Ussher (1911), in the Geological Survey Memoir for the Sidmouth area (Sheet 326/340). Large areas of clay-with-flints and -chert were shown to cap the Chalk and Upper Greensand of the east Devon tableland. These deposits were divided into two groups (both Eocene): 1. clays and gravels with quartz, quartzite and other materials in addition to flint and chert; 2. clay with flint and chert — at least, in part, true clay-with-flints (Woodward and Ussher, 1911). Material infilling the pipes at Beer would appear, albeit visually, to belong to the latter category.

More recently, Waters (1960d, 1960e), Edwards (1973) and Hamblin (1968, 1973a, 1973b) have studied the plateau deposits: an origin involving the dissolution of the Chalk beneath a cover of Tertiary deposits has generally been invoked. The broad twofold division of deposits (Woodward and Ussher, 1911) has been upheld and, in the Haldon Hills, a lower residual unit and an upper fluvial unit have been identified (Hamblin, 1968, 1973a, 1973b).

Similarly, Isaac (1979) originally divided Tertiary plateau sediments in the Sidmouth area into two lithostratigraphic formations: 1. the Peak Hill Gravels (composed of unabraded flints in a matrix of kaolinite, and formed by the removal of calcium carbonate from the Chalk under lateritic weathering conditions); and 2. the Mutters Moor Gravels (derived from the Peak Hill Gravels by aeolian and fluvial processes). These formations are separated by an unconformity and, locally, silcretes are present.

Subsequently, Isaac revised this scheme and termed the *in situ* stony clays the Combpyne Soil, and their reworked equivalents the Peak Hill Gravels (Isaac, 1981). The former, he argued, originated as a Palaeocene lateritic weathering profile (with pallid and mottled zones), formed as the Chalk underwent dissolution beneath Tertiary overburden. This led to the development of kaolinitic residual flint gravels up to 10 m in thickness over much of the east Devon tableland: well-differentiated lateritic weathering profiles were preserved in irregular deep pockets in the Chalk, and it seems likely that the material infilling the pipes at Beer can be assigned, at least in part, to the Combpyne Soil lithostratigraphic formation.

Tertiary history in south and east Devon: a synthesis

Isaac (1981, 1983b) has argued that the Tertiary plateau deposits of east Devon are characterized by a complex of superposed weathering profiles which reflect a protracted pedological, diagenetic and geomorphological history, beginning with the emergence of the post-chalk land surface at the end of the Cretaceous. In essence, the plateau deposits represent a series of Tertiary palaeosols in part reworked during the Tertiary and disturbed by subsequent frost-action in the Pleistocene.

The oldest, and principal, Tertiary stratigraphic unit recognized in the Beer/Sidmouth area is the Combpyne Soil, developed as the Chalk underwent dissolution in a tropical (Palaeocene) climate on a relatively stable land surface (Isaac, 1981, 1983b). The depth of chalk dissolved and removed is unknown, but likely to have been substantial. Residual deposits (initially the Combpyne Soil) are mainly kaolinitic, non-indurated, lateritic weathering products. They include, however, a range of silcretes and siliceous indurated deposits reflecting protracted soil formation and diagenesis: the silcretes may indicate several separate periods of desiccation in an arid environment (Kerr, 1955; Isaac, 1979, 1981, 1983a, 1983b). A cycle, beginning with decalcification of the Chalk (and Greensand), followed by kaolinization accompanied by dissolution of residual quartz, and ending with localized silicification at various depths in the weathering profile, can thus be identified (Isaac, 1983b).

Subsequent reworking of the Combpyne Soil altered the structure of the original profile and led to the formation of the Peak Hill Gravels (Isaac, 1979, 1981, 1983b). West and north of Sidmouth, the Combpyne Soil was eroded differentially: where it was removed completely, Pleistocene gravels rest directly on deeply weathered Upper Greensand (Isaac, 1981). The Peak Hill Gravels (themselves reworked Combpyne Soil) have been correlated by Isaac (1979) with plateau'deposits on the Haldon Hills to the east of the Bovey Basin. The residual flint gravel there, the Tower Wood Gravel, rests on decalcified Upper Greensand and is overlain by fluvial gravels (Hamblin, 1973a, 1973b). It has a similar clay mineralogy and lithological content to the Peak Hill Gravels, and is thus regarded as a westward continuation of the Sidmouth/Beer kaolinitic residual deposits (Isaac, 1979, 1981).

A Palaeocene age for the residual Tertiary sediments is based on several lines of evidence (Isaac, 1983b). First, the residual gravels underlie Upper Eocene to Lower Oligocene beds of the Bovey Formation (Edwards, 1976; Isaac, 1981), and are cut by faults thought to be of late Middle Eocene or early Upper Oligocene age (Isaac, 1981). Second, these lateritic weathering products have been correlated with the Interbasaltic Formation of Northern Ireland (Eyles, 1952), where clay-with-flints rests on chalk and is overlain by basalt. Radiometric dates (Evans *et al.,* 1973) show the Irish residual gravels to span 65–66 Ma BP, and thus a lowest Danian to Maastrichtian age has been proposed (Figure 3.1). A Palaeocene age for the Tower Wood Gravels of the Haldon Hills, with which the Peak Hill Gravels are correlated (Isaac, 1981, 1983b), was proposed independently by Hamblin (1973a, 1973b). A Palaeocene age thus seems appropriate for the Combpyne Soil, Peak Hill Gravels and associated silcretes (Isaac, 1979).

Following deposition of the Peak Hill Gravels and before the Mutters Moor Gravels were emplaced, a second deep weathering profile was established in the Sidmouth area — the Seven Stones Soil (Isaac, 1981). This zone of weathering, again characterized by mottled and pallid zones, occurs at some localities beneath Mutters Moor Gravels, and elsewhere affects the surfaces of the Peak Hill Gravels, Combpyne Soil and even the Upper Greensand where the former sediments are absent (Isaac, 1981) (Figure 3.5).

In addition to the residual flint gravels and associated pedogenic and diagenetic horizons, the plateau deposits of east Devon include the Buller's Hill Gravel (Hamblin, 1973a, 1973b) and the Aller Gravel (Edwards, 1973), both thought to be fluvial in origin (Figure 3.5). The former is believed to have originated from erosion and subsequent redeposition of the Tower Wood Gravel and, in addition, contains material from deeply weathered Upper Palaeozoic sediments (Isaac, 1983b). The Aller Gravel consists of up to 20 m of rounded quartz and flint gravels and sands with subordinate bodies of white to pale-grey silt and sandy clay (Isaac, 1983b). Although Hamblin (1974a) and Edwards (1973) have differed as to the origin of the Buller's Hill and Aller gravels, Isaac (1983b) is of the opinion that they are 'spatially and temporally closely related'. However, differences in lithological content could indicate that the two deposits are separated from one another perhaps by a fairly substantial time interval — in fact the time necessary to remove the Chalk cover from most, if not all, of South-West England. The Buller's Hill Gravel could therefore be Palaeocene, the Aller Gravel possibly mid-Eocene. Important evidence for the stratigraphic relationships of these deposits comes from solution cavities in Devonian limestone exposed along the margins of the Newton Abbot bypass (Brunsden *et al.,* 1976). Here, Aller Gravel overlies Buller's Hill Gravel which in turn overlies Tower Wood Gravel resting on Upper Greensand (Brunsden *et al.,* 1976; Isaac, 1983b; (Figure 3.5)). Since all four units are overlain by beds of the Bovey Formation (Upper Eocene to Oligocene), it is likely that the fluvial flint-rich gravels represent a phase of erosion and destruction of the flint-rich Palaeocene weathering profiles (residual sediments) before Bovey Formation sedimentation began: this must have occurred before Upper Eocene times (Isaac, 1983b).

Isaac (1983b) has argued that intra-Eocene tectonism played a key role in the destruction of the residual mantle formed by the deep weathering (Palaeocene) of Cretaceous sediments, and culminated in the initial downwarping of deep tectonic basins along wrench-fault zones: the Bovey Basin, for example, saw subsequent redeposition of the weathered Cretaceous mantle together with weathering products from the adjacent Dartmoor granite (Bristow, 1968) as well as more recently weathered (during the Eocene) Upper Palaeozoic metasediments which became exposed as the downwarping progressed.

In the Sidmouth area (Figure 3.5), a further flint-rich gravel, the Mutters Moor Gravel, has been identified (Isaac, 1981, 1983b). Unlike the Tower Wood and Buller's Hill gravels, which are offset by faulting associated with downwarping of the Bovey Basin (Hamblin, 1973a, 1973b), the Mutters Moor Gravels were not so affected (Isaac, 1981). These flinty gravels, with profuse angular chalk-flints in a sandy clay matrix, contain many silcrete fragments. They appear to have been eroded from Palaeocene weathering products (= Combpyne Soil, Peak Hill Gravels and Seven Stones Soil), and to have been redeposited during the Pleistocene (Isaac, 1981). Isaac has argued that part of the level plateau at *c.* 180 m OD in the Sidmouth area (northern Mutters Moor), may be an exhumed palaeodeflation surface. Intensely mechanically weathered Peak Hill Gravels and Seven Stones Soil kaolinite, found in the Mutters Moor Gravels, is consistent with the material having been reworked by aeolian and fluvial agencies in the Pleistocene, when cold desert conditions at times prevailed. In such an environment, cryoturbation, solifluction and other periglacial processes were instrumental in reworking the older weathering profiles (Isaac, 1981).

The origin and significance of the infilled pipes at Beer must therefore be viewed against the extremely complex history of Tertiary weathering and the subsequent destruction of the weathered mantle both during later Tertiary and Pleistocene times. Without detailed laboratory analyses of the pipe-sediments, it is impossible to reach firm conclusions as to their origin. However, as a working hypothesis, it seems likely that the pipe structures themselves began to form at the end of the Cretaceous as a stable land surface emerged, and subsequent tropical weathering (Palaeocene) developed a thick mantle (flint-rich residual gravels) from beneath a covering of clay-rich Tertiary sediment. From Isaac's descriptions, it is not entirely clear whether the clay-with-flints contained in the pipes at Beer would represent the earliest *in situ* Palaeocene lateritic weathering products, the Combpyne Soil, or material reworked from these beds (Peak Hill Gravels). Certainly, two main fabrics can be discerned within the Beer pipe infill; the first, which occurs near the base of the pipes, shows a dense packing of tightly interlocking flints with little matrix. The second occurs towards the top of the pipes and in the continuous gravel capping. Here, the flints are less profuse, being supported in a red clay matrix. It seems reasonable to assume that the developing pipe structures, with steep sides and restricted lateral extent, would have prevented erosion and downslope reworking of the residual gravels, under almost any but the most severe conditions. The lower, densely packed flint material in the pipes may therefore have formed as lines of tabular and nodular flints were gradually let down, passively, from above as the Chalk was removed by solution (cf. Isaac, 1979). Small 'rafts' of chalk found towards the bottom of some pipes may have escaped complete solution, giving further credence to this hypothesis: a correlation of these deposits with the Combpyne Soil would thus seem appropriate. The overlying, less densely packed flint material, in the upper part of the pipes and in the capping layer, may, on the other hand, have undergone some reworking, and may thus be equivalent to the Peak Hill Gravels (Isaac, 1979, 1981, 1983b). The uppermost layers of flint gravel at Beer were, alternatively, probably subjected to reworking and, at the very least, severe disruption by Pleistocene frost-action. That some part of the infill should more properly be ascribed to the Mutters Moor Gravel lithostratigraphic formation cannot therefore be ruled out. Indeed, comparable solution cavities at Dunscombe (2 km east of Sidmouth) were recorded by Isaac (1983b). Here, they are filled with black montmorillonitic clays, and residual flint gravels protrude down into limestone and decalcified sediments beneath (Isaac, 1983b).

Solution of the Chalk at Beer has clearly been on a large scale. Small-scale features have been described from the area, for example, in the Devonian limestone (Ussher, 1913), although larger structures have been described from the Carboniferous Limestone and the Chalk elsewhere in southern Britain (Kirkaldy, 1950; Walsh *et al.,* 1972, 1973). Indeed, similar solutional cavities in excess of 100 m diameter have been described from Dorset (Arkell, 1947), Wiltshire (Jukes-Browne, 1905) and Kent (Worssam, 1963). Large-scale solution pipes were more recently described from Devonian limestone exposed during construction of the Newton Abbot bypass (Brunsden *et al.,* 1976), and comparable features in the Chalk near South Mimms, Hertfordshire, have long attracted attention (Wooldridge and Kirkaldy, 1937; Kirkaldy, 1950; Thorez *et al.,* 1971); there, the largest pipe noted was 10 m in diameter at the base of the pit.

Thorez *et al.* (1971) described the solution pipes at Castle Linné Works, South Mimms, as being filled with sands and pebbly deposits believed to be part of the Thanet Beds (Palaeogene). They argued that the Chalk had dissolved *in situ* beneath a cover of the Thanet Sands, by percolating water, the effects of which were heightened by the anticlinal structure of the Chalk and by a resultingly very low water-table (cf. Walsh *et al.,* 1973; see below) (Wooldridge and Kirkaldy, 1937). Initially, the Chalk was dissolved beneath the Bullhead Bed at the base of the Thanet Sands: at first, this bed supported the sand, but with continued dissolution of the Chalk and enlargement of the cavities, eventually collapsed with the overlying sands into the pipes. Deposits overlying the Tertiary infill are believed to be colluvial and solifluction deposits, which smoothed out irregularities in the local ground surface during the Pleistocene (Thorez *et al.,* 1971).

A dark brown, porous clay lining to the cavities has a more complex origin. Although closely related to dissolution of the Chalk, this is not a pure chalk residue: much of it is oriented and laminated (Thorez *et al.,* 1971), and it is interpreted as an illuvial deposit, washed in from the Tertiary sediments above. Small chalk fragments remain incompletely dissolved towards the base of some cavities (cf. Beer). Here, the Chalk dissolved along joints, eventually becoming sealed on all sides by the illuviated clay. Continued solution of the isolated chalk 'rafts' was effected by ions passing through the relatively porous clay: once completely dissolved, further deposition of clay in the space provided by the dissolved chalk was impossible, and voids were left as the remaining chalk was dissolved (Thorez *et al.,* 1971). The large pore space and low bulk density of the clay have been taken as indicating its relatively recent formation. In older clay-with-flints (e.g. at Beer?), the voids in the clay have frequently been reduced by continual collapse, alternate swelling and shrinking and the continued deposition of illuvial clay (Thorez *et al.,* 1971). Thus, although the same basic geological controls (namely a stable chalk surface overlain by Tertiary sediment) exists at both South Mimms and Beer, albeit in an entirely residual state at the latter, solution of the Chalk may have taken place at radically different times. This is also a conclusion drawn by Chartres and Whalley (1975) who studied dissolution features in chalk at Basingstoke. They argued that a brown clay lining to the cavities there had formed relatively recently, indicating that truly residual clays can form at any time by dissolution of underlying chalk. A similar explanation was put forward by Worssam (1981) to account for clay linings in loess-filled gulls (cambered fissures) at Allington in Kent. Here, large limestone blocks are surrounded by silt and are capped with clay linings: the linings must have been deposited after the blocks became incorporated into the silt, or they would show significant signs of tilting and/or disruption (Worssam, 1981).

In contrast, the large solutional features described in the Devonian limestone near Newton Abbot (Brunsden *et al.,* 1976) could show that the solutional processes there operated over a much more protracted timescale (Figure 3.5). These pipes contain sediments representing the Upper Greensand and the Chalk as well as the Eocene Buller's Hill and Aller gravels, and the beds of the Upper Eocene to Oligocene Bovey Formation (Brunsden *et al.,* 1976; (Figure 3.5)). It has been suggested that these pipes could therefore be the result of subsidence related either to: 1. prior hydrothermal alteration of the limestone; 2. a cover of permeable Cretaceous and Tertiary sediments; or to a combination of both factors (Brunsden *et al.,* 1976).

Walsh *et al*. (1973) attempted to synthesize evidence from a wide range of sites throughout Britain exhibiting solutional cavities and associated infill materials. They concluded that a common age and origin was unlikely: pipes had clearly developed more than once, and post-Eocene, post-Pliocene and Pleistocene interglacial phases of piping could all be recognized. On balance, most pipe structures were considered to have formed by selective solution effected from beneath by artesian groundwater. The process was considered to be self-propagating: the more chalk eaten away from below, the more progressive the collapse of solution residues and overlying fill-sediments (Walsh *et al.,* 1973). Gravitational collapse of infill sediments was only likely to cease when the local water-table dropped to a position where fissure systems were effectively bridged or shut off from the artesian source. Thus, in areas where water-tables and hydrological conditions had changed radically and repeatedly, complex histories and sequences of pipe development were likely. Walsh *et al.* also recommended that the varied, and often confusing, terminology used to describe 'pipes', 'pockets', 'fissures' and their associated infill, be rationalized to include three principal terms: 1. solution subsidence (the process); 2. solution subsidence deposit (the materials involved); and 3. solutional subsidence mass (the cavity or host body).

The evidence from Beer Quarry, in conjunction with detailed work carried out throughout the Beer and Sidmouth areas (Isaac, 1979, 1981, 1983a, 1983b), is of considerable relevance to understanding the origin of the controversial clay-with-flints and solutional processes operating in limestone terrains. Overwhelming evidence from this area suggests that solutional subsidence deposits, namely flinty residual gravels (= clay-with-flints) were formed as chalk underwent dissolution (solution subsidence) beneath Tertiary deposits. The pattern of structures (largely vertical or slightly oblique pipes) probably reflects major vertical joints in the Chalk subsequently exploited by solution. Well differentiated lateritic weathering profiles, developed in local sediments comparable to the infill material, together with locally developed silcretes, point to weathering, with complex patterns of diagenesis and pedogenesis, in a tropical environment: distinct phases of humid and arid conditions are likely to have prevailed at different times (Isaac, 1981, 1983b).

There is strong local stratigraphic evidence that most of this weathering occurred during the Palaeocene (see above). The concentration of illu-vial clay towards the pipe margins at Beer (where there is a distinctly darker or blackened zone) has not yet been proven: in any case, there is evidence elsewhere to suggest that eluviation of clay minerals from overlying sediments could have occurred almost at any time from the earliest Tertiary to the present day. However, the identification of lateritic weathering products in residual flinty gravels found between the Chalk or Upper Greensand and Bovey Formation sediments (Upper Eocene to Oligocene) in east Devon, tightly constrains the age of the weathering event(s) and also, therefore, the principal phase of solutional activity, to the Palaeocene.

This degree of precision contrasts markedly with evidence from elsewhere in Britain and France where the age of the clay-with-flints has been much disputed (Pepper, 1973): most British workers have favoured a Pleistocene age, whereas workers in France have generally accepted ages within the Palaeogene for similar deposits. Neither is there agreement as to the age relationship of the clay-with-flints and its associated silcretes, in the form of 'sarsens' elsewhere in southern England (Isaac, 1979; Summerfield and Goudie, 1980). Thus although: 1. radiometric dates and the stratigraphic relations of the clay-with-flints in Northern Ireland (e.g. Wright, 1924; Fowler and Robbie, 1961; Evans *et al.,* 1973); 2. the evidence from east Devon (e.g. Isaac, 1979, 1981, 1983a, 1983b; Hamblin, 1973a, 1973b); together with 3. climatic evidence (Dury, 1971); and 4. a knowledge of the conditions necessary for silcrete formation (e.g. Watkins, 1967; Watts, 1978) would all support a Palaeocene age for the clay-with-flints at Beer, this can by no means be accepted for all other occurrences of similar deposits. Chartres and Whalley (1975), for example, provided convincing evidence to show that solution of the Chalk at Basingstoke had taken place almost entirely within the Quaternary. Using evidence from clay mineralogy, particle-size analyses and the morphology of chalk rubble within the infill sediments, they showed that the Chalk was affected by frost-action before the infill material (clay-with-flints) was formed, and that solution of the Chalk has since continued to produce an irregular weathering front. The clear implication is that there, no significant solution of the Chalk, in the Tertiary, preceded this sequence of events, or if it did, that evidence was removed first. Such a view has been upheld by Pepper (1973) although it is at variance with French (e.g. Dewolf, 1970; Mathieu, 1971) and some English workers (e.g. Loveday, 1962).

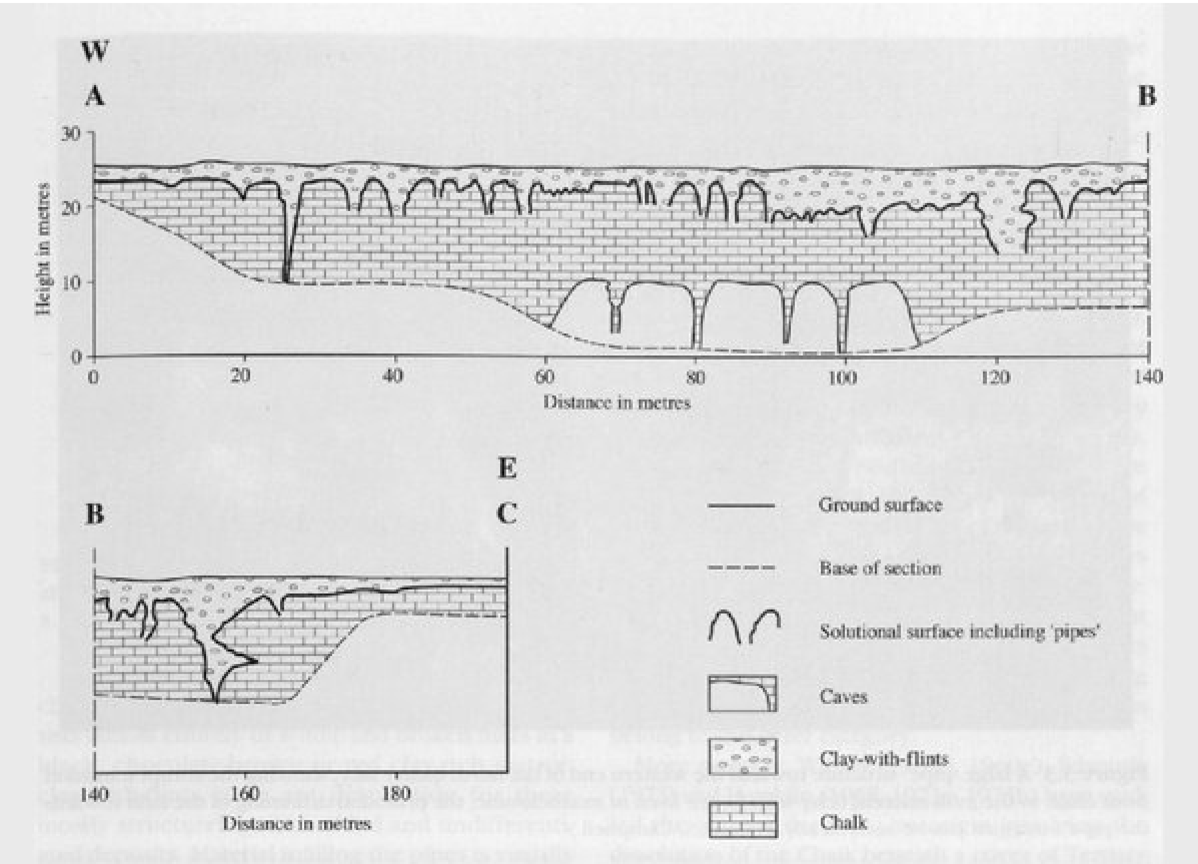
The interpretation of solutional cavities and associated infills is therefore fraught with difficulties: rarely is any firm dating possible. Controversy even exists regarding the origin of the clay-rich zones found in some of the pipes, namely whether they are autochthonous (that is derived directly by decalcification of the Chalk with only superficial pedogenesis) or allocthonous (that is derived from material other than the Chalk, for example, washed in from a permeable cover) (Chartres and Whalley, 1975). Whether the kaolinite found in the residual gravels of east Devon was formed by *in situ* weathering (e.g. Green, 1974a) or derived from the granite mass of Dartmoor (e.g. Hamblin, 1973a, 1973b) where it may have formed by hydrothermal processes, is significant: a supergene origin, at least in part, for the Dartmoor growan is given some credence by the substantial evidence for weathering found in the Tertiary and Cretaceous rocks of east Devon (Bristow, 1968) (see Chapter 4).

Conclusion

The lack of detailed work so far carried out at Beer is surprising because the site demonstrates probably the finest examples of solutional pipes found in the Chalk anywhere in southern England: its conservation status can be justified on this basis alone. Although a preliminary description and interpretation of the site have been given here, precise details of the nature and origin of the pipe infill must await more comprehensive laboratory and field examination. Nonetheless, the infill material strongly resembles that studied elsewhere in the region and ascribed, on the basis of pedological and diagenetic characteristics and stratigraphic relationships, to Palaeocene tropical weathering. If, as seems likely, a correlation can be proved between the residual Palaeocene clay-with-flints of the east Devon tableland and the infill sediments at Beer, the latter will be one of very few examples of solutional activity in Britain which can be related to a precise stratigraphic timescale and to a well-established sequence of landscape evolution. The east Devon tableland deposits, typified by those at Beer, and the residual deposits (growan) of the Dartmoor area (Chapter 4) together record vital evidence for the climatic and denudation history of South-West England during the Palaeogene. Collectively, they demonstrate a long and complex history of pedogenesis and diagenesis which is also typical of other deeply weathered regions of the world (Isaac, 1983b).

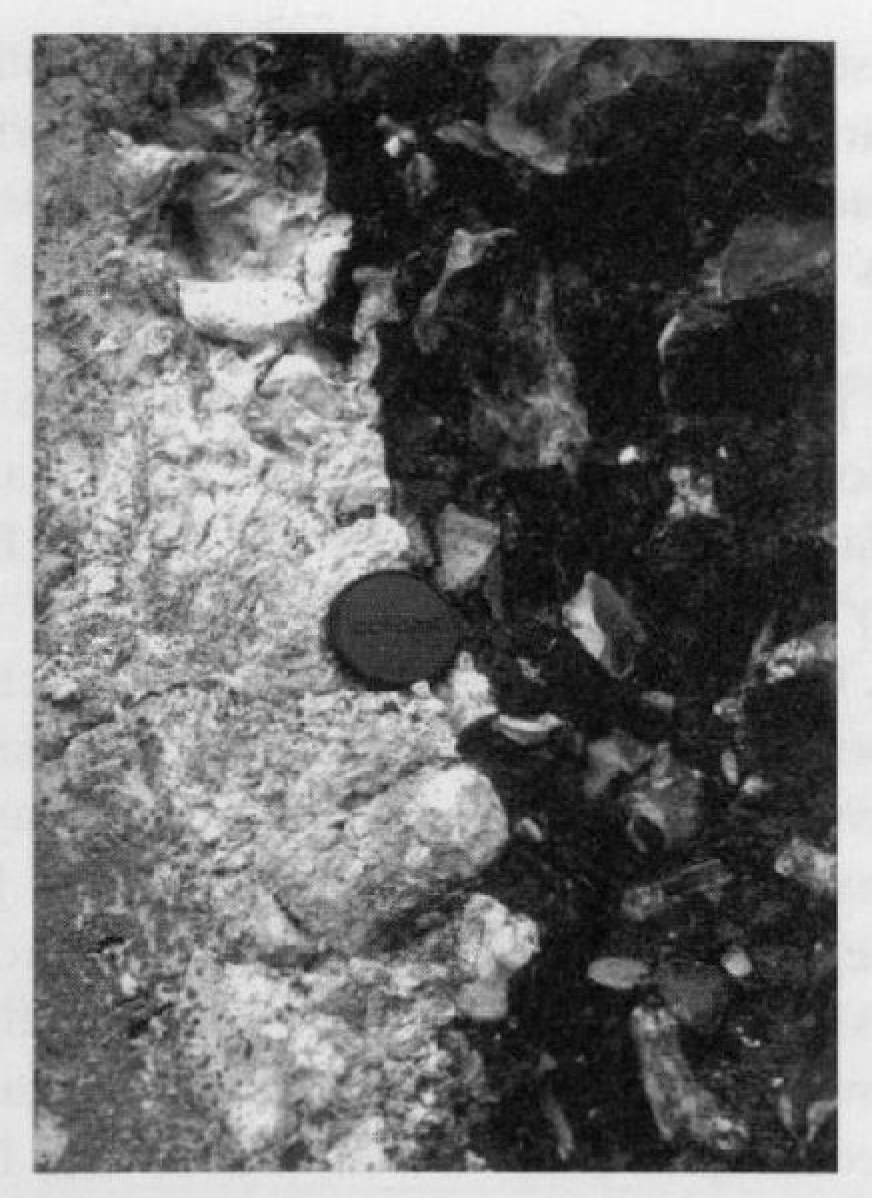
Until more detailed evidence is available from a wide range of sites, it is perhaps prudent to regard solutional cavities in general, and indeed the clay-with-flints as polygenetic (e.g. Hodgson *et al.,* 1967; Mathieu, 1971; Walsh *et al.,* 1973; Chartres and Whalley, 1975). It is certain that the debate concerning the origin of both will continue. In this context, Beer Quarry together with other GCR sites at South Mimms, Allington Quarry, Spot Lane Quarry and Bath University, provide a range of contrasting evidence for processes operative in limestone landscape development: these sites will be central to resolving the outstanding controversies.

References

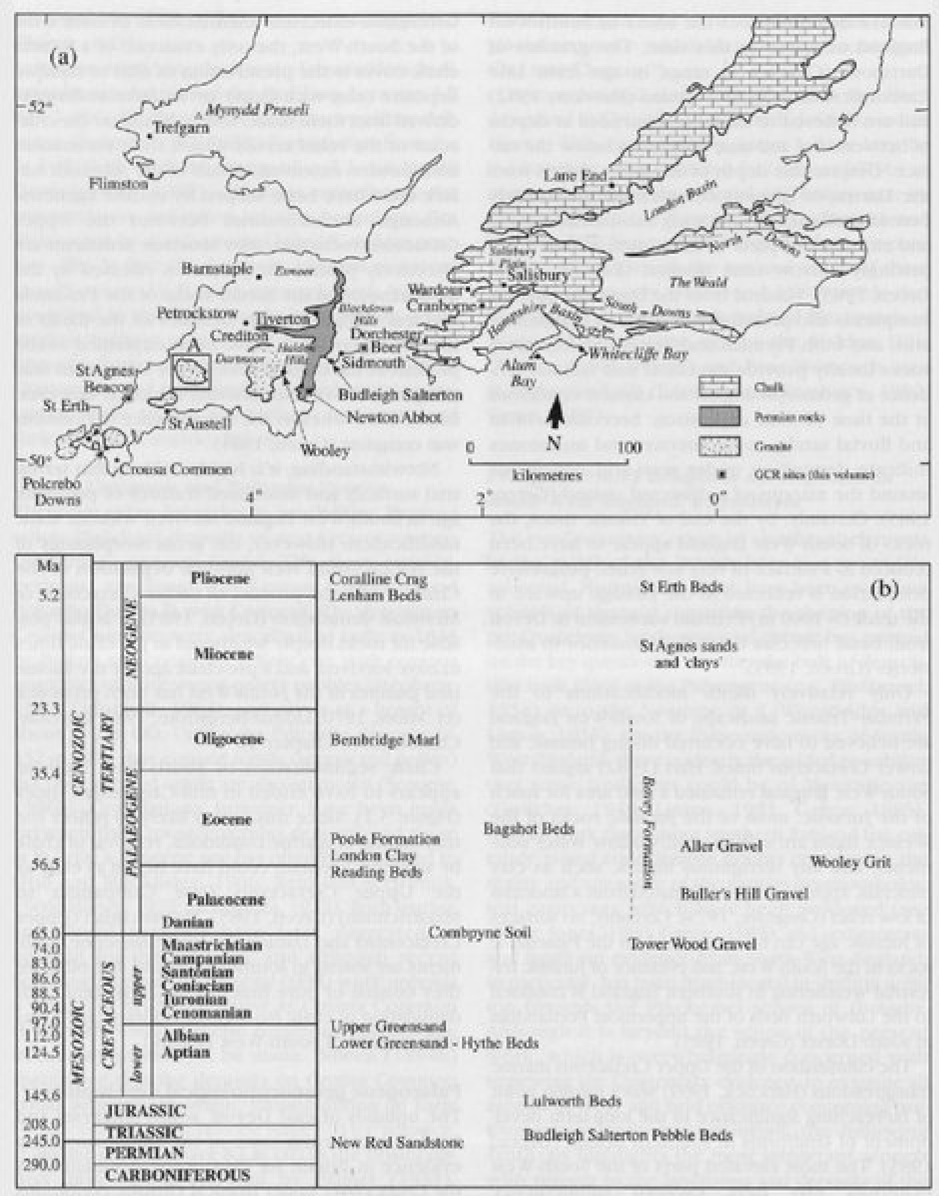


(Figure 3.2) Clay-filled chalk 'pipes' exposed along the northern working face of Beer Quarry in 1990.

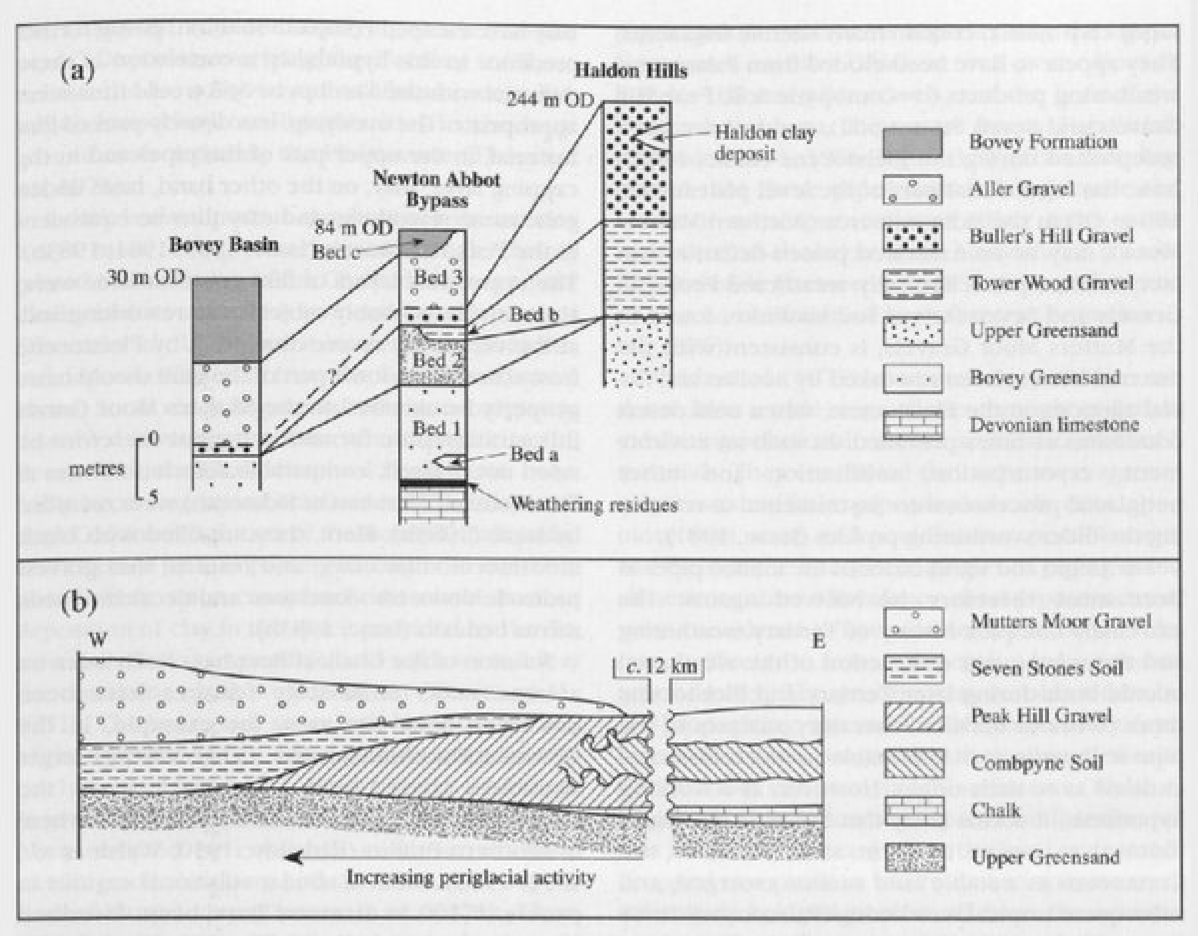
(Figure 3.3) A large 'pipe' structure towards the western end of the north quarry face, showing the abrupt transition from chalk to the infill material (clay-with-flints). Even in monochrome, the profound darkening of the infill towards the pipe's margins can be seen clearly. (Photo: S. Campbell.)



(Figure 3.4) Detail of a typical pipe margin, showing the abrupt transition from chalk to clay-with-flints. (Photo: S. Campbell.)



(Figure 3.1) (a) Southern and South-West England, showing localities referred to in the text, and selected geological outcrops. (b) Significant deposits and events in the geomorphological evolution of southern Britain. (Adapted from Green, 1985, with timescale based on Harland et al., 1982.)



(Figure 3.5) (a) Stratigraphic correlations of successions in the Bovey Basin, Newton Abbot bypass and Haldon Hills. (Adapted from Edwards, 1973, Hamblin, 1973b and Brunsden et al., 1976.) (b) Schematic representation (not to scale) of field relations of major lithostratigraphic units in the Sidmouth area. (Adapted from Isaac, 1981.)