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Solution weathering of the Devonian limestones of Torbay

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This paper presents the results of a combined geophysical and sub-surface investigation into the nature and extent of solution weathering of the Devonian limestones in Torbay, Devon. The results indicate that large areas of the limestone outcrop have been affected by solution weathering, albeit to a highly variable degree. The extent of solution features present in Torbay ranges from minor solution along joints to major doline karst with extensive cave systems such as at Kent's Cavern, Torquay. An appreciation of the nature and extent of such features is important for planning and development, and it is suggested that geophysical methods are likely to provide much valuable information as to the nature of the overburden thickness.

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Introduction

A review of relevant site investigation records and consultants' reports, carried out as part of the recent environmental geology mapping programme for Torbay (Lee *et al.* 1988; Doornkamp *et al.* 1988) has revealed that special geotechnical problems occur in limestone areas affected by solution weathering. The overburden often exhibits wide variations in composition, strength and thickness even over small areas, causing variable bearing capacity and creating problems for foundation design. The variability in depth to rockhead encountered over small distances can also hamper certain excavation methods. In addition, uncontrolled run-off can cause piping and erosion of the soil infilling the solution features, leading to the development of more extensive cavities and creating further foundation problems.

Solution features have been identified by many authors elsewhere on limestones in Great Britain, including the Carboniferous limestones of the Pennines (e.g. Waltham and Sweeting 1974), the Peak District (e.g. Ford 1977), South Wales (e.g. Thomas 1971) and the Mendips (e.g. Ford and Stanton 1968). In Devon similar karst features recorded within the Devonian limestones have caused considerable problems during engineering operations. Infilled solution pipes in a road cutting caused problems during the construction of the Kingsteignton-Newton Abbot By-pass (Low and Bramwich 1971; Brunsden *et al.* 1976), and limestone pillars hindered excavation work during construction of the Caton Cross Overbridge on the A38 (Fookes and Hawkins 1988).

Within Torbay large sediment-filled solution pipes in the Devonian limestones are visible along many stretches of the limestone sea-cliffs such as between Breakwater Beach and Shoalstone Point, Brixham. However, not all the limestone outcrops appear to be affected by solution weathering, with such features being absent from many quarry faces in Torquay. In order to make an appraisal of the nature and extent of solution weathering within the Devonian limestones a detailed investigation was undertaken, involving:

(i) a geophysical survey;

(ii) a ground investigation comprising augerholes and trial pits.

The basis of this investigation was to see if variations in ground conductivity existed, and then to determine, by means of boreholes and trial pits, whether some correlation could be established between ground conductivity and overburden thickness, and hence the presence of karst features.

Geophysical Survey

A low-frequency electromagnetic survey was carried out using the 'Geonics EM-31', at two contrasting sites (Fig. 1):

(i) Wall's Hill, Torquay (94m); this flat topped hill forms part of the Torquay promontory and is characterised by slightly irregular microtopography;

(ii) the plateau between Churston Ferrers and Brixham, ranging from 53-82m in elevation with considerable variations in microrelief.

The EM-31 consists of a transmitter and receiver coil located at either end of a 3.7m long boom. These are connected to a central microprocessor control unit which provides a direct reading of ground conductivity. .A low frequency alternating current is applied to the transmitter coil which produces a primary magnetic field. This field induces an electrical current flow in any conductive materials in the ground, which in turn produces a secondary magnetic field. Both primary and secondary fields

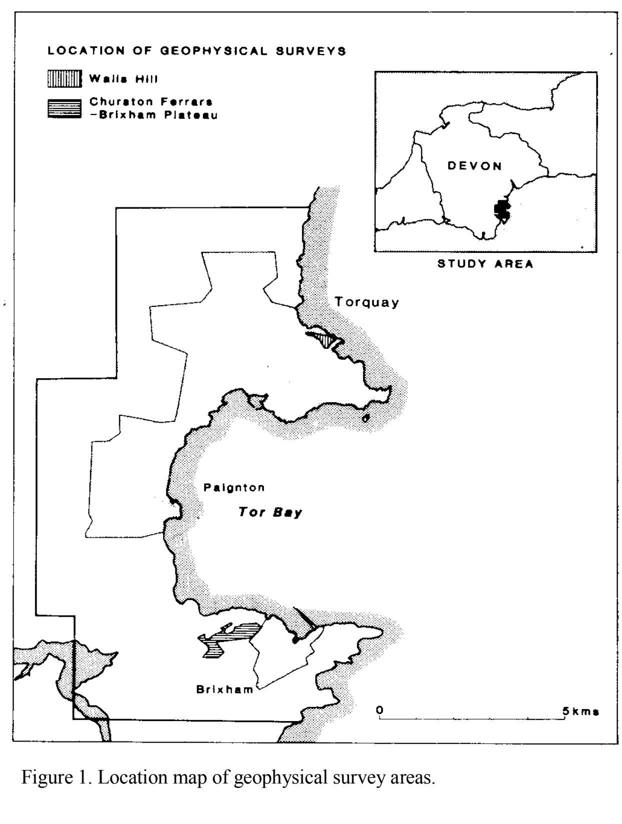

Figure 1. Location map of geophysical survey areas.

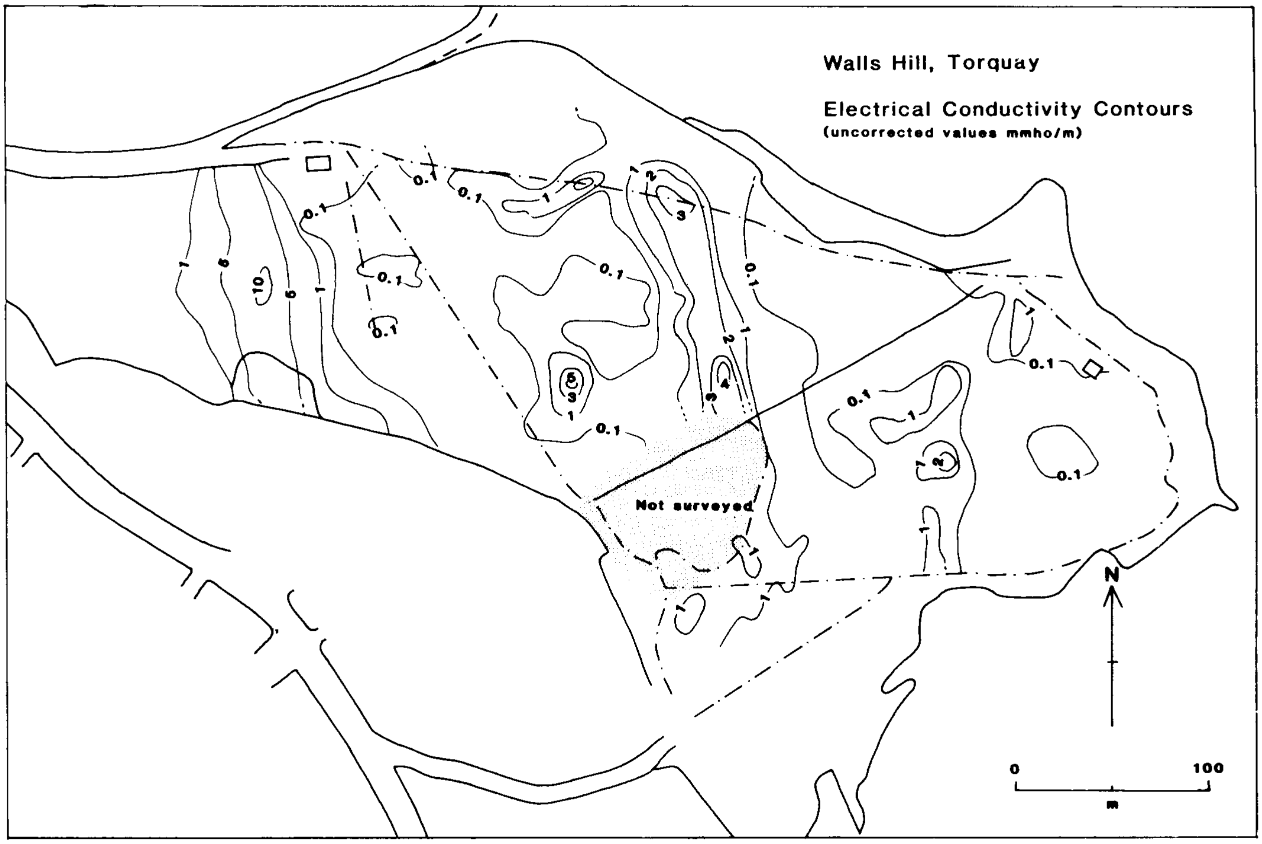

Figure 2. Electrical conductivity contours, Wall's Hill, Torquay.

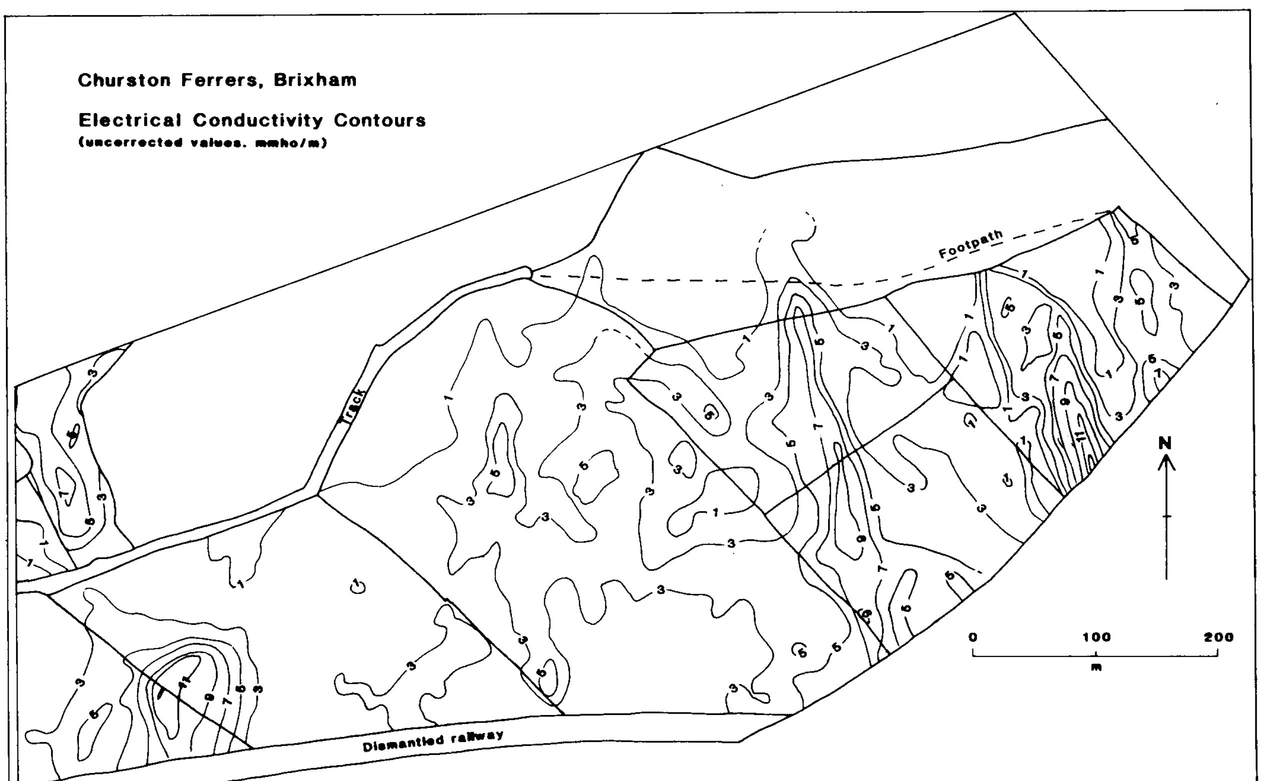

Figure 3. Electrical conductivity contours, Churston Ferrers-Brixham plateau.

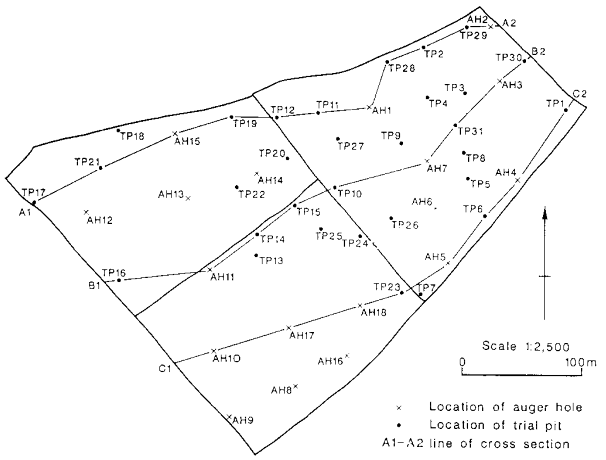

Figure 4. Location of augerholes and trial pits, Churston FerrersBrixham plateau.

are detected at the receiver coil. The ratio of the primary to secondary field can be shown to be linearly proportional to the electrical conductivity of the ground. The instrument produces a continuous, direct reading of ground conductivity and consequently allows anomalies to be rapidly identified and delineated. The electromagnetic survey method was selected on the assumption that the underlying rock type was limestone and in the knowledge that air-filled cavities would not be detected by this method, nor would cavities at depths in excess of 6m.

In order to maximise the possibility of identifying buried cavities of 5-10m diameter, survey lines were spaced at 10m intervals. The EM-31 instrument provided a continuous readout of electrical conductivity along each survey line and the position and value of any significant changes were recorded. Both Wall's Hill and the Churston Ferrers-Brixham plateau are underlain by limestones of Givetian age, which proved at outcrop to give very low electrical conductivity values (less than 0.1mmho/m). Higher conductivity values can therefore be related to either increased fracturing and weathering of the bedrock, or thickening of the overburden material which is assumed to contain sufficient moisture and clay content to provide a conducting medium.

The results from the two sites can be summarised as follows:

(i) Wall's Hill (Fig. 2); this area is characterised by very low conductivity values (less than 0.1mmho/m) suggesting a uniform thin soil cover. However, a number of small anomalies do occur:

(a) two sub-parallel linear features trending NNW-SSE, probably corresponding with joint or fault orientations;

(b) a circular conductivity anomaly (5mmho/m) suggesting a small infilled depression in the bedrock.

(ii) The Churston Ferrers-Brixham plateau; background electrical conductivity values in the north of the area were generally below 2mmho/m. Further south there was an overall increase in background values to above 5mmho/m reflecting the increased thickness of overburden, with the limestones mantled by variable depths of silty and shaley head deposits (Griffiths and Lee 1989). Part of the conductivity plot for this area has been reproduced as Fig. 3, which highlights the range of anomalies recorded across the plateau:

(a) large N-S and NNW-SSE trending linear anomalies, probably corresponding with joint or fault orientations;

(b) large circular anomalies with no apparent directional trend;

(c) small isolated features.

Ground investigation

In order to establish the relationship between ground conductivity and overburden thickness a detailed ground investigation was carried out on part of the Churston Ferrers-Brixham plateau, involving:

(i) augering; using a Craelius Minuteman mobile drilling unit with a 47mm continuous-flight auger. A total of 18 augerholes were drilled to a maximum depth of 6.4m unless prevented by bedrock or an impenetrable layer (Fig. 4);

(ii) trial pitting; 31 trial pits were hand-dug to bedrock or a maximum depth of lm (Fig. 4).

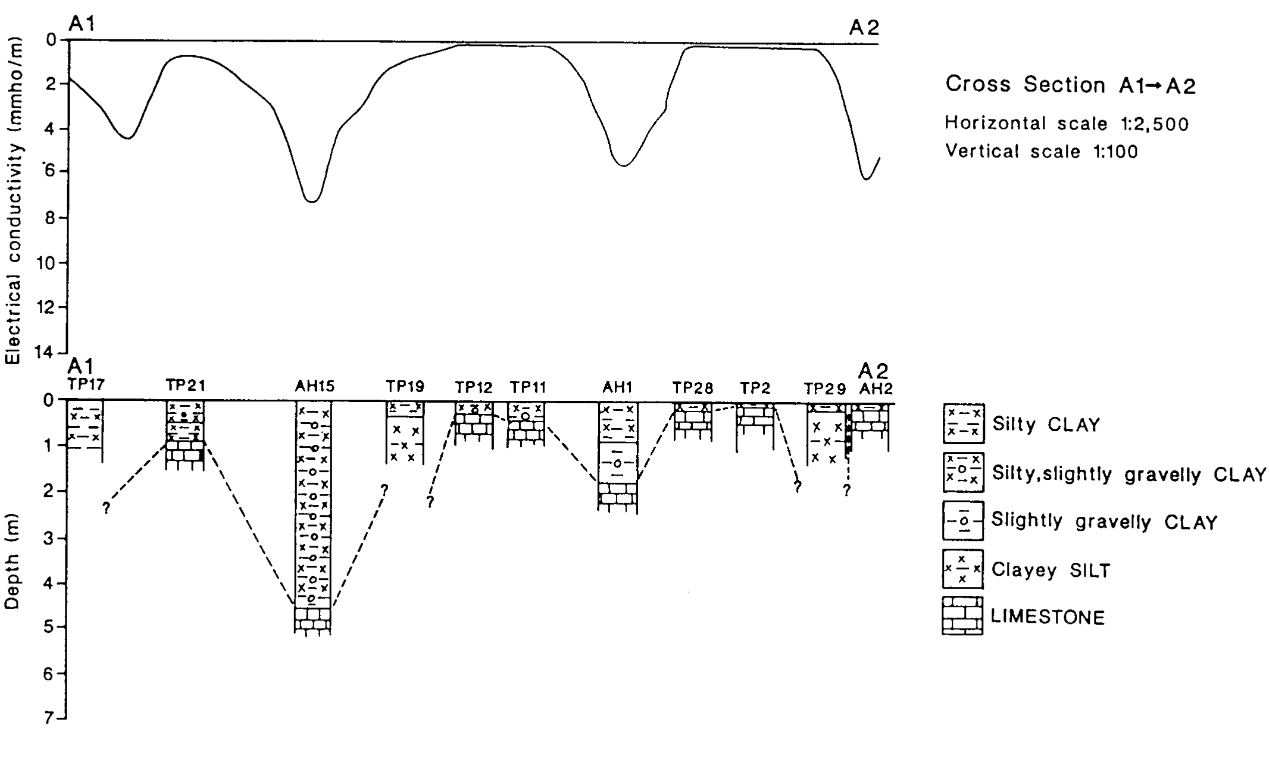

Figure 5. Cross section Al-A2, Churston Ferrers-Brixham plateau.

The results of this investigation are presented as a series of cross sections which compare the rockhead profiles with the conductivity results over the area (Figs 5-7). These figures reveal a close correlation between the pattern of observed overburden thickness and ground conductivity, with greater depths of soil corresponding with high conductivity anomalies. The exceptions to this trend appear to be the result of ground disturbance along field boundaries. It is clear from the results that although conductivity anomalies generally mark the presence of infilled cavities (Lee *et al.* 1988) variations in conductivity values within anomalies do not necessarily appear to reflect changes in the depth of soil, but may also be related to variations in the nature of the infill material. In general the infill material appears to be fairly uniform, comprising brown silty, slightly gravelly clays with occasional Permian sandstone boulders.

It should be borne in mind that the techniques employed have only revealed the extent of surface features as reflected by variations in overburden thickness, and cannot be expected to identify underground cave systems, features over 6m below the ground surface or air-filled voids. In addition, the recorded depths of overburden must be seen as representing the minimum potential thickness at a particular site, as the augering operations may not necessarily have penetrated to bedrock.

Discussion

The results of the geophysical survey and subsequent detailed ground investigation indicate that large areas of the Devonian limestones in Torbay have been affected by solution weathering, albeit to a highly variable degree. For example, the geophysical survey indicates that the limestones at Wall's Hill have only been slightly affected, possibly with some joints and faults enlarged by solution, and only a single circular pipe feature. By way of contrast, the Churston Ferrers-Brixham plateau appears to have been more strongly weathered with a wide variety of infilled circular pipes, large linear dolines and localised variations in the rockhead profile.

Elsewhere within Torbay, extensive cave systems have developed in the limestones, as at Kent's Cavern in Torquay, which has a history of human occupation dating back to the Upper Palaeolithic period (Pengelly 1869). Other important cave systems have been identified, including Happaway and Anstey's Cove Caverns, Torquay; Windmill Hill, Ash Hole and Bench Caverns, Brixham. Large sediment-filled pipes are visible along many stretches of the coastlines developed in the limestones, notably between Breakwater Beach and Shoalstone Point, Brixham. Major karst features can also be identified in the Quarry Bends cutting along the A379 between Paignton and Goodrington, and on the eastern side of Yalberton Quarry. However, not all limestone outcrops appear to have been affected by solution weathering, with many quarry faces and sea-cliffs in Torquay showing very few enlarged joints or cavities. It is important to note that records collected by Engineering Geology Ltd subsequent to the construction of the Kingsteignton By-pass indicated that 68 out of 72 limestone exposures visited in south Devon (inland, coastal, natural and man-made) showed only minor variations in rockhead (Fookes and Hawkins 1988).

It is clear that the extent of solution weathering varies from minor solution along joints to major doline karst features with extensive cave systems, as defined by Fookes and Hawkins (1988). This variability is probably related to lateral sedimentary facies changes within the Middle and Upper Devonian limestones, which collectively represent a reef complex (Doornkamp *et al.* 1988), comprising: (i) the Daddyhole Limestone of Eifelian age consists of an interbedded sequence of dark grey shales with dark to medium grey limestones;

(ii) the Wall's Hill Limestone of Givetian age is typically a pinkish grey massive or poorly bedded limestone, occasionally dolomitised;

(iii) the Barton Limestone of Givetian-Lower Frasnian age is characterised by medium grey massive fossiliferous limestones, interbedded with thin shale bands.

There is also great structural complexity within Torbay, resulting from Variscan recumbent folding, thrusting and faulting. As a consequence there is no simple discontinuity pattern within the limestones, with the nature, orientation and

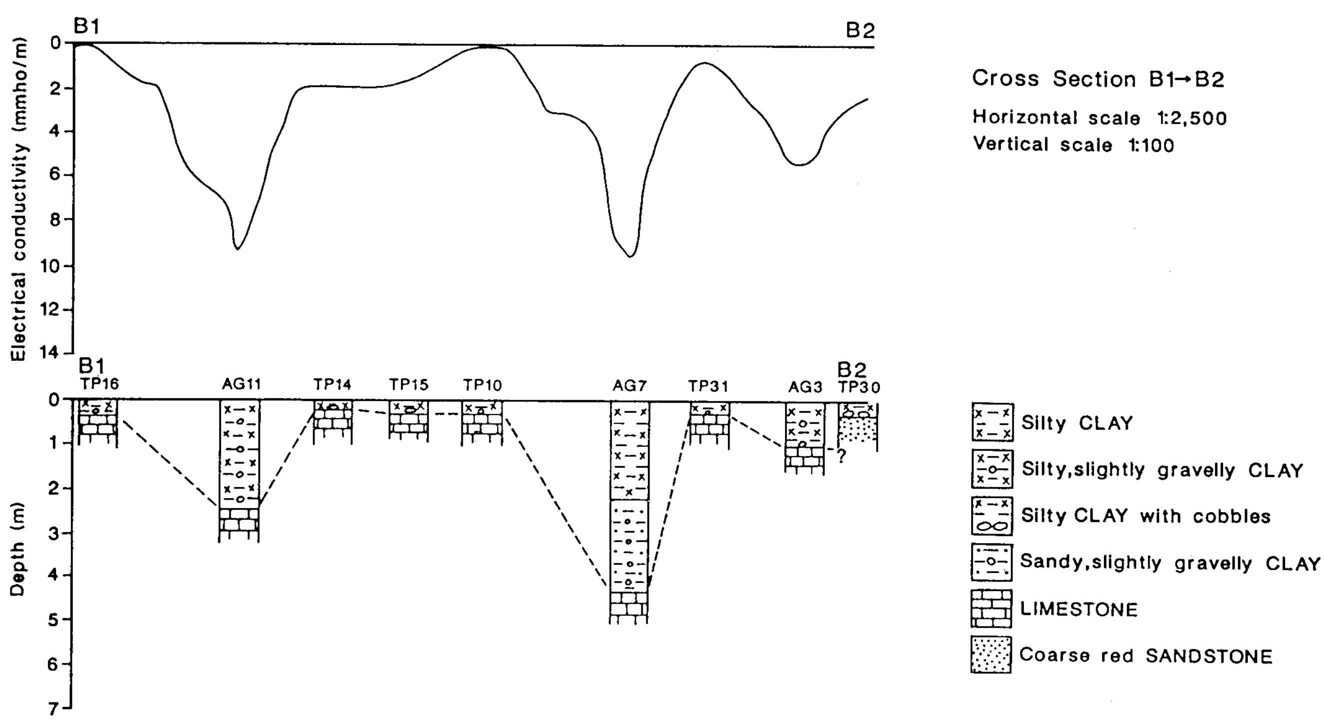

Figure 6. Cross section Bl-B2, Churston Ferrers-Brixham plateau.

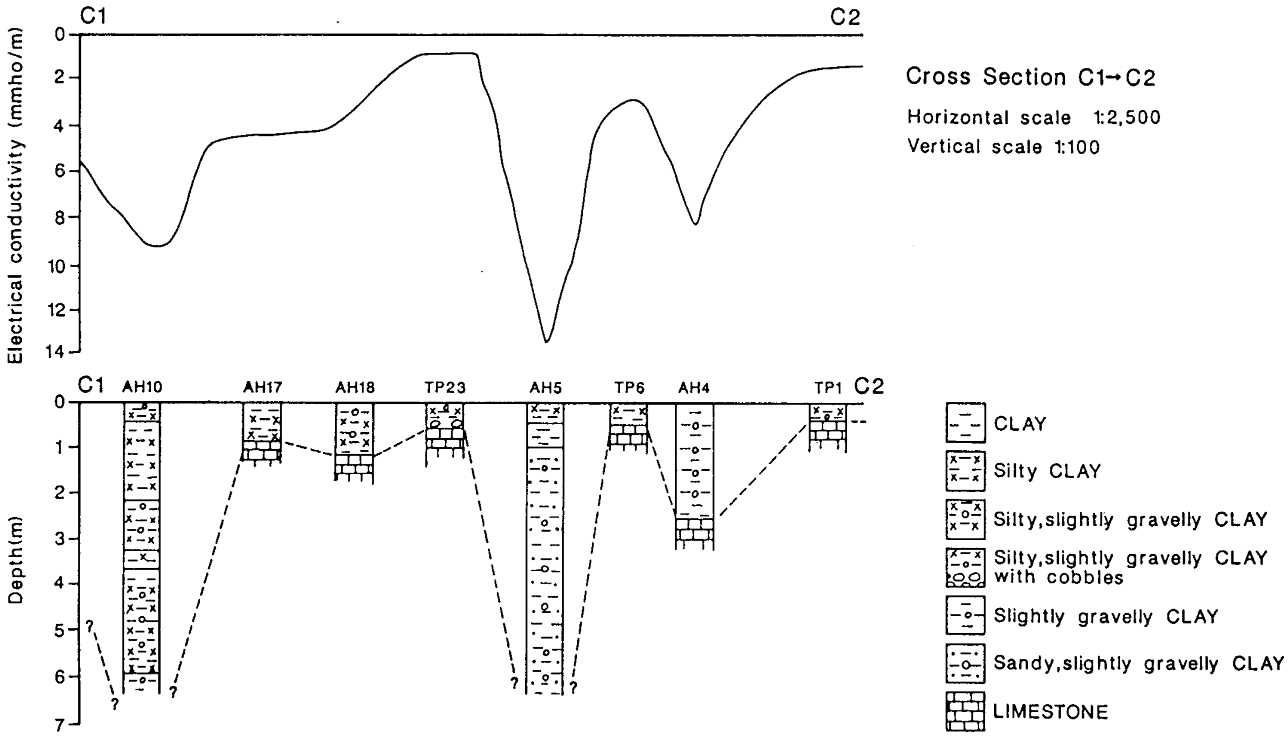

Figure 7. Cross section C1-C2, Churston Ferrers-Brixham plateau.

frequency of fracture showing considerable variation over the outcrops (Doornkamp *et al.* 1988). This is likely to have had considerable influence on the available length and direction of flow paths within the limestones, and hence the intensity of solution weathering. However, NNW-SSE trending structures do appear to have had a significant influence on the orientation of many solution features both in the Wall's Hill and Churston Ferrers-Brixham areas.

In summary, it is clear that an appreciation of the nature and extent of solution weathering is an essential prerequisite to planning and development within the Devonian limestone outcrop. The geophysical approach, as adopted in this study, is likely to provide some indication of the variations in the rockhead profile without the developer having to rely solely on the traditional, and more `hit-or-miss' techniques of drilling or trial pitting.

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