The Sourton Tors geophysical anomaly revisited

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The Sourton Tors area has been surveyed geophysically using a range of instrumentation including a resistivity imaging system, Overhauser gradient magnetometer, EM and SP. This confirms the presence of a near-surface target, which gives the expected response of a massive sulphide orebody. Previous geophysical and drillhole investigation of the area by the then Institute of Geological Sciences also revealed similar results but coring failed to detect massive mineralisation but instead encountered disseminated mineralisation. Nevertheless the results are of such high quality that it is suggested that the Sourton Tors area should be used as a natural geophysical test site for comparison of modern geophysical instrumentation used in the search for sulphide mineralisation. The data collected will be made available publicly for educational purposes.

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Introduction

The Sourton Tors geophysical anomaly is located close to the NW margin of the Dartmoor Granite 6.5 km southeast of Okehampton. The anomalous area lies within the metamorphic aureole of the granite in hornfelsed mudstones and cherts of Carboniferous age and is located along strike from several former mines. The area produces well-defined geophysical signatures that are typical of the expected responses for massive sulphide mineralisation using a range of geophysical techniques. It was originally identified from a regional aeromagnetic survey and IGS/BGS subsequently conducted a range of ground geophysical studies and follow-up drilling programmes (1964-66 reported in Beer and Fenning, 1976). These surveys revealed a series of well-defined electrical and electromagnetic geophysical anomalies, which were and are, consistent with an interpretation indicating the presence of a sulphide orebody. In contrast, the limited gravity surveying conducted along selected profiles failed to identify any anomaly. Subsequent drilling of 7 relatively short cores (total length ~400 m) at 5 locations encountered essentially limited disseminated sulphides but with minor localised concentrations of sulphides in veinlets along fractures and associated with particular bedding planes. The sulphides were principally pyrrhotite and pyrite with minor chalcopyrite and traces of arsenopyrite and sphalerite. The apparent conflict between the main geophysical results and the gravity survey and borehole results led Beer and Fenning (1976) to the conclusion that the electrical and electromagnetic anomalies could only be explained by a stockwork of interconnected sulphide bearing veinlets. This would provide a significant conductive electrical 'target' capable of producing the anomalies observed but to be insufficiently dense as to provide a gravity signature.

As a result of the very well defined geophysical anomalies over the Sourton Tors area it has been used for a number of years as a teaching site for UK undergraduate geoscience courses by at least three universities. As part of an ongoing geophysics teaching programme the anomalies have been remapped with a number of techniques and instruments with the aims of: (1) providing a robust geophysical dataset for use as a teaching resource, (2) providing more insight into the causative body itself and (3) encouraging the use of the Sourton Tors site as a natural site for testing and demonstrating new geophysical instruments and techniques whose results can then be compared to existing baseline studies. Such sites already exist for shallow buried targets (under the auspices of the Environmental and Industrial Geophysics Group of the Geological Society of London based at the University of Leicester) and are currently being developed for archaeological applications. The Sourton Tors site provides the potential for a reference data set across what appears to be a massive sulphide orebody, which is one of the most typical targets for commercial geophysics.

The geophysical data will be made freely and permanently available as a series of digital data files via the WWW through the University of Plymouth website. In addition to standard classical methods a modern multi-electrode resistivity imaging technique has also been used which appears to indicate a well-defined ore body which is remarkably consistent from one profile to the next. The new data are briefly presented, described and interpreted in relation to the overall geological setting.

Geological setting

The structure and stratigraphy of Sourton Tors and the immediately adjacent Meldon area were originally described by Dearman and Butcher (1959), Dearman (1959) and Edmonds *et al*. (1968). The basic outline of the geology presented here is based on these studies supplemented by our own detailed studies of the immediate area. Lower and Upper Carboniferous strata crop out as an arcuate belt sub-parallel to the granite margin with the Lower Carboniferous being repeated by folding (Figure 1). A major anticlinal structure overturned to the S, plunges gently to the W-SW with both limbs dipping N-NNW. The Sourton Tors anomaly is located on the more southerly, overturned, limb of the anticline within Upper Carboniferous rocks with dips of 50-60° NNW. The Lower Carboniferous strata exposed at outcrop immediately around Sourton Tors consist, from NW to SE, of the Meldon Shale and Quartzite Formation intruded by a coarse-grained dolerite dyke. These are in turn overlain by tuffs and blocky tuffs of the Meldon Volcanic Beds which with overlying thinly bedded cherty mudstones with very thin limestones form part of the Meldon Chert Formation. Uppermost in the sequence are shales, mudstones and sandstones, which were encountered from the boreholes located within the area of the geophysical anomaly itself, and were tentatively identified as the Upper Carboniferous Crackington Formation (Beer and Fenning, 1976). All of the strata have been extensively hornfelsed and lie well within the metamorphic aureole of the granite, which extends some 2 km to the north and west of the mapped margin of the granite.

Northwest trending faults with an apparent dextral sense of strike-slip displacement are observed within the area and are thought to be related to the nearby Sticklepath fault. Other faults

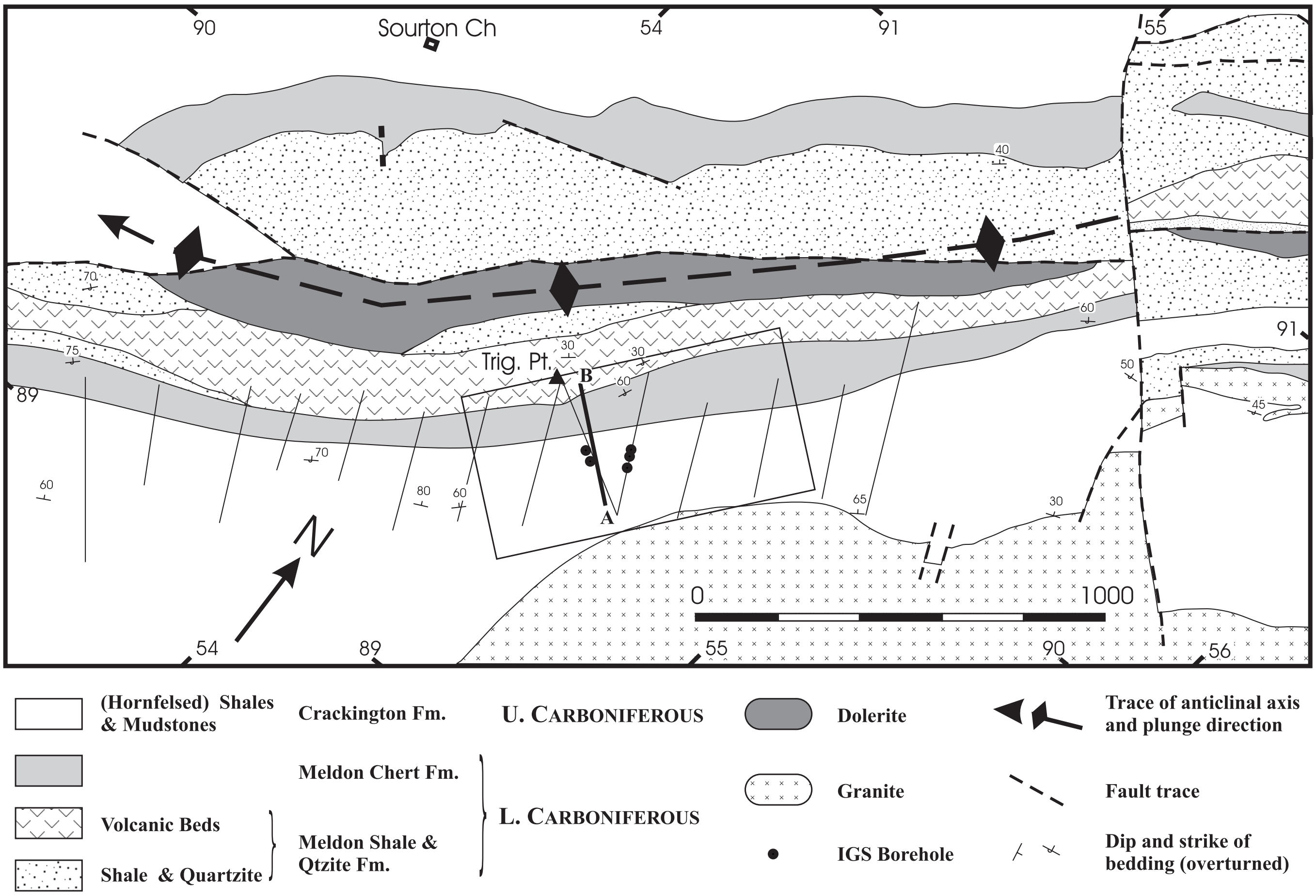

Figure 1. *Geological sketch map of the area showing the geophysical lines of Beer and Fenning (1976) (faint lines), the traverse line illustrated in Figure 2 (bold line) and the mapped areas of figures 3 and 4 (box). The trigonometric point at the Tor has been used as the origin for all the other maps. (After Beer and Fenning, 1976)*

have been mapped as being strike parallel with dip-slip components of movement (Dearman, 1959; Dearman and Butcher, 1959; Edmonds *et al.,* 1968).

Geophysical surveys

The original geophysical survey (Beer and Fenning, 1976) comprised 14 traverses ~150 m apart and of ~400 m line length over a strike length of some 2 km. In this new survey the core area of the anomaly as identified by the previous survey was concentrated upon. For SP, magnetic field and gradient measurements data from over 30 traverses all located within an along strike distance of 700 m have been collected. For most survey types the station spacing for readings was 10 m but with 5 m electrode spacings for the resistivity surveys. Data have been collected over a number of years in a series of undergraduate projects and hence traverses overlap in some areas. Despite the variation in survey parameters (e.g. instruments used, operators etc.) the data show a remarkably well-defined series of anomalies. All traverses are orientated NW at right angles to the geological strike. Most traverses have been very accurately located using optical or laser ranging survey techniques with the Trigonometric point being used as a common reference point. Older lines, which were located using magnetic surveying, show no significant discrepancy with respect to the more recently acquired data. On most traverses a combination of self potential, electrical resistivity, electromagnetic and magnetic methods were applied, often employing more than one survey technique and/or employing differing instruments.

Self (or spontaneous) potential (SP) surveys measure naturally occurring voltages within the ground either with reference to a distant fixed electrode located in barren ground (the amplitude method) or between two relatively closely (10 m) spaced electrodes in which case one measures the local gradient. Negative potentials associated with massive sulphide bodies often reach hundreds of millivolts and are stable over time. The top of the ore body is generally assumed to lie directly beneath the position of the minimum potential. Both methods have been used over the Sourton Tors anomaly and both yield distinct, well-defined anomalies

A range of electromagnetic instruments have been used during different field seasons and these include the tilt angle method of the Geonics EM16 Very Low Frequency (VLF) instrument, and the phase based systems of the Geonics EM31 and EM 17 twin loop methods. All produce well-defined anomalies and should, in theory, have varying depths of penetration. Resistivity results were originally collected using a variety of Wenner arrays with differing interelectrode spacings, these however, have now largely been superceded by the use of resistivity imaging systems which provide a combination of profiling and sounding techniques which allow for the construction of 2D resistivity images. In this case an ABEM Lund imaging system was used and the results are presented.

The most extensive dataset is the ground magnetic survey, which was conducted originally with standard proton magnetometers and more recently with a high sensitivity GSM Overhauser proton gradiometer. This instrument records both the total and gradient fields with an accuracy of some ± 0.2 nT for the total field compared to an accuracy of some ±2 nT for the older instruments.

Results

The results are presented here as multi-instrument profiles (Figure 2), maps of individual survey data (Figures 3-6) or 2D

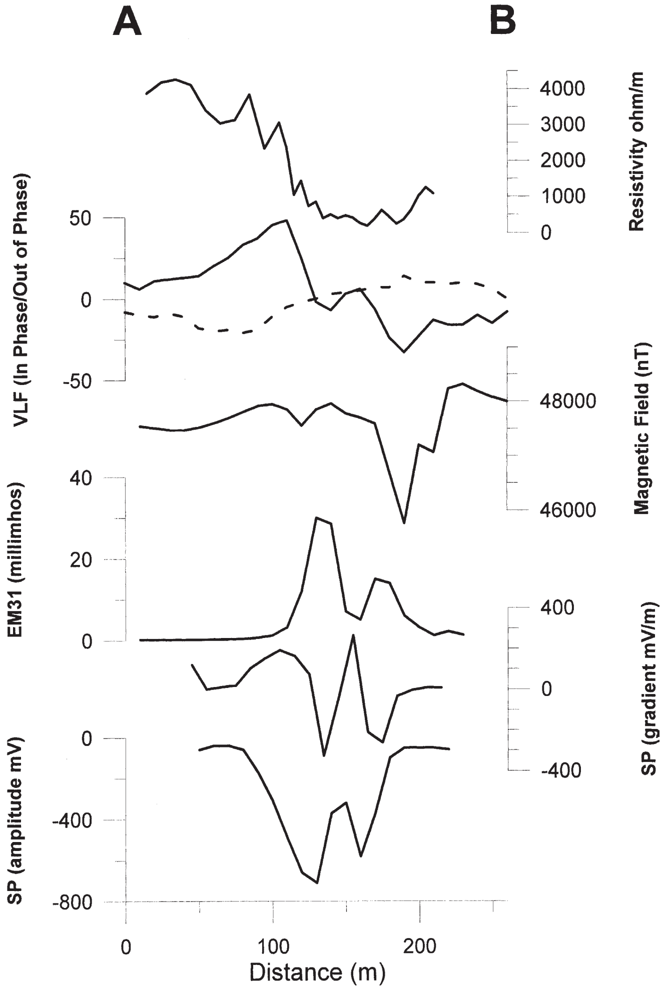

Figure 2. *Multi-instrument profile showing two strongly anomalous zones set within a broader anomaly. Top to bottom, Resistivity (ohm m), VLF-EM (tilt angle) in-phase (solid line) out-of-phase (dashed line), Total magnetic field (nannoTesla), EM31 conductance (millimhos), SP gradient (millivolts per metre) and SP amplitude (millivolts). The peaks in the EM31 data and their coincidence with troughs in the SP (amplitude) and inflection points in the VLF (In Phase component) and SP (gradient) data indicate the location of two potentially mineralisation concentrations. The resistivity and magnetic profiles only indicate the broad zone of mineralisation.*

resistivity sections (Figures 7 and 8). Profile data for a SW-NE trending line located close to the trig point (Figure 1) shows distinct anomalies on electromagnetic and SP surveys which define two anomalous zones at 120-135 m and 165-175 m on this profile (Figure 2). The anomalous zones are highlighted by strongly negative (upto -750 mV) SP anomalies using the amplitude method, clear positive to negative inflection points on the SP gradient method, high conductivity zones using the EM 31 and clearly marked inflection points on the in-phase readings of the VLF. Slight locational discrepancies between the SP and electromagnetic responses may be a function of the variation in the depth of target to which they are most strongly responding too. For example the EM 31 results will most closely reflect targets in the top 2 m of the sub-surface while the SP would be expected to most strongly respond to a larger/deeper target. In addition topographic slopes are known to affect SP anomaly location such that they are commonly displaced downhill which in this case is consistent with the observed discrepancy and topography. A resistivity profile, in this case conducted with a standard Wenner array of electrode spacing 10 m, in contrast picks out a broad anomalous zone of low resistivity but is unable to discriminate between the two anomalous zones which is also true of the VLF out of phase component. Likewise the magnetic results show a broad area with significant variations in magnetic field intensity but whose anomaly shapes are not readily interpretable nor do they define the individual target zones.

Given the current density of reliable data points there is full coverage of the surveyed area for the SP (amplitude), magnetic (total field) and resistivity methods and partial coverage with the VLF, EM31, magnetic gradient and SP gradient methods. SP and magnetic maps are presented here which illustrate the existing dataset. The SP map (Figure 3) shows a broad negative anomaly within which two very intense and distinct anomalies are observed, the more north-westerly of which can be traced almost continuously for some 550 m with peak amplitudes of ~700 mV while the more south-westerly, shorter one (~300 m), is more intense reaching a maximum of ~850 mV. Less intense (<200 mV) anomalies but which are nevertheless sufficiently well defined to be traceable from traverse to traverse are present within the broad low zone of Figure 3 and these minor anomalies, like the main two, all strike parallel to the observed geological strike.

The contoured magnetic total field map (Figure 4) of the area clearly shows that there is an anomalous zone which is, essentially, coincident with the anomalous area identified on the SP map. In detail there is not a one-one correlation between magnetic and SP anomalies (Figure 2) but this would not be expected given the complex nature of magnetic anomalies and that the two techniques respond to different geophysical parameters. This relatively broad magnetic zone contains several high amplitude and distinct paired dipolar anomalies whose axes appear to be NW-SE orientated. The often highly localised nature of the paired anomalies suggests a series of high concentrations of magnetic minerals. Given that a purely induced anomaly would have a N-S axis it is reasonable to assume that there must be a strong remanent component to the inferred total magnetisation. The orientation of such a remanent component would need to be dominantly east-west directed to produce the observed anomalies. This is consistent with the palaeomagnetic data from the Okehampton area (Meldon quarry and Belstone) which although highly scattered do show a dominant east or west shallowly inclined component of magnetisation (Cornwell, 1967).

VLF mapping of the area is currently incomplete and only the in-phase and out-of-phase maps for the southern half of the area are presented (Figure 5). These show distinct electromagnetic anomalies with both in-phase and out-of-phase components showing complimentary anomalies over the same area. The in-phase component does however, show more clearly a better resolved pair of traceable anomalies which is typical for the VLF system as the out-of-phase component is generally more difficult to measure and is often regarded as responding to a combination of near surface variation in the overburden as well as targets at depth. The lines were all measured by traversing in a NW direction so that the location of the conductors is at inflection points on the NW side of the 'highs', as was also the case in the profile data (Figure 2). The data is perhaps more easily understood when it has been filtered using the well-known Fraser Filter (Fraser, 1969). This highlights the anomaly location by transforming the inflection points of interest (positive or real crossovers of the literature) into peaks and filtering out undesired high and low frequencies in the data. This filtered map (Figure 6) shows very clearly two anomalies which appear to be cut and displaced laterally some 50-60 m by what is interpreted as a NW trending fault, which is also observable, if less obvious, on the original unfiltered data. This fault orientation and the apparently dextral sense of displacement are consistent with the regional pattern of faulting but as of yet it has not been possible to locate the fault at outcrop.

Two dimensional resistivity imaging (sometimes known as resistivity tomography) has been used to produce a series of 15 sections at 30 m intervals covering almost all of the surveyed area. These sections were interpreted using an automated modelling process (Zohdy, 1989). They reveal a strikingly similar anomalous zone of pattern of low resistivity anomalies, which can be traced readily from section to section (Figure 7). In general a strong anomalous zone is present whose margins correspond with the

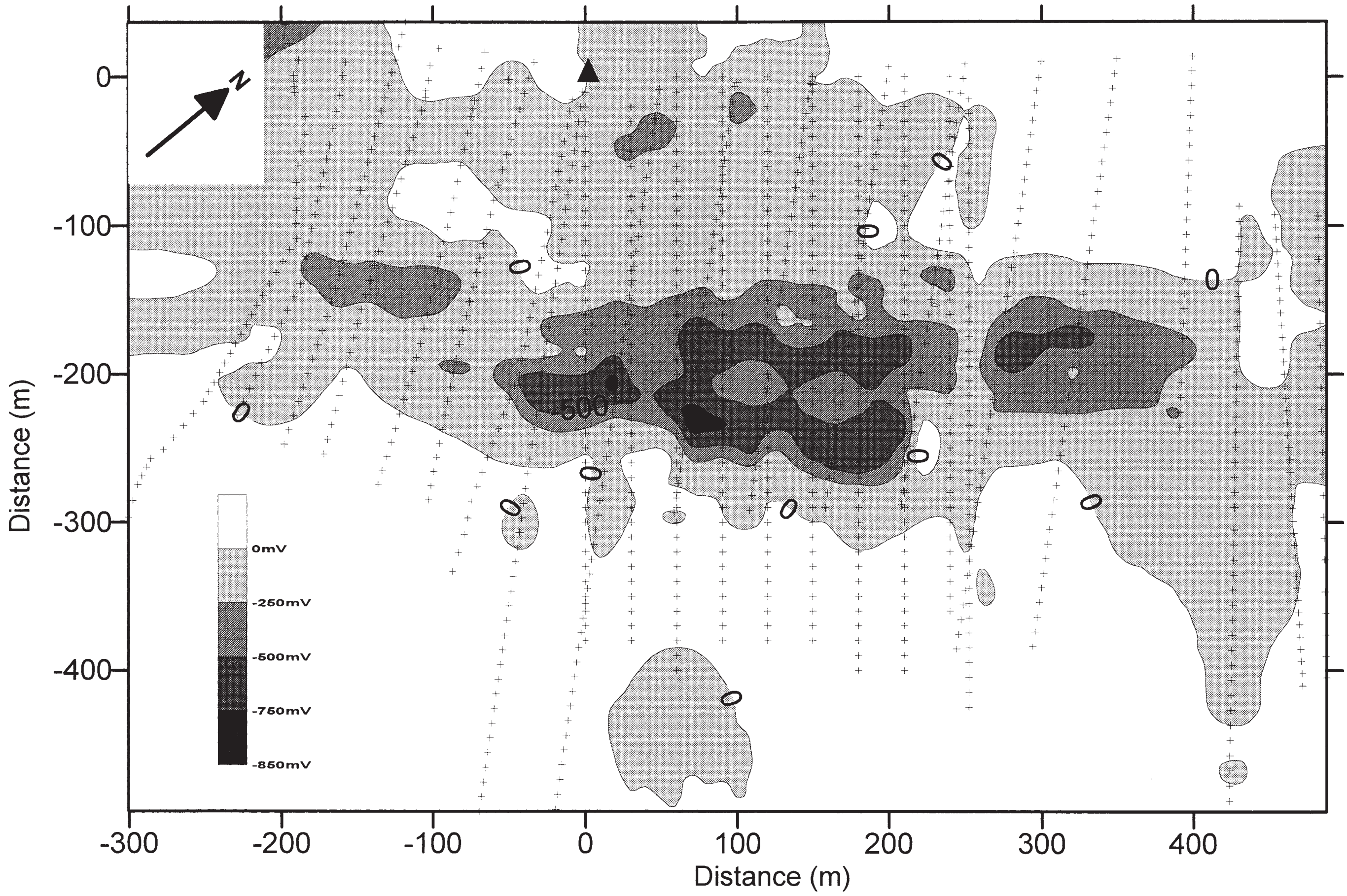

Figure 3. *Map of the Self Potential amplitude showing two well-defined high amplitude (strongly -ve) anomalies trending NE-SW, parallel to the geological strike. The black triangle is the Trigonometric point at Sourton Tor. Small crosses are the individual measurement stations. Note the orientation of the map, which was rotated to provide maximum integrity during the gridding and contouring process.*

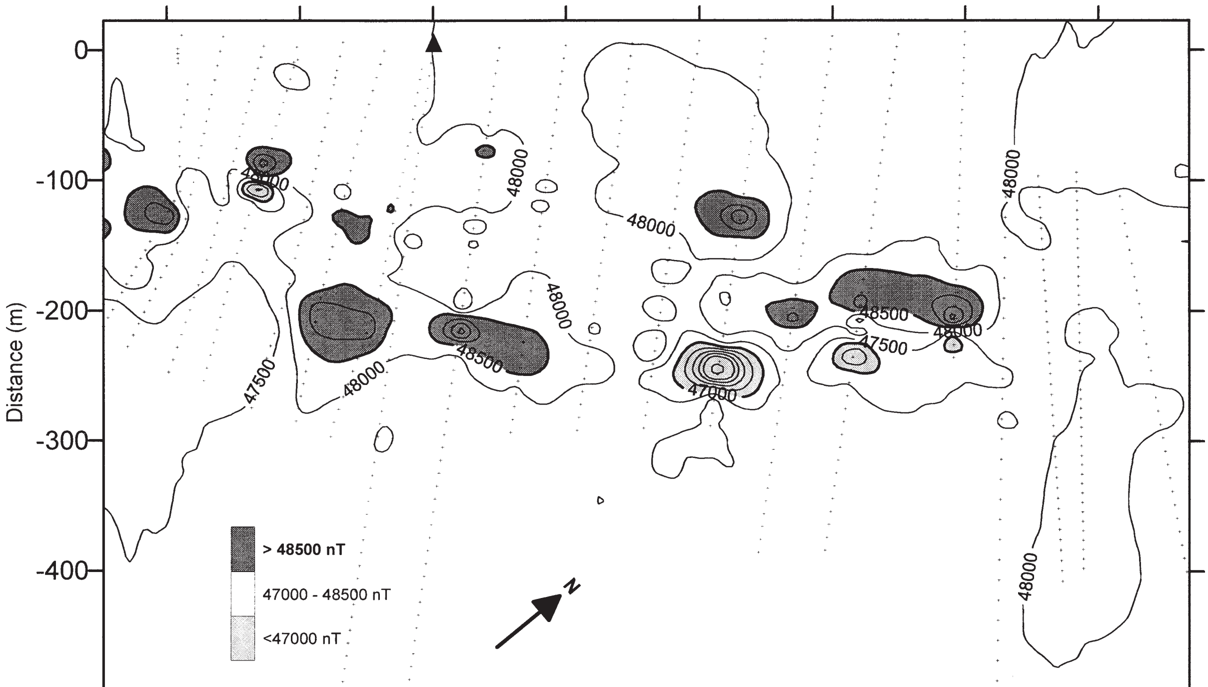

Figure 4. *Total magnetic field map, which shows a generally anomalous area which is broadly coincident with the SP map which also includes several strong localised, dipolar anomalies with NW-SE axes within this zone.*

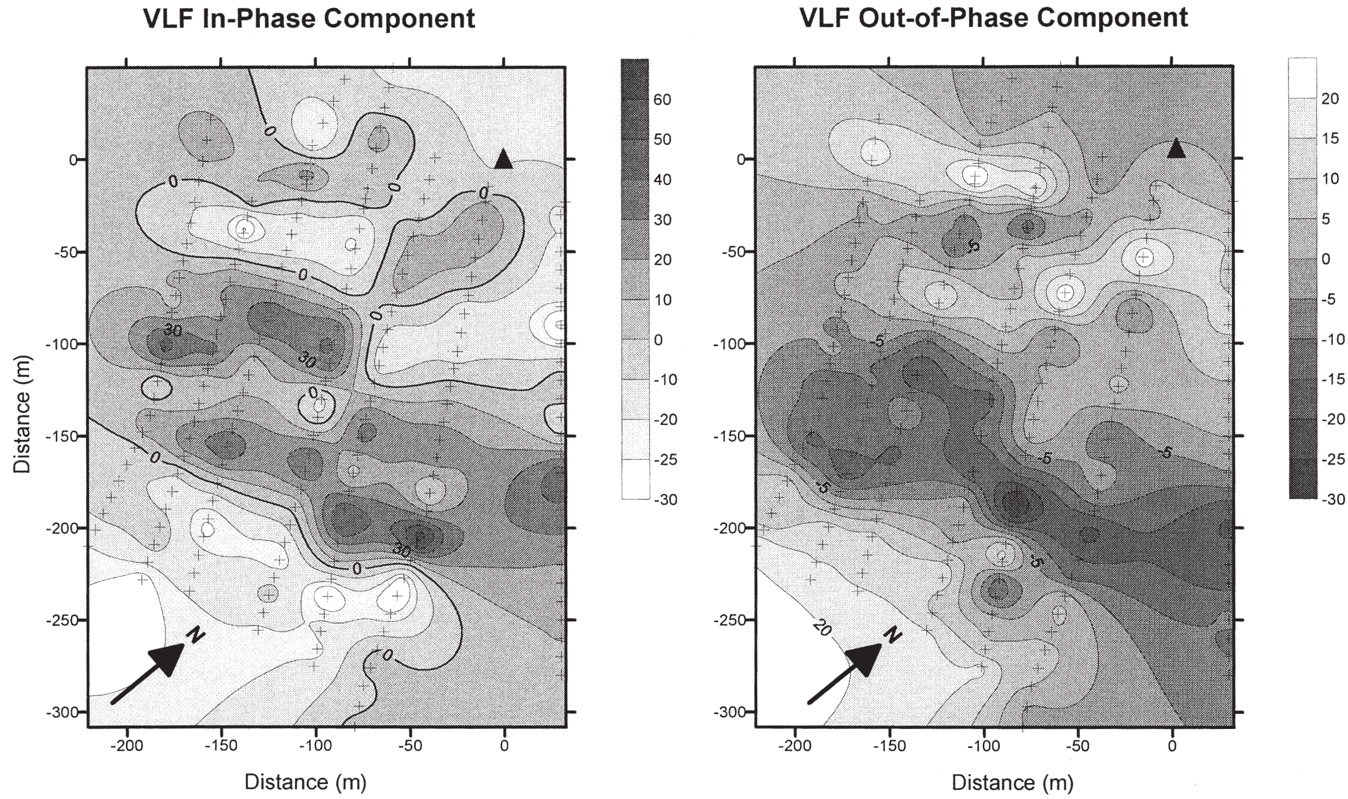

Figure 5. Map of the in-phase and out-of-phase component of the VLF. The location of the conductor axes is best seen on the in-phase map, where they are marked by inflection points (generally close to the 0 contour on the more northerly one cf. the response shown on Figure 2) on the NW flanks of positive anomalies.

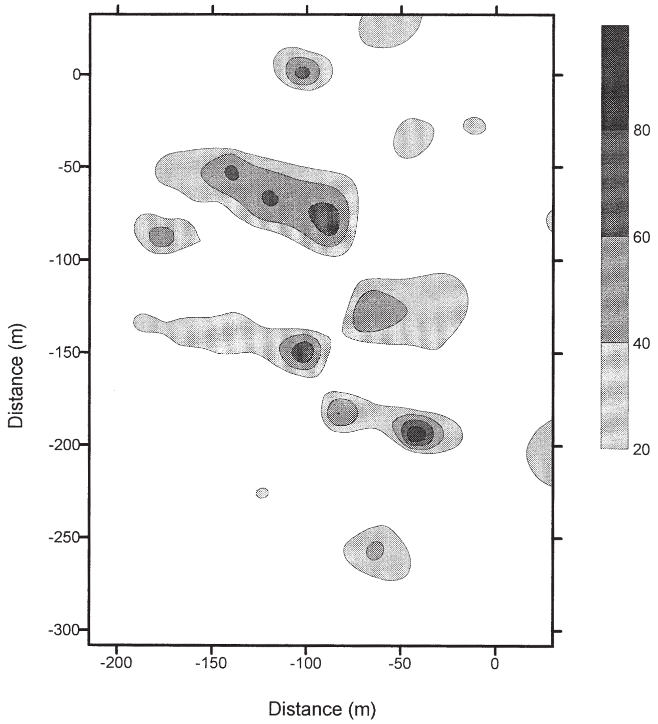

Figure 6. The Fraser filtered in-phase component of the VLF. This map transforms the inflection points of figure 5 to high positive, but dimensionless, values. This more clearly shows a pair of conductors that are obviously offset dextrally along a putative NW trending fault. Note that this can also be seen on the unfiltered data.

two main anomalies identified by the other techniques (EM31, VLF and SP). Furthermore a weak but distinctive branching of the anomaly occurs which extends northwestward toward the outcrops that occur at the Tors itself. This outlying anomaly is often picked up by other techniques as a much weaker anomaly, which is not always easy to trace continuously. If the overall shape of the anomaly indicated by resistivity is reliable, the repeatability of the shape of the anomalous zone suggests that there must be some consistent structural control on its shape and location. However, if this control was because of disseminated mineralisation associated with bedding it could be predicted to dip to the northwest, consistent with the observed bedding in outcrop and in the IGS boreholes. It is therefore tentatively suggested that the main control on the location and shape of the mineralisation is strike-parallel faults whose dip is different from the dip of bedding. Indeed the similarity of the low resistivity zone from line to line suggests to us a body which changes shape little along strike and hence it may be more consistent with a concentrated mineralisation as opposed to disseminated mineralisation which might be expected to be much more variable in form. The arguments against massive sulphide mineralisation being present is that in the original study (Beer and Fenning, 1976) the boreholes only encountered disseminated mineralisation and that two gravity traverses revealed no anomaly and therefore no high density body was present. Arguments against these conclusions include the fact that the boreholes were limited in number and distribution and the gravity data appear to be highly correlated with topography and/or affected by a significant gradient due to the granite. Furthermore the data do not cover a sufficiently large enough area to permit reliable regional/residual separation. Nevertheless it remains open to speculation as to the actual form and concentration of the mineralised body and further research is required.

Discussion

The Sourton Tors area provides good geophysical responses for a wide range of electrical and electromagnetic techniques,

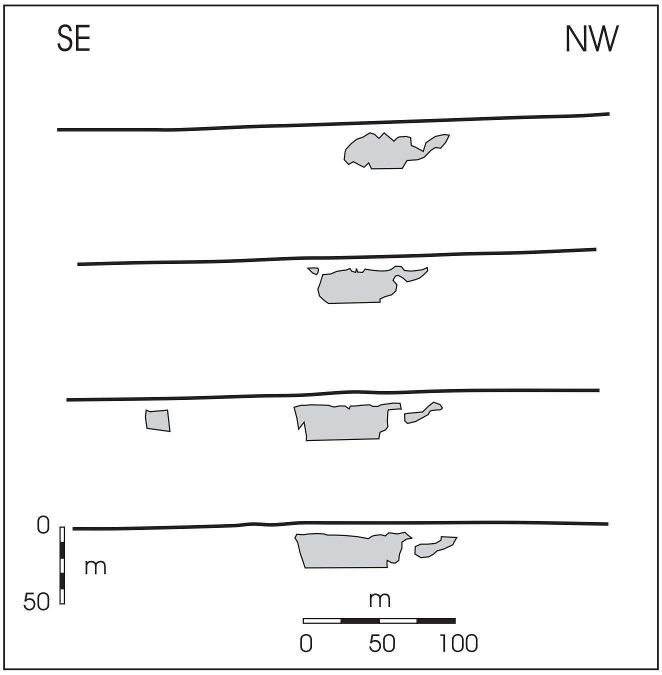

Figure 7. Simple line drawings of four resistivity traverses taken at 30 m intervals north and east of the trig point which show a marked consistency in the anomalies. The areas slope gently downhill from NW to SE and the ground surface is shown for each profile. The shaded area represents the very low resistivity areas (<32 ohm.m) which generally occurs at depths of less than 10 m and extends for some 40-60 m in length with a consistent NW extension present on all these and other profiles.

which are indicative of sulphide mineralisation at very shallow depths. The data from the area will be made available as a teaching resource via the world wide web. As the area lies within the Dartmoor National Park it is unlikely to be disturbed in any manner which might produce unwelcome geophysical noise. It could and should therefore provide an ideal natural test site for comparing geophysical techniques whose results can be used for teaching purposes.

Acknowledgements

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The Godrevy dog; early canine or lost pet ?

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Crisp, G., Pirrie, D., Shail, R.K. and Sabin, R.C. 2001. The Godrevy dog; early canine or lost pet ?
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During sampling of the late Devensian St. Loy Member of the Penwith Formation at Godrevy, Cornwall, several ribs and vertebrae were discovered within the cliff face. The visible bones appeared in context with the surrounding geology with no evidence for later site disturbance or burial. During the excavation the skeleton was entirely enclosed within the coarse grained head deposits. The skeleton was articulated and nearly complete and is identified as *Canis familiaris*, the "domestic" dog. The recovery of this skeleton from the St. Loy Member of the Penwith Formation, generally regarded to be of mid to late Devensian age, is scientifically problematic. The accepted age for the late Devensian is 12-15,000 years BP. The oldest known domestic dogs are dated at about 10,000 years BP, although the burial of a dog or wolf puppy with a human skeleton from Israel 12,000 yrs BP is taken as early evidence of domestication. There are three possible interpretations: (1) the St. Loy Member of the Penwith Formation is younger than previously thought; (2) that Godrevy dog is a very early domestic dog; (3) that it is possible to incorporate a rcent articulated dog skeleton into Quaternary head deposits without any signs of physical disturbance at the site. Dating of the right radius bone by accelerator mass spectrometry has given a likely age for the skeleton of between 1620 AD and 1680 AD. Thus a 17th century domestic dog has been enclosed within Devensian coarse grained head deposits with no signs of disturbance to the site.

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Introduction

Fossil mammal remains are very rare in the Quaternary sedimentary record of Cornwall. Several early accounts describe deer and whale bones recovered from "marine" Holocene sediments within both the Pentewan Valley near St. Austell (Winn, 1839; Flower, 1872) and the Carnon Valley (Couch, 1865a). Couch (1865b) in a description of the submerged fossil forests around the Cornish coast suggested that deer and elk fossils were common in association with the fossil forests, with samples from Whitsand Bay, to the east of Looe, Polperro, Lantivet Bay, near Fowey, Carnon Valley, Pentewan, Marazion and at Land's End. However, all of these occurrences are within Holocene sediments; no mammal fossils have been reported from the underlying Devensian sediments. During regional mapping of the clast composition of the Devensian sediments in west Cornwall, a number of vertebrae and ribs were observed weathering out of the St. Loy Member of the Penwith Formation at Godrevy, Cornwall (Figure 1). In this paper, the vertebrate skeleton recovered from this site is described and mechanisms whereby a 17th Century domestic dog was enclosed within Devensian sediments without any signs of site disturbance are considered. The implications of this work for both archaeological and geological studies are considered.

Regional setting

Godrevy is one of the most important Pleistocene sites in south-west England (Campbell, 1998; Campbell *et al.,* 1999a) and was first described in early studies by De la Beche (1839), Whitley (1866, 1882) and Ussher (1879). The Devonian Porthtowan Formation is unconformably overlain by conglomerates and locally cemented sands which were assigned to the Godrevy Formation (Scourse, 1996) which has now been revised as the Godrevy Member of the Penwith Formation (Campbell *et al.,* 1999b). At this locality, dating of the Godrevy Member based on amino acid ratios measured from samples of *P. vulgata* has suggested a correlation with either oxygen isotope stage 7 (pre-Ipswichian post Hoxnian temperate stage) (Bowen *et al*., 1985; Scourse, 1999) or with the younger oxygen isotope stage 5e (James, 1995). It is possible that several different aged raised beach deposits are superimposed at the Godrevy site (James *pers. comm*., 2001). This dating suggests that the overlying head deposits may have accumulated during several

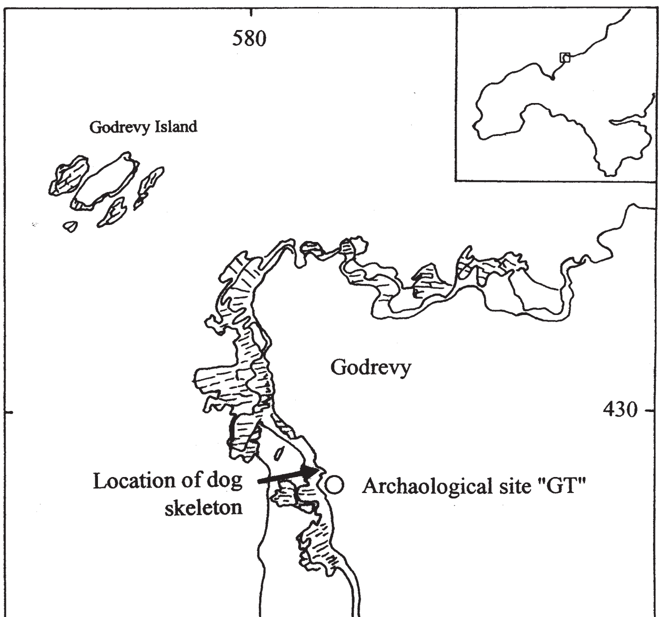

Figure 1. *Map showing the location of the studied section at Godrevy. The approximate location of Mesolithic and Romano-British sites in the area is also indicated (based upon Thomas, 1958).*

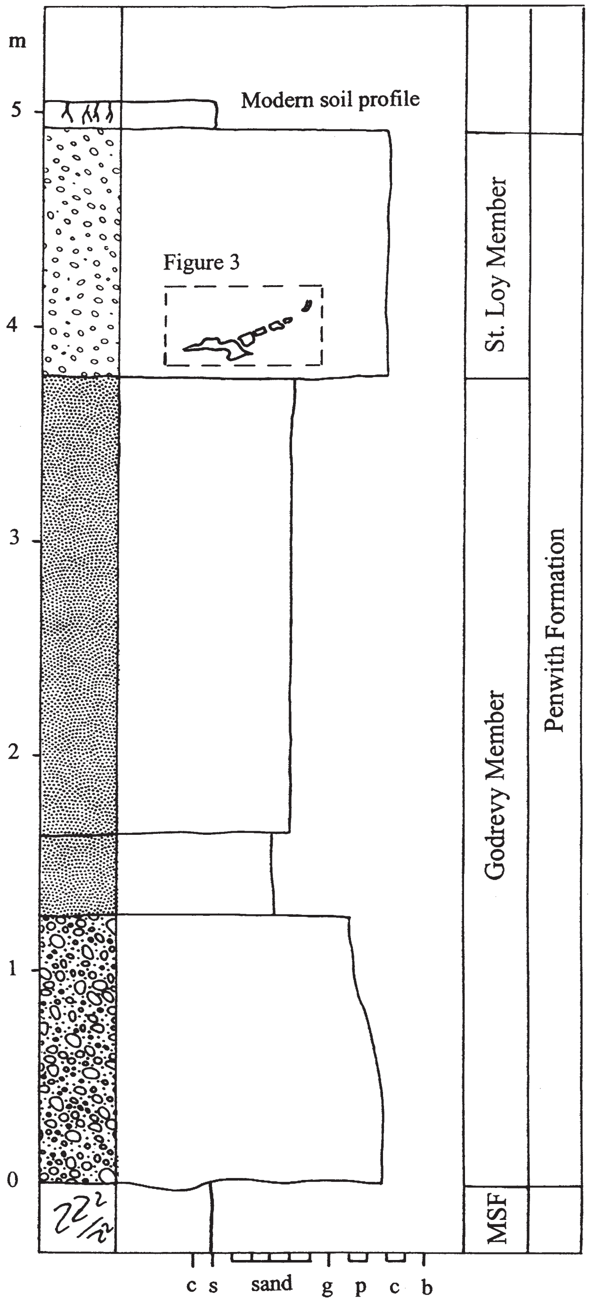

Figure 2. *Sedimentary log through the studied section showing the location of the skeleton. The lithostratigraphy for the section is also shown (after Scourse, 1996; Campbell, 1998; Campbell et al., 1999a). PF - Porthtowan Formation.*

different Pleistocene cold stages (Campbell, 1998). The Godrevy Member is in turn overlain by the head deposits of the St. Loy Member (Penwith Formation) which comprise poorly sorted coarse grained conglomerates (Campbell *et al.*, 1999b). This member is largely considered to have a periglacial soliflucted origin and is generally regarded to be mid to late Devensian in age (Scourse, 1999; Campbell *et al.,* 1999b).

A simplified graphic sedimentary log through the Penwith Formation at Godrevy (SW 5815 4315) is shown in Figure 2. The measured section at this site was 5.04 m thick. 1.22 m of well rounded pebble to cobble sized clasts, predominantly composed of metasediments and vein quartz are overlain by 2.58 m of medium to coarse grained unconsolidated sands. The lower 0.39 m of the sands are medium grained and poorly sorted with a clayey matrix; these are in turn overlain by poorly sorted coarse grained sands which are poorly exposed. Together this lower section represents the Godrevy Member. The contact between the Godrevy Member and the overlying St. Loy Member is sharp and planar at the sampling site although laterally along the cliff section at Godrevy it is locally loaded. The St. Loy Member is 1.14 m thick and comprises angular clast supported conglomerates with a clayey matrix. The Penwith Formation is overlain by a 0.1 m thick modern soil profile. The skeletal remains were initially found 0.4 m above the base of the St. Loy Member (Figure 3) although during the subsequent excavation the skeleton was found to be rotated and slightly inclined from a horizontal plane into the cliff.

At this location, the skeletal remains are present within a 3 m wide slump zone with a small active stream through the middle of the section. The block in which the skeleton was recovered was slightly displaced and rotated, yet the stratigraphy within the block could be matched directly with that on either side of the minor slope displacement.

The excavation

The Godrevy section is an SSSI and the land is owned by the National Trust. Prior to excavation, permission to work at the site was sought from the National Trust and a methods statement was agreed with English Nature. Archaeologists from the Cornwall Archaeological Unit and also representing the National Trust visited the site and considered the remains to be in context with the surrounding stratigraphy with no evidence for site disturbance. The skeleton was articulated, but rotated, so that the head and upper part of the spine were rotated round into the cliff section. The skeleton was entirely enclosed by coarse grained head deposits which appeared identical to the surrounding sediment (Figure 3). During the excavation approximately 80% of the skeleton was recovered, including the skull, the majority of the vertebrae and most of the fore and hind limbs (Figures 4 and 5). Some rib and limb bones were recovered from a recent talus deposit under the cliff section and it is likely that the remaining 20% of the skeleton was lost during weathering of the cliff section prior to the excavation. No other organic remains or "exotic" material were found during the excavation.

Sample identification and description

The recovered skeleton was examined at the Natural History Museum, London, and identified as *Canis familiaris* - the "domestic" dog (A. Currant, *pers. comm.*, 2000). Examination of the skull showed that the outer layer of compact bone on the surface of the skull has been degraded through abrasion by sediments, probably as a result of post-depositional compression (Figure 5). However, damage to the bone caused by the actions of fine plant root matter can also be seen. Root matter was also found inside the brain case after removal of the coarse grained sediment, which was densely packed into the cranial cavity. This evidence, plus the presence of root matter on many of the bones of the axial and appendicular skeleton, suggests that exposure of the semi-articulated remains in, or on, organic deposits supporting plant life, must have taken place either before enclosure in the head deposits or by root systems penetrating through the head deposits after deposition. The nature of the sediment removed from the cranial cavity via the foramen magnum suggests that the deposits must have been comparatively 'mobile' to pass through such a relatively small aperture. However, there were shale clasts measuring up to 6 mm in length by 3 mm in width mixed in with the sediment removed from the skull.

The permanent dentition on the skull is fully erupted and shows signs of attrition (Figure 5). There are no visible signs of dental pathology. In the region of the basi-sphenoid bone in the skull are two small apertures, approximately 3-4 mm in diameter (Figure 5). The sides of the apertures are smooth with some remodelling of the bone, and appear to be pathological in nature (i.e. caused by disease, infection or injury) rather than the result of post-depositional or excavation damage. Few post-cranial elements have survived intact, though the diaphyses of most of the long bones are relatively complete. Sections of the post-cranial skeleton, including parts of the pelvis and left femur, show areas of green 'staining' which may be the result of algal growth.

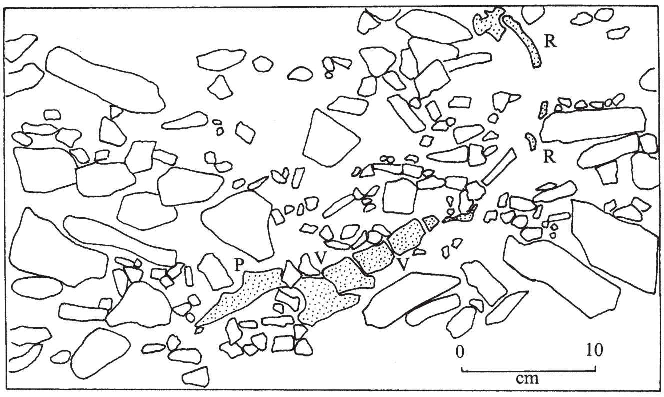

Figure 3. *Schematic diagram showing the field appearance of the skeletal remains weathering from the cliff section at Godrevy prior to excavation. The skeletal remains were enclosed within coarse clasts of vein quartz and Devonian metasediments in a poorly sorted clayey matrix. P - pelvis, V - vertebrae, R - rib.*

The morphology of the Godrevy dog skull (Table 1) was compared with both a 2000 year old dog skull from a Roman excavation and the skull of a pariah dog, an extant form of ancient dog from India which is comparable with small dog skeletons found at numerous prehistoric sites. Whilst the skull was broadly comparable with both the Roman dog and pariah dog, it was still considered possible that the skull was much younger in age and had been introduced (J. Clutton-Brock pers comm. 2000). In terms of the overall size of the Godrevy animal, its morphology is comparable with that of the fox terrier, a small to medium sized dog that grows to approximately 40 cm high at the withers.

Age dating

Wolves found in archaeological excavations probably represent the early stages of domestification and are generally regarded to be the wild progenitor of the domestic dog (Davis and Valla, 1978; Benecke, 1987). The earliest known dog remains are based upon a mandible dated at about 12,000 BP from the Zagros Mountains, Iraq (Turnbull and Reed, 1974) along with the remains of a wolf or dog puppy associated with a human burial dated to 12,000 BP in Israel (Davis and Valla, 1978). In the UK the oldest known domestic dog is from Star Carr in Yorkshire (Degerbol, 1961) which is dated at 9538±350 BP (Davis and Valla, 1978). Thus the identification of the skeleton as being a domestic dog raises a significant scientific problem, for which there are three possible interpretations. (1) If the skeleton is in context with the geology, then the St. Loy Member of the Penwith Formation would have to be younger than previously thought. (2) If the age dating of the St. Loy Member is correct then the Godrevy dog is a very early domestic animal. Previous archaeological studies had recognised a Mesolithic site at the cliff top very close to the location of the dog skeleton (Thomas, 1958). Indeed, Thomas (1958) stated that the Mesolithic cliff top site at Godrevy was a flint-chipping floor, which at that time was partially exposed "in the cliff edge". A Romano-British homestead enclosed within an encircling bank is also described by Thomas (1958) from this site, hence there is evidence for lengthy nearby human occupation (see Figure 1). (3) The third interpretation is that the skeleton is much younger and is not in context with the surrounding geology. This would indicate that it is possible to enclose an articulated dog skeleton into coarse grained head deposits without any signs of physical disturbance at the site.

To test these three hypotheses a bone sample was taken from the right radius and was dated using accelerator mass spectrometry (AMS) at the Oxford University Radiocarbon Accelerator Unit (sample number OxA-9992). The sample gave an uncalibrated date in radiocarbon years BP (before present - AD 1950) of 251±30 and had a $d^{13}C$ value of -18.9‰. Isotopic fractionation has been corrected for using the measured $d^{13}C$ value quoted. When calibrated using the OxCal program (Ramsey, 1995) using atmospheric data from Stuiver *et al.* (1998) an age of 1620 to 1680 AD is given at 95.4% probability (Figure 6).

Discussion

The Godrevy dog skeleton is therefore dated at between 1620 and 1680 AD yet enclosed within head deposits of probably mid to late Devensian age. The skeleton was articulated which implies that soft tissues were present around the skeleton when it was incorporated into the sediment. The lack of evidence for scavenging and disarticulation also implies that the animal was not present on the land surface for any significant length of time post mortem. However, the sediment removed from the skull along with root matter on many of the bones, suggests that the semi-articulated remains were on, or enclosed, within organic deposits prior to enclosure within the head deposits or that root systems penetrated through the skeletal remains after inclusion within the head deposits. Thus a mechanism is needed whereby an animal can be incorporated within the coarse grained sediments after death without disrupting the local stratigraphy. There is however, no way to test the potential hypotheses, consequently the discussion is, by its very nature, speculative.

There was no evidence at the site that the animal had been buried. The overall sedimentological profile of the section surrounding the skeleton was identical to the adjacent sections, suggesting that if a pit had been dug, then the sediment was replaced in stratigraphic context. An alternative interpretation may be that the dog entered an animal burrow and became trapped and decayed *in-situ*, and the sediment subsequently collapsed and compacted around the skeleton. The very coarse grain size of the head deposits would preclude burrowing activity by rabbits or hares which today burrow into the recent wind blown dune systems forming the nearby Gwithian Towans. However, it is broadly conceivable that a badger may be able to burrow in such coarse grained sediment and that coastal recession has subsequently exposed this burrow within the current cliff profile.

As described above the sample location is within a narrow valley that leads to a gulley incised into the wave cut platform of Devonian metasediments. The area in which the skeleton occurred was slightly displaced within a ?rotated land slipped block which retained its stratigraphical integrity. Landslides and rotational failures are common within the Quaternary sediments along the Cornish coastline. A possible alternative explanation for the inclusion of the skeleton within the head deposits involves a three stage process related to coastal erosion. During slope failure tension cracks may develop landward of the cliff profile, subsequent back rotation during slope failure may cause the closure of the tension crack as the block back rotates. The block may retain stratigraphical integrity but undergo down slope translation. It is conceivable that an animal may fall into and become trapped within a tension crack, which subsequently closed during back rotation apparently incorporating the skeleton

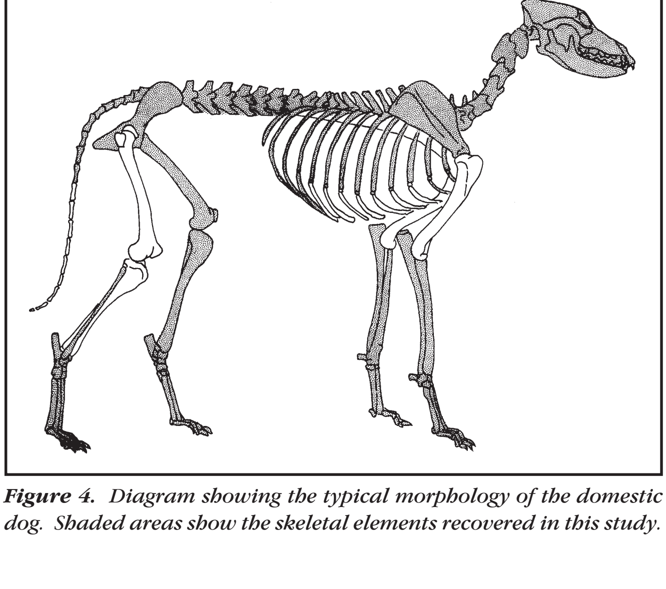

Figure 4. *Diagram showing the typical morphology of the domestic dog. Shaded areas show the skeletal elements recovered in this study.*

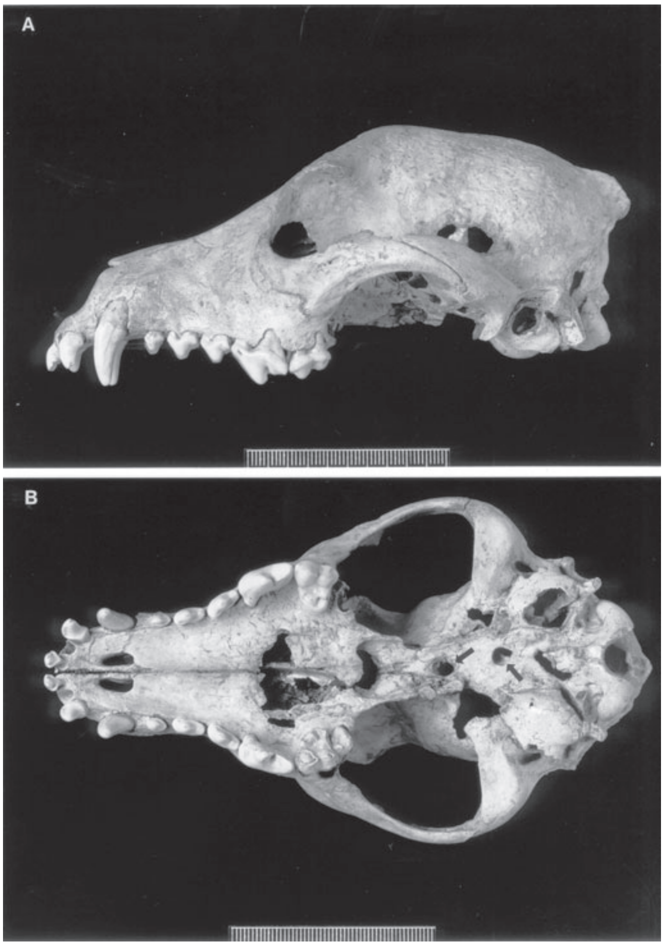

Figure 5. *Photographs showing the skull of Godrevy dog. (a) Side profile of the skull; note that the dentition is fully erupted. (b) View of the underside of the skull. Note the two small apertures in the region of the basi-sphenoid bone (arrowed). These are smooth sided and appear to be pathological in origin. Scale bar in both photographs is in mm.*

Basic dimensions of the skull	millimetres
Total length of skull	153.5
Condylobasal length	142
Basal length	134.5
Upper neurocranium length	80
Facial length	73.5
Zygomatic breadth	89
Greatest neurocranium breadth	53.5
Frontal breadth	45.5
Least breadth of skull	34.25
Least breadth between orbits	31
Greater inner height of orbit	26.25
Greatest breadth of foramen magnum	16.5
Height of foramen magnum	14.5
Greatest mastoid breadth	54.25
Skull height without sagittal crest	44.5
Length of cheek tooth row	52
Length of molar row	16
Greatest palatal breadth	53
Least palatal breadth	30.25
Breadth at canine alveoli	32

Table 1. *Basic dimensions of the Godrevy dog skull (all measurements in mm, following Von den Driesch, 1976).*

within the head deposits. However, for this mechanism to be viable it implies that the rate of erosion of the Quaternary section at Godrevy is low as tension cracks are unlikely to have developed more than a few metres back from the cliff line. If we assume that the tension crack is unlikely to have developed more than 5 m back from the position of the cliff line in c. 1620 then a coastal recession rate of 1.3 cm/yr would be suggested. If the tension crack was closer to the c. 1620 cliff line then a lower rate of coastal recession would be predicted. Whilst it is impossible for us to test these hypotheses it is considered that the most likely model is that of inclusion within a rotated block during cliff failure in the 17th Century.

Implications

It could be argued that the presence of a 17th Century dog skeleton within Devensian sediments is not worthy of documentation. However, there are clear implications of this discovery for both archaeological and geological studies. No aspect of the skeleton or the surrounding sedimentology indicated that a much younger animal had been incorporated within significantly older sediments. If the skeletal remains had been of a typical late Devensian mammal such as the red fox (e.g. Stuart, 1995) both the geology and the fossil taxa would have been compatible. How often are vertebrate samples AMS dated to confirm that they are compatible in age with the assumed age of the sediments ? In addition, AMS dating has only been widely available in recent studies; prior to the development of this method the skeletal remains themselves would have been the key to effectively providing the biostratigraphic control on the age of the sediments. Mesolithic and Romano-British sites have been excavated within a few metres of the skeleton site; it is entirely possible that the dog skeleton could equally well have been incorporated within the archaeological evidence again providing an erroneous occurrence. This study suggests that the context and significance of any fossil occurrence within the Quaternary coastal sections must be treated with caution unless there is clear dating control to confirm the age relationships of the skeletal remains and the associated sediments. It is unfortunate that many of the skeletal remains described from the Holocene sediments in Cornwall by earlier workers have subsequently been "lost" as AMS dating would provide an unambiguous solution to their age and true geological significance.

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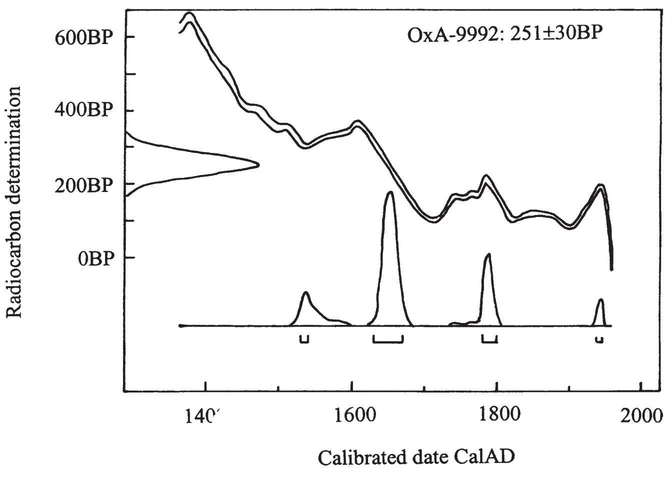

Figure 6. *AMS dating results showing the most likely age for Godrevy dog to be between 1620 and 1680 AD.*

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