Chapter 7
Karst

The term *karst* defines a terrain with distinctive landforms and drainage arising from greater rock solubility in natural waters than elsewhere (Jennings, 1987). Karst has also been defined as a diagenetic facies; an overprint in subaerially-exposed carbonate bodies produced and controlled by dissolution and migration of calcium carbonate in meteoric water, occurring in a wide variety of climatic and tectonic settings and generating a recognisable landscape. The realisation that karst processes were active in carbonate rocks throughout geological time added a further dimension to research in this field and led to the introduction of the term *palaeokarst* meaning simply fossilised carbonate features.

In the Yuen Long district, carbonate rock exists in the form of marble which by metamorphic and tectonic action is in part well-jointed, faulted and folded, resulting in the juxtaposition of many different lithologies. Such situations are ideal for the development of karst features given the necessary hydrological conditions (Plates 15 & 16).

Karst is found in all latitudes ranging from the poles to the equator, but the higher the temperature the faster the dissolution of carbonates by acid groundwater. The rate of karst development depends also on the hydraulic conditions, which together with the strength of the calcareous rock controls the erosion rate. The Yuen Long marble is a very strong rock when fresh, with uniaxial compressive strength ranging from 65 MPa to 140 MPa (GCO, 1990), ensuring a slower rate of erosion than for softer carbonates such as chalk. However, the Ma Tin Member of the Yuen Long Formation is chemically almost pure calcium carbonate, and although one of the strongest rocks of the district, is more susceptible to dissolution than the marble from the weaker more impure Long Ping Member. This reversal results from a high insoluble residue in the Long Ping Member which slows down the dissolution process and at times may form a protective barrier to further reaction.

Plate 15 - Karst Features in Borehole Cores: Solution Feature Showing Ferruginous Staining

Plate 16 - Karst Features in Borehole Cores: Solution Widened Joint Showing Fretted Surface

Notwithstanding the above variables, no rock surface is ever uniform, even if horizontal and of recent age. It will have suffered variable pressures resulting from the diagenetic processes, experienced local compaction effects, and may have been subjected to regional tectonic and metamorphic events. Bodies of rock respond to stresses occurring during geological history by forming joints and fractures. It is along such hydraulic channels that the initial attack by acidic water is concentrated, leaving other zones virtually unchanged. Selective chemical weathering and erosion is therefore started, which with time results in the many types of karst geomorphology now well documented throughout the world (Jennings, 1987). Examples of some of the types detected in the palaeokarst of Yuen Long are described below.

A site adjacent to Wang Lok Street [212 357] on the Yuen Long Industrial Estate was investigated by 24 drillholes, and the configuration of the marble rockhead is shown in Figure 18. It is dominated by a north-south trending ridge with a steep eastern face. The marble shelves both to the east and west to depths greater than -70 mPD, with the top of the ridge close to -20 mPD proving a relief of some 50 m. A nearby site [213 356] proved by thirteen boreholes shows a depression with a diameter of some 100 m and side slopes inclined at angles between 20° and 40° (Figure 19). The bottom of the depression is at about -75 mPD, confirming a range in relief of about 50 m. The bedrock here comprises both marble and granodiorite, and the faulted/intrusive boundary is obviously an important factor in the formation of this fossil sinkhole structure.

The terms *sinkhole*, *swallow hole* or *swallet* refer to closed depressions in karst. These English terms have, however, been used very loosely and the word *doline* is now accepted for closed depressions varying from circular to oval in plan and dish-shaped, conical or cylindrical in cross-section. Such variety of forms results from the solution, erosion and collapse processes operating (Jennings, 1987; James & Chokuette, 1987). A doline, therefore, is an indication at the rock surface of a process of removal underground of a considerable volume of material. Numerous closed depressions exist within the marble rockhead of the district, and clay-filled joints and cavities occur commonly at depth. It can be logically concluded that the dolines and cavities are connected. In Yuen Long, doline formation was halted at least 50 000 years ago, based on the age of the overlying sediments, with the connecting channels between doline and the epikarst being sealed.

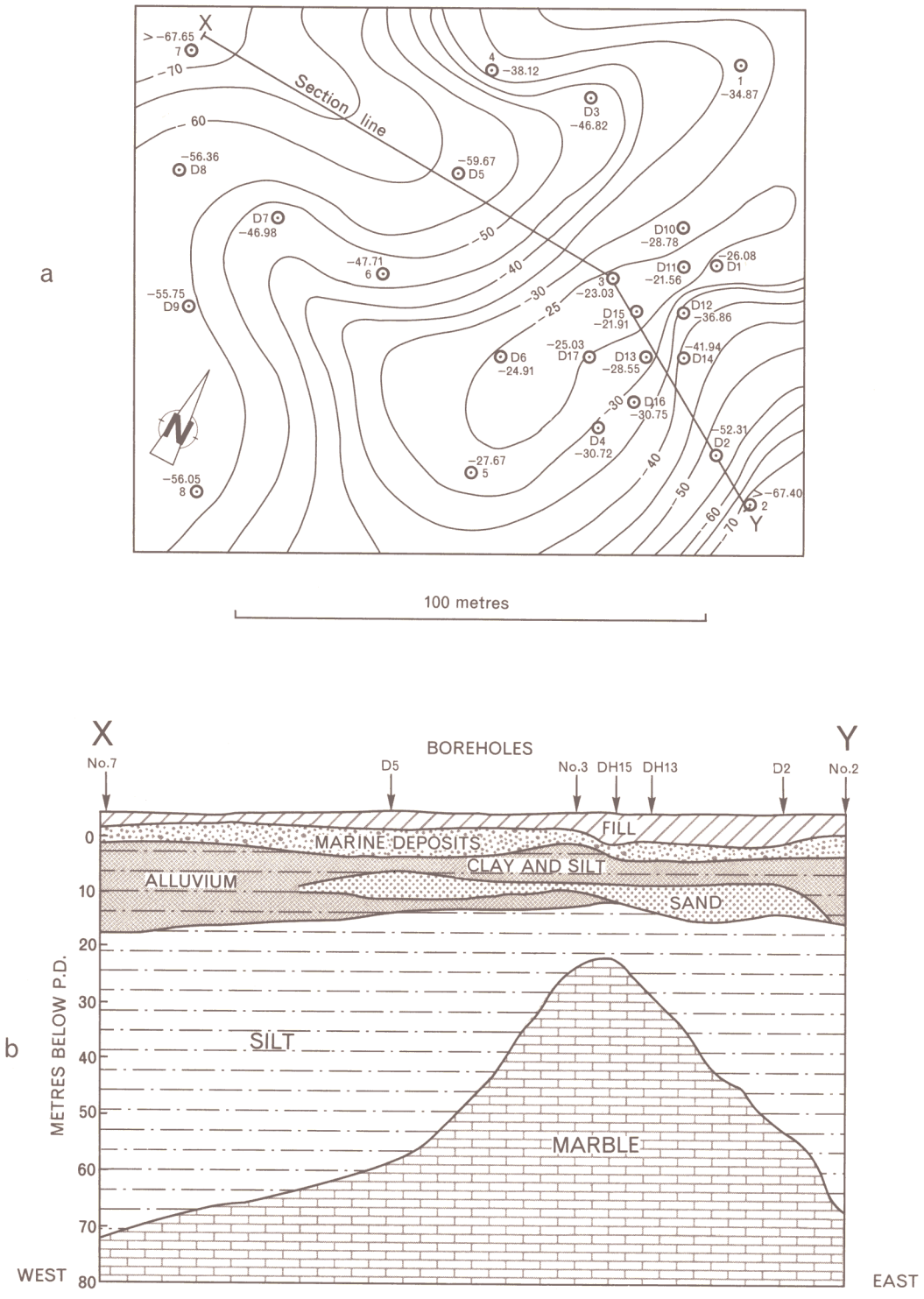
The geological model derived from nearly one hundred drillholes at a site on Hop Choi Street [2115 3375] in the southeast of Yuen Long illustrates the juxtaposition and alignment of the irregularities in a palaeokarst terrain (Figure 20). It also shows not only the surface phenomena of karst, but also more fundamental structural trends in the north of the site where the marble surface dips steeply beneath overlying formations. Examination of the direction of jointing for site YLTL 429 [2065 3355] in the south of Yuen Long adjacent to Ma Tin Road (Houghton, 1988) showed a wide spread of values but with a dominant strike along a northwest-southeast axis. Most joints dip at angles greater than 50°. The first few metres of the karst top are usually poorly recovered in drillholes, and the core consists of numerous broken fragments of stained marble. Although this surface profile of the karst is irregular, possibly with sporadic detached corestones, the drilling process has however exaggerated this disruption of the surface. Inspection of more than 1 000 drillholes through marble in the district shows that in general the top 5 m of the karstic rockhead is most affected by dissolution (Plates 15 & 16). The next 25 m also shows karstification which decreases in intensity with depth until the only indications of dissolution are stained joint planes. This total zone of karstic erosion is termed the epikarst.

One of the main concerns for development in an area of karst terrain is the presence of cavities within the carbonate formation. These may be shallow structures closely linked by widened joints to the surface or deep-seated voids, partially or totally filled by recent sediments. Such sediments are usually poorly cemented silts and sands or soft clays, commonly with an organic content.

Cavities within the district are of three types:

1 Cavities in the epikarst usually in the top 30 m of the marble bedrock
2 Cavities beneath the epikarst, usually 30 to 60 m below the marble rockhead but probably linked to the surface by major joints or discontinuities
3 Cavities associated with other lithologies or faults

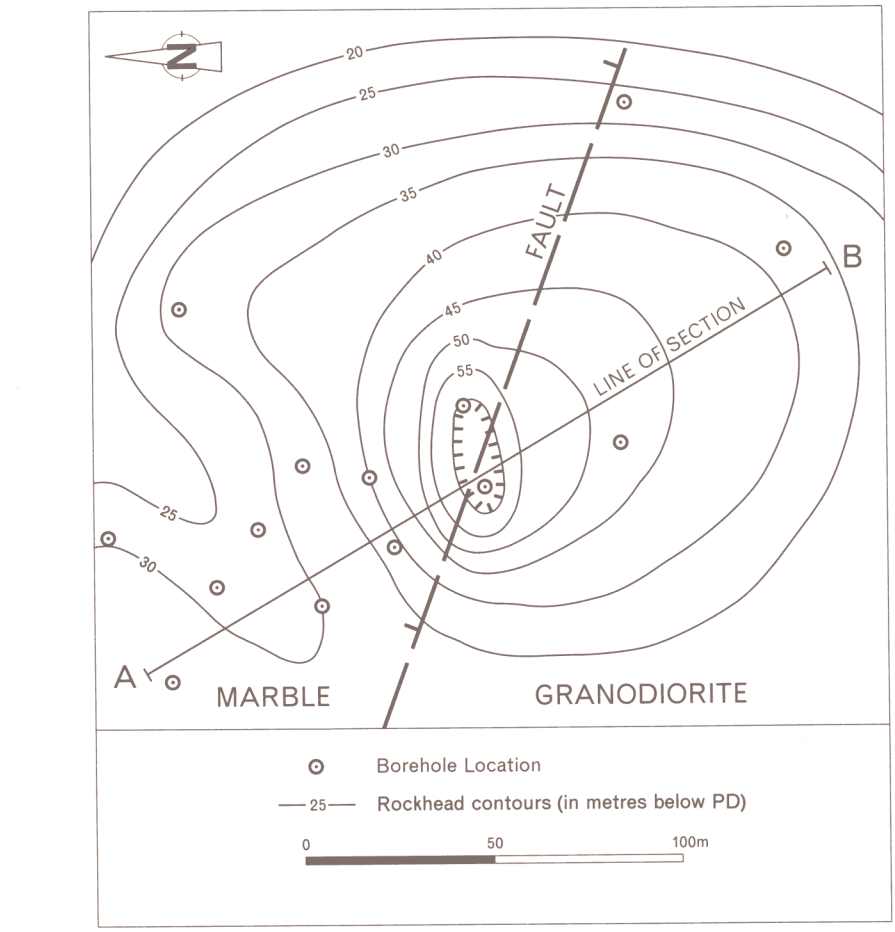
Recovery of cavity-fill material from drillholes is usually poor, with the soft sediments being washed away by the drill flush. However in BGS 2 a mazier sample provided an excellent section from 76.28 to 77 m of part of a 3.45 m wide cavity (Figure 21) which indicates a repetitive cyclical sedimentation. The basal 100 mm of the recovered section consists of cross-bedded silty fine sand with interlaminated clay layers, proving an initial surge of sediments in a relatively high energy environment. These sands are overlain by structureless grey to black organic sandy clays, suggesting slow deposition possibly in brackish water. The clays contain angular fragments of chert up to 20 mm long which may have fallen from a vein in the roof or side of the cavity. The clays pass upwards by interlamination into grey silts.



a. Contours drawn on the top of the marble.

b. Section X-Y showning assymmetrical ridge of marble. Note the thinning of the superficial deposits over the axis of the ridge.

Figure 18 - Karst Features on Part of Site YLTL 313, Wang Lok Street, Yuen Long Industrial Estate



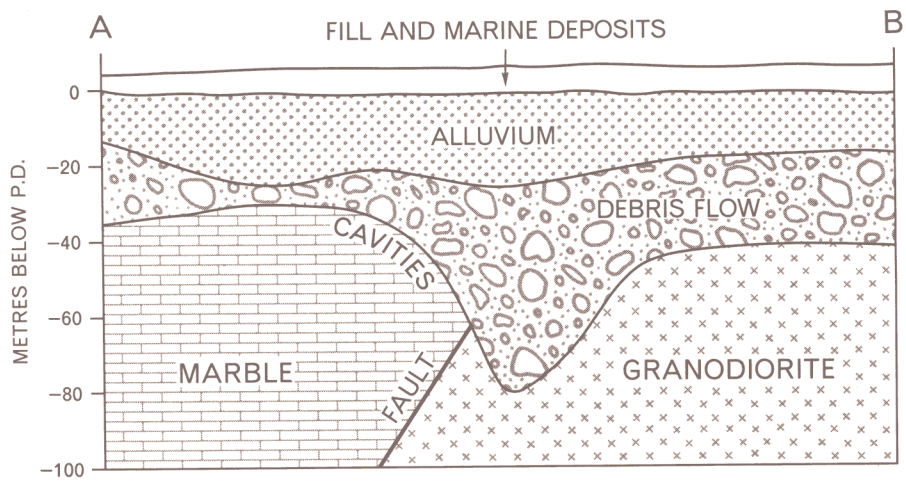


Figure 19 -Rockhead Contours and Section Showing a Doline Developed along the Faulted Boundary

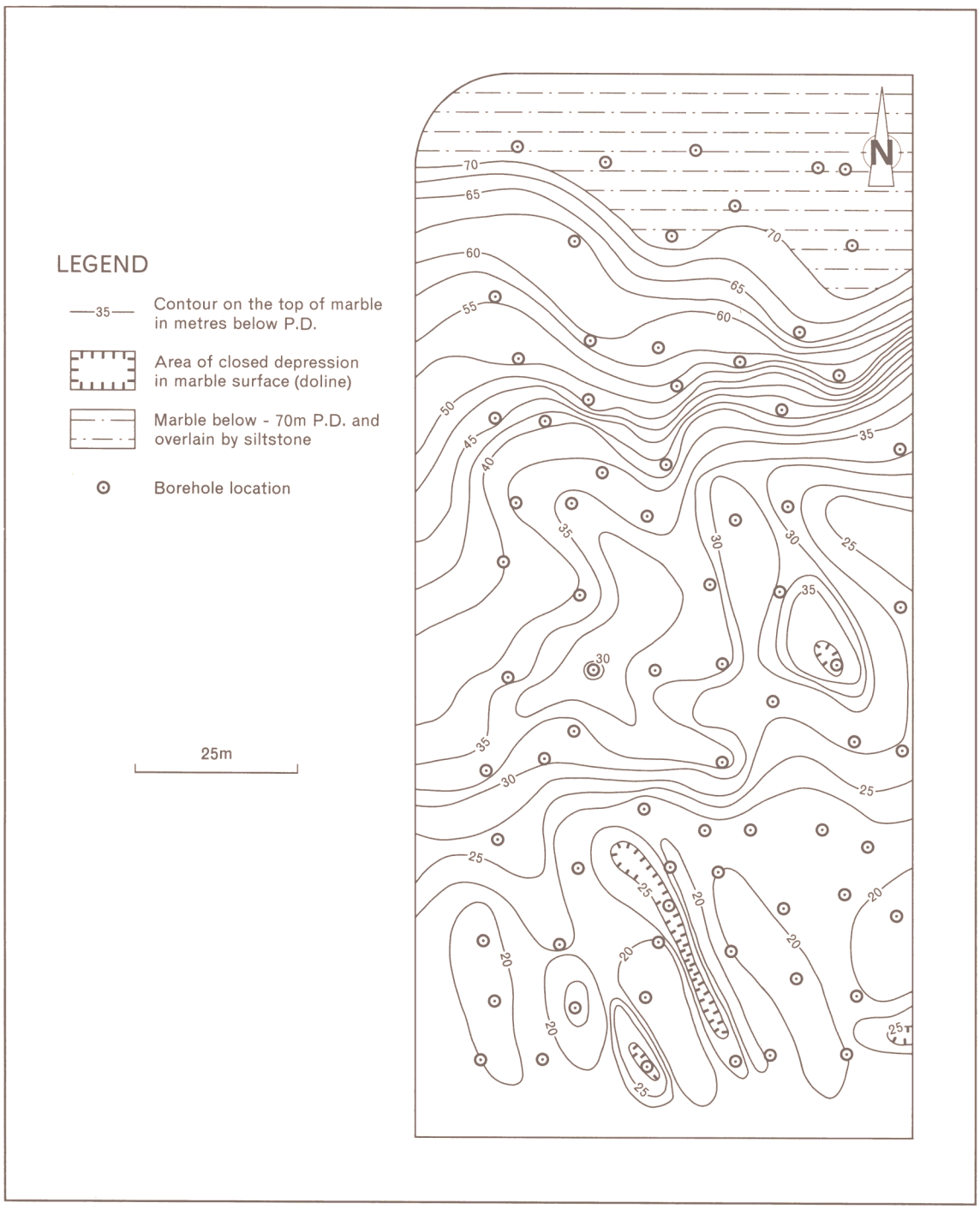
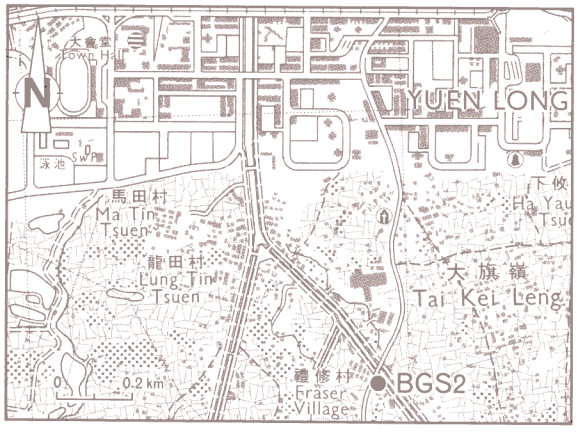


Figure 20 - Contour Map of the Top Karstic Surface of the Marble at Site YLTL 442 adjoining Hop Hoi Street, Yuen Long

A prominent clay lamina separates the grey lower silts from higher pale brown silts. The top of the cavity fill is formed by some 120 mm of grey-brown calcareous silty fine sand without evidence of internal structure.

Attempts to date the cavity fill sediments from Yuen Long by palaeomagnetic methods failed because their natural remanent magnetisation was too weak and scattered in direction. However, deposits in southern China within Carboniferous and Devonian carbonates have been proved to range in age from Pliocene to late Pleistocene (Lai, 1990).

The configuration of cavities in marble beneath building sites can only be determined by closely spaced boreholes. At the Light Rail Transit (LRT) site north of the Castle Peak Road in Yuen Long [215 340], some 600 boreholes have been sunk in an area of about 2 hectares. The evidence here suggests that the



LOCATION

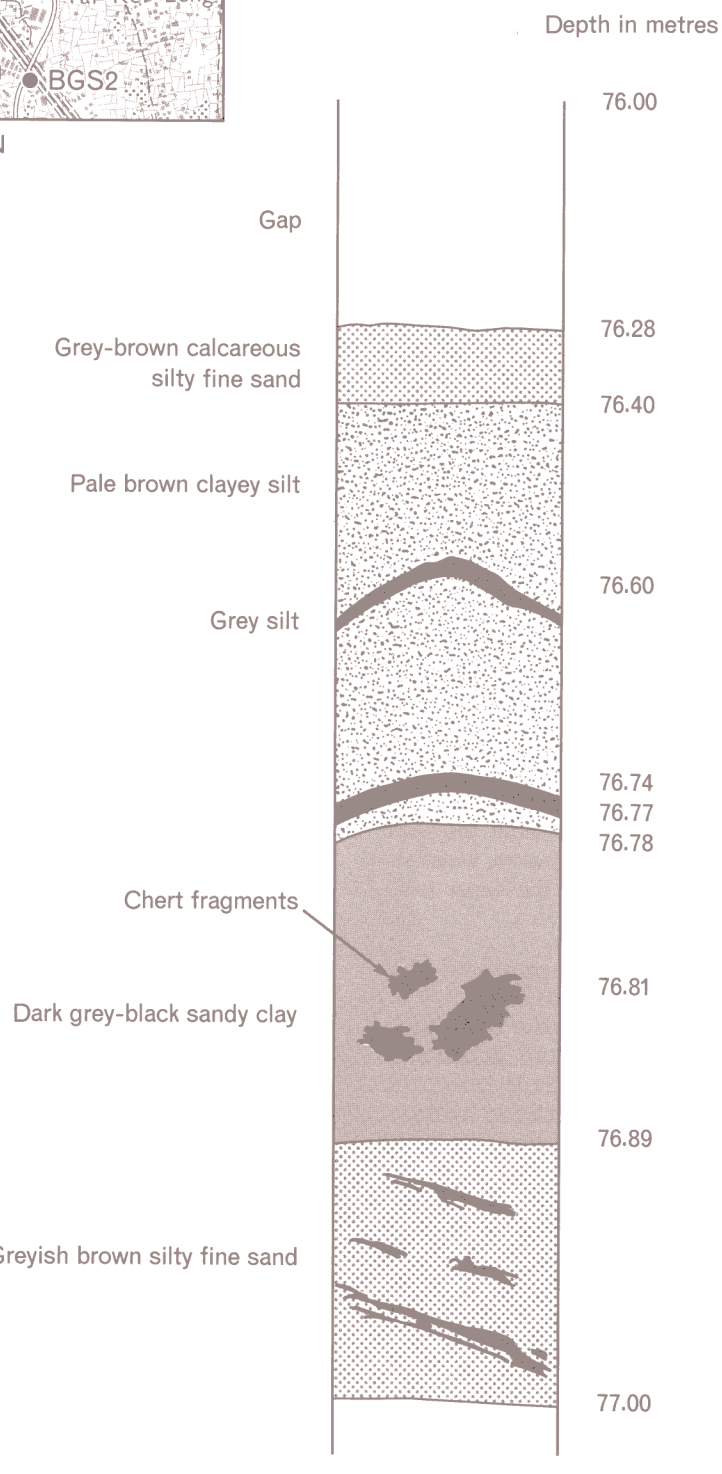


Figure 21 - Cavity Infill Deposits from a Mazier Sample in BGS 2

cavities are near vertical or steeply dipping joint-controlled features which have been widened, and in places filled or partly filled with sands and clays. These joints are the dominant overprint in the marble of the regional metamorphism of the district, and therefore form the commonest type of cavity. Their steeply dipping attitude explains why one borehole will show well developed karstification, whilst an almost adjacent borehole proves sound rock. In Florida it has been calculated that some 6% of the limestone has been dissolved in one area affected by karst processes. Similar calculations in the Yuen Long area show a range of 6% to 50% dissolution of the marble in the karst zone. The high figures are derived, however, from many boreholes which have been drilled vertically down karstic joints. If most of the cavities are formed along near vertical joints then an inclined borehole should pass through multiple sets of cavities, joints or discontinuities within the rock formation. This was confirmed by Houghton (1988) for a site in southern Yuen Long.

Whilst the majority of cavities occur in the epikarst zone within some 30 m of the rockhead, some boreholes have encountered clay-filled cavities at depths down to -80 mPD. Such voids must have developed at a stage of the karstification process when the sea was at its lowest level relative to the land. The hydraulic link between these deep cavities and the rockhead surface must have been very tenuous, particularly with the discontinuous nature of the marble outcrop; such cavities should be infrequent and small. In parts of the district a large number of major discontinuities such as faults and lithological boundaries exist which have been a focus for karstification, and in many cases have given rise to cavities with a greater lateral extent than those developed from joints.

Figure 22 shows the position of a thrust plane separating marble from siltstone and sandstone near On Hong Road [2050 3365] towards the southern margin of Yuen Long. This plane was bordered by a zone several metres wide containing numerous fractures associated with tectonic movements. Water movement appears to have been channelled into this zone, with dissolution and erosion creating an inclined void some 50 m deep by 10 m wide. This void, which tapers with depth, probably does not extend beyond -100 mPD. It is one of the deepest cavities identified in the district and is filled with soft silts and sands.

Reactivation of Karst Features

In certain parts of the world where shallow buried karst exists, catastrophic ground collapses occur where palaeokarst sinkholes are reactivated. In most cases these collapses are caused by fluctuations in groundwater level. Old sinkholes form a vertical hydraulic link between differing lithologies and in the Yuen Long area are now plugged by sediments such as recent silts sands and clays. Erosion of this sediment plug over a period of time may undermine the adjacent strata and transmit the disruption to the surface with resulting ground movement and damage to structures built upon it (Culshaw & Waltham, 1987).

There are paleokarst sinkholes beneath the district which, if reactivated, are potential areas of collapse. However, the fluctuations of the groundwater are slight (Gale & Cook, 1989) so the opportunities for disturbance of sinkhole plugs are limited. Under certain abnormal conditions, such as surface water inundation by a broken water main or flood, sufficient erosive force from surface water may weaken sediment plugs if the water table has been lowered locally by excessive extraction of groundwater by pumping.

Chan (1988) considered the factors affecting sinkhole formation, and concluded that their widespread recurrence in Yuen Long was unlikely, provided that the water table remained above rockhead. There has been no evidence of sinkhole formation at the surface since the sealing of the karst surface by the overlying superficial deposits, despite hydrogeological conditions which must have been far more conducive to sinkhole development than those of the present day. However, civil engineering works may disturb the existing hydrogeological regime, for example by causing ponding of surface water, and drilling operations may also induce local ground collapse.

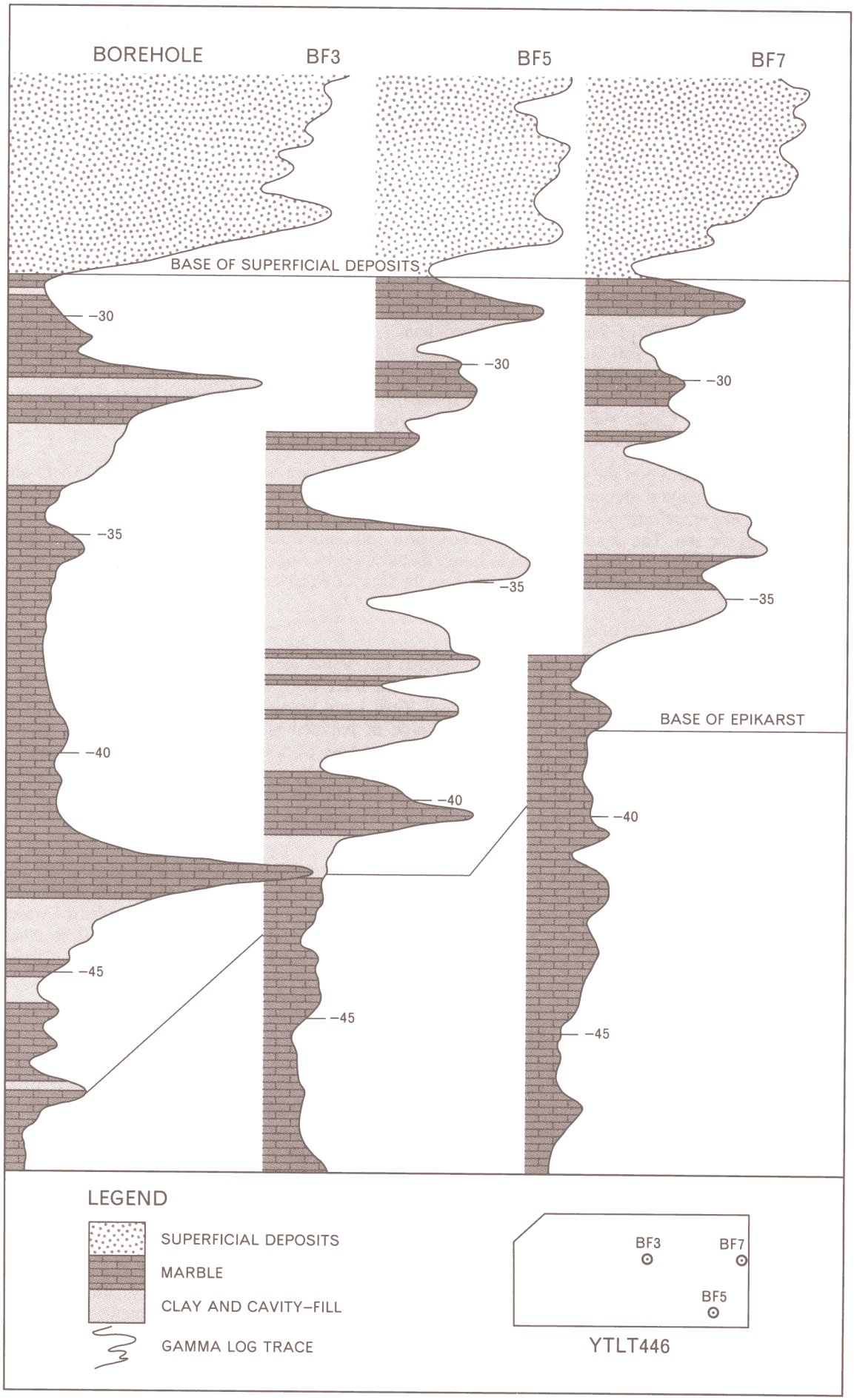


Figure 22 - Large Area of Soft Silt Formed at the Thrust Boundary Between the Mai Po and Ma Tin Members of the San Tin Group. Site YLTL 446, Yuen Long