GCO PUBLICATION No. 4/84

REVIEW OF SUPERFICIAL DEPOSITS AND WEATHERING IN HONG KONG

J.D. Bennett

Geotechnical Engineering Office
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PREFACE TO FIRST REPRINT

Since this report was first published in 1984, there has been considerable advancement in the knowledge and understanding of the geology of Hong Kong. Much of this new information can be found in the Hong Kong Geological Survey series of memoirs which accompany the published 1:20 000 scale geological maps of the Territory. Additionally, a full revision of the topics discussed in this report is being made for inclusion in a new publication 'The Geology of Hong Kong'. However, until this becomes available, GCO 4/84 remains a convenient and useful source of information. Consequently, it has been decided to reprint a limited number of copies to cater for anticipated demand.

Perhaps the greatest progress in knowledge of the geology of Hong Kong in the last ten years has been in the offshore area. Much more is now known about the subject matter of Section 3.2 of the report (Fluviatile and Marine Deposits) and it is recommended that readers refer to the following publication for a summary review of these advances :

Fyfe, J.A. (1992). Towards a Quaternary Stratigraphy of Hong Kong. Geological Society of Hong Kong Newsletter, vol. 10, no. 2, pp 5-10.

J.B. Massey
Acting Principal Government Geotechnical Engineer
June 1993

FOREWORD

This report reviews the identification, classification and distribution of the transported superficial deposits commonly encountered in Hong Kong. It also briefly discusses weathering and the formation of residual deposits derived from the parent bedrock types of Hong Kong.

The report is essentially a review of published information available up to late 1983. It incorporates the provisional views of R. Addison, a geological mapping consultant from the British Geological Survey engaged in the new geological survey programme of the Geotechnical Control Office. This programme has as its prime task the remapping of the entire territory at a scale of 1:20,000. The aim of the report is thus to provide background information for the new geological survey.

The report was prepared in the Geotechnical Control Office by J.D. Bennett of the British Geological Survey under the terms of Consultancy Agreement CE/29/82 awarded to the Natural Environment Research Council, Swindon, U.K. by the Engineering Development Department of the Hong Kong Government.

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E.W. Brand
Principal Government Geotechnical Engineer
December 1984

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SUMMARY

The report reviews previous studies of rock weathering and the superficial deposits of Hong Kong to provide background information for the geological remapping programme.

Factors critical to the development of in situ weathering profiles as a consequence of the chemical decomposition of the bedrocks include rock composition, texture and structure, geological history, groundwater circulation, erosion rates, climate and vegetation.

For the purpose of the geological remapping programme it may be considered feasible to display in a general manner the degree of weathering (e.g. low, moderate, high) of the outcrop (bedrock) areas delineated on the 1:20 000 superficial geology maps. Likewise, a distinction can be envisaged between undifferentiated residual deposits and those characterised by abundant bedrock relicts (i.e. boulder spreads of essentially in situ nature).

In simplistic terms the climate of southern China during the Tertiary and the Quaternary was humid, tropical to subtropical and thus conducive to chemical decomposition. Estimates of the maximum ages of the weathering profiles observed in Hong Kong today range from c. 200 000 years to the late Pliocene. Although subaerial weathering continues to the present day profiles predating the deposition of fluviatile and marine deposits, dated provisionally at > 33 400 years BP, are now widely recognised.

The transported superficial deposits are divided into those formed under fluviatile and marine conditions and those derived by gravity-induced mass wasting processes. A preliminary stratigraphy is emerging for the first group of deposits, reflecting fluctuating sea levels during the Late Pleistocene and Holocene. The mass wasting deposits are grouped into two broad categories for the purposes of geological mapping: the slightly transported (quasi-residual) deposits and the substantially transported deposits. It is envisaged that greater attention will be directed towards the latter category during the remapping programme.

The gross topography and major drainage systems of the Territory were

established prior to the formation of the mass wasting deposits which are thus effectively catchment-bounded, although the topography is locally modified by them and considerable erosion subsequent to their formation is evident. The deposits are considered to be associated in general terms with postglacial and interglacial/interstadial periods but reliable age determinations are not available. In view of the mode of occurence of the deposits conventional lithostratigraphic correlation is unlikely to be applicable other than locally where original contiguity between deposits can reasonably be expected or demonstrated. The use of lithostratigraphic terminology for individual deposits is to be deprecated to avoid erecting a multitude of localised and areally limited formations. Efforts should be made to map the substantially transported deposits in terms of depositional processes and morphology.

1. INTRODUCTION

1.1 TERMS OF REFERENCE

The report is prepared in partial fulfilment of Consultancy Agreement CE 29/82, signed by the Natural Environment Research Council (NERC) and the Geotechnical Control Office (GCO), Engineering Development Department, in September 1982.

The Agreement requires _inter alia_ reports on the superficial deposits of the Territory and on the weathering of the rocks which underlie it. Both topics are considered in the present review. They are closely related, reflecting different stages in the cycle of weathering and erosion of the bedrocks and their subsequent reworking and re-deposition.

The terms of reference as stated in the Brief to the Agreement, sections 3(1)(f) and 3(1)(g) (in part) are as follows :

(i) "to submit a Report on the disposition of Superficial Deposits in Hong Kong, their relative and absolute ages, palaeo-geography, mode of formation, distinguishing characteristics, and other factors relevant to planning and engineeering practice and recommendations for further study."

(ii) "to submit a Report on ...... processes and products of ...... Weathering of Hong Kong rocks."

1.2 TERMINOLOGY

In the context of a geological mapping programme the term 'superficial deposit' generally refers to transported surface materials which mask the underlying bedrocks and their associated _in situ_ weathering products (cf. Allen and Stephens 1971). In Hong Kong these transported materials developed in response to fluvial, gravitational and marine processes acting upon weathered and eroding bedrock and upon any previously existing superficial deposits.

The residual deposits (saprolite and residual soil) that develop as a consequence of _in situ_ weathering and decomposition are not superficial deposits in the above sense. They are most appropriately considered in terms of their parent lithology and hence as part of the stratigraphic column established for the bedrock units.

This report considers the superficial deposits _sensu stricto_ and the residual deposits. Both can be described as surficial materials which together constitute the regolith, a term used to embrace all mantling cover of 'unconsolidated' material (cf. Fairbridge 1968).

1.3 BACKGROUND AND SCOPE OF THE REPORT

An understanding of the nature and behaviour of the superficial and residual deposits and of the weathering characteristics of the bedrocks, is of obvious importance in engineering practice. This is especially valid in Hong Kong where failures associated with these materials have caused considerable damage and loss of life in the past and where there is a real need to minimise the likelihood of similar disasters in the future.

To help achieve this understanding the GCO embarked at an early stage on a reconnaissance study of the mass wasting (colluvial) deposits of the Territory at a scale of 1:20 000. This work, completed in 1979, gave rise to the more comprehensive Geotechnical Area Study (GAS) Programme, involving regional and detailed district terrain classification at scales of 1:20 000 and 1:2 500 respectively. One of the major aims of the programme was to delineate more rigorously than before the distribution of the mass wasting deposits on a Territory-wide basis. In the urban areas colluvium had already been shown to be a problematical engineering material. The GAS Programme is described by Brand _et al_. (1982) and Styles (1982 and in press). Preliminary assessment of the available data indicates that there are approximately 20 000 hectares of colluvial deposits within the Territory. This represents some 20 percent of the total land area.

The present report was requested under the terms of the Consultancy Agreement to provide a preliminary review of weathering and of the residual and superficial deposits in the context of the geological remapping programme, to complement and extend the work already undertaken by GCO using terrain classification techniques. The report is based on information available in November 1983. The results presented and the conclusions drawn must be considered provisional and liable to modification as the remapping programme proceeds.

The present state of geological knowledge is reviewed and attention is drawn to aspects meriting further examination, having regard for what is considered feasible within the remit of the remapping programme. The general approach envisaged for the mapping of the superficial deposits is described, namely a broad, threefold breakdown of bedrock and surficial materials into (i) bedrock outcrop; (ii) residual and slightly transported (quasi-residual) deposits; and (iii) substantially transported deposits, i.e. the superficial deposits sensu stricto. Further refinement and subdivision, possibly of category (ii), more particularly of category (iii) should be feasible. However, the scheme presented here may require modification in the light of practical experience as the work proceeds and as it becomes more evident what information can realistically and routinely be acquired and represented at the 1:20 000 scale.

The report deliberately avoids involvement in the specialist engineering classification and description of soils. These topics are considered fully elsewhere (e.g. Anon 1981a,b) and specific reference to local conditions can be found, for example, in Lumb 1962a,b, 1965; Geotechnical Control Office 1979; Hencher and Martin 1982. The subject is currently undergoing further scrutiny within the GCO.

2. WEATHERING AND THE FORMATION OF RESIDUAL DEPOSITS

2.1 INTRODUCTION

Subaerial weathering affects bedrock and transported superficial deposits alike. Investigations into the weathering processes and the development of weathering profiles were pioneered in Hong Kong by L.

Berry and B.P. Ruxton (e.g. Berry 1962; Berry and Ruxton 1959; Ruxton and Berry 1957, 1959, 1961). They concentrated on a field assessment of the subject and particularly emphasised the responses of the granitoid rocks. The other main lithologies were neglected by comparison although passing reference to some of these was made later (e.g. Ruxton 1980; Koo 1982a,b). However, the models erected by Berry and Ruxton were idealised and their general application or contribution to a regionally-orientated geological mapping programme is difficult to envisage, particularly because of the rapid variations in ground conditions which occur, whatever the underlying rock type. Information recorded on weathering grades, for example, is likely to be highly site-specific and therefore extremely localised. Attempts to extrapolate could give rise to a misleading impression of the weathering behaviour of the bedrock and of the ground conditions which might be expected.

Preliminary chemical and mineralogical studies of the breakdown of the common rock types in Hong Kong and of the changes wrought by weathering were undertaken by several workers (e.g. Brock 1943; Knill and Best 1970; Lumb 1962a,b; Lumb and Lee 1975; Ruxton 1968, 1980).

2.2 WEATHERING PROCESSES AND PRODUCTS

The main weathering processes and the factors controlling them are fully described in standard reference texts and, with particular reference to Hong Kong, in the various publications cited above. Only a brief review will be given here to set the scene and to avoid undue repetition.

In Hong Kong weathering is accomplished largely by the _in situ_ chemical decomposition of the rocks, but physical or mechanical agencies also operate, in part controlled by the nature of the bedrock (see below). Chemical weathering requires the presence of percolating groundwater acting in an acidic, oxidising environment on the mineral phases present by processes of hydrolysis and carbonation. The effectiveness of these processes is influenced by rock type, i.e. its susceptibility to dilute acid attack, and its structure and texture. Structure, notably the development of jointing and other structural surfaces, is particularly important as a means of channelling the circulating groundwaters while in near surface zones tunnelling by animals and penetration by roots are also significant in directing water flow. Texturally, the grain size of the rocks, and the effect this has on rock porosity is relevant. The degree to which chemical decomposition occurs is also influenced by the rate of erosion, time, climate, vegetation cover and landform.

Ruxton (1980) indicated the following decreasing resistance to weathering and erosion in Hong Kong: conglomerate (e.g. Port Island Formation red beds, Bluff Head Formation), volcanics, granitoids and sheared volcanics. Lumb (1962a,b, 1965), however, noted all the acid igneous rocks to show a similar resistance to chemical weathering and emphasized the importance of grain size and joint spacing rather than rock composition in controlling the development of the weathering profile, a view with which the Consultants would concur. Ruxton and Berry (1957) erected a zonal classification of the granitoid weathering profile based on the relative abundance in the profile of relict corestones. In favourable circumstances the profiles may attain 90 m in depth (e.g. in fault zones, cf. Randall and Taylor 1982; Rodin et al. 1982). However, the various factors responsible for weathering give rise to capricious local variations in the degree to which it develops and in the depth of the weathering profile that is formed. Berry (1957) demonstrated maximum profile development on hilltops, ridge crests and other gently sloping or formerly gently sloping surfaces, particularly in the granitoids. He appeared to exclude the possibility that thick weathering profiles may also have developed in stream courses but, in such situations, these would have been more susceptible to subsequent active erosion.

The volcanic rocks display mechanical and chemical weathering effects (e.g. see Hong Kong Government 1982; Koo 1982a,b), their more closely jointed nature favouring, at least initially, physical disintegration, and their often finer grain size and more 'compact' texture resisting the chemical breakdown of the minerals to a greater degree than in the coarser granitoids. Thick residual profiles are less common, rarely exceeding 20 m (Brenner and Phillipson (1979), although Forth and Platt-Higgins (1981) recorded profiles of upto 85 m. The latter also noted that although the granitoids appear to be more deeply weathered than the volcanics this is often illusory. Berry and Ruxton (1960) described weathering profiles in the volcanics of 60 m. They observed that near the granitoid contacts the volcanics were particularly resistant to chemical decomposition as a result of contact metamorphism and generally subscribed to the view that the granitoids were more susceptible than the volcanics to weathering of this type. There seems to be no over-riding reason why the reverse situation could not be equally applicable if structural or other factors exerted a dominant role. Hard and fast generalisations should be avoided.

Chemical decomposition takes place by leaching of the more mobile elements (e.g. Ca, Na, K) and this gives rise to a relative concentration of more stable oxides (e.g. Fe_2O_3, Al_2O_3) and the development in Hong Kong of surficial ferruginous red clays. Laterites are not developed, however. The chemical attack results initially in the alteration and breakdown of plagioclase followed by biotite and K-feldspar to form minerals of the kaolinite group (Lumb 1962a; Lumb and Lee 1975). Allophane and halloysite were reported to be abundant in the early stages of decomposition and kaolinite in the later stages, Lumb and Lee (op. cit.) concluding that the kaolinite was not formed directly from the feldspar. (When reworked and redeposited in a marine, reducing environment the kaolinite converts to illite which is reported to be the dominant clay mineral of the marine superficial deposits). The common presence of ferruginous and manganiferous paints and crusts on fracture surfaces in variably decomposed bedrocks of different types and in different environments (e.g. inland and coastal) is indicative of the preferential concentration of Fe and Mn during weathering, although the process has clearly also involved mobilisation and deposition from solution.

As decomposition proceeds from fresh to weathered rock and residual soil the grading of the material changes, depending upon the bedrock type. Walker et al. (1972) showed the granitoids to break down progressively to coarse sand, silty coarse sand and clayey coarse sand, while the volcanic rocks pass through sandy gravels to sandy silt and clayey silt. This process primarily reflects the grain size differences in the parent material and the tendency of the more closely jointed volcanics to be subject also to mechanical breakdown. The fine granitoids are more likely to progress in a manner more closely akin to the volcanics than to their coarser-grained equivalents.

Little information exists on the weathering of the sedimentary units. The cleaner, more siliceous rocks are unlikely to be susceptible to chemical weathering. They tend to form resistant outcrops (e.g. Bluff Head Formation, Port Island Formation) which would be subject to mechanical weathering and erosion. The finer, less clean sediments containing a higher proportion of original argillaceous material can be expected to yield clayey silts and sands during weathering. Their layered nature, may render rock exposed in surface outcrop more liable to physical breakdown and subsequent attrition and dispersion, and their reaction may have been modified by low grade metamorphism and annealing of the original clast-matrix fabric (e.g. Tolo Harbour Formation, Allen and Stephens 1971). Deep weathering was reported by Allen and Stephens, however, in the Lok Ma Chau Formation.

2.3 DISCUSSION

The investigation of weathering carried out to date in Hong Kong are clearly preliminary in nature and have emphasised the changes taking place in the granitoid rocks at the expense of the other lithologies. Field-orientated studies have also prevailed over laboratory investigations and two main channels for future research are thus readily identifiable.

Ruxton (1968) noted a significant correlation between the physical (especially the engineering) properties of the weathered profile and the degree of chemical weathering of the rocks. The remapping programme, involving also the careful selection of representative sites for documenting chemical, mineralogical and physical changes occurring during weathering should contribute useful additional information. This should in turn permit a more controlled evaluation of the likely engineering response of the main rock units in their weathered state than was possible hitherto. Time and manpower constraints in particular, however, may necessitate the involvement of external researchers, particularly to conduct the more specialised and sophisticated chemical and mineralogical studies which can be envisaged.

In the context of the remapping programme sensu stricto it may prove feasible to indicate general weathering grades or ranges for particular outcrops or outcrop groups which can be delineated at the 1:20 000 scale. The classification adopted should be simple (e.g. low, moderate and high categories of weathering) and may be represented on the superficial map sheets either by means of a coded annotation or a suitable overprinted ornament. In areas underlain predominantly by residual and quasi-residual deposits, a general classification based on the relative abundance (e.g. high, low) of corestones or residual boulders and blocks, including the differentiation of essentially in situ boulder fields, merits consideration. A classification of this type would need to be based on the surface information available, having due regard to the scale of the mapping. The map representation of such features, if it proves feasible, will inevitably involve generalisation and the need to extrapolate from limited data. It will not remove the need for careful examination of ground conditions during site investigation work but should assist the engineer to anticipate likely major problems.

Preliminary attempts have been made to estimate the age of the weathering profiles observed today but there is scope for further study. Berry and Ruxton (1959) dated the commencement of weathering of the granites as probably post-mid-Tertiary and the development of the thick weathering profiles as dating from the late Pliocene. (It may be noted that in Guangdong ?Jurassic - Lower Cretaceous granitoid bodies were already unroofed and contributing to the Upper Cretaceous red bed formations, implying a considerably longer weathering history for those rocks, but not necessarily resulting in profiles that have survived to the present day). The late Pliocene date accords broadly with the view that the present topography was initiated at about that time (e.g. Hong Kong Government 1982; Hsu 1983). Little evidence for this view is given in the references cited. However, it is considered to be a reasonable estimate given that the onshore topography was almost certainly influenced and modified by tectonism, particularly tensional faulting, associated with the opening of the South China Sea. This activity, initiated in the end-Cretaceous-Paleocene interval, was essentially completed during the Miocene (Holloway 1982; Workman 1983).

Chinese research (e.g. Hsu 1983; Li 1983; Song et al 1983; Wang 1982; Wang 1983) indicates the climate of southern China during the Tertiary to have been humid, tropical to subtropical, and thus conducive to in situ chemical weathering. The climate reflected in part the position of the subcontinent which Wang (1982) noted to lie between 5° and 40°N latitude and which Hsu (op. cit.) considered to lie some 3° to 5° south of its present position during the Miocene. The latter also considered that the present gross topography of the region was established by the late Miocene. P.X. Wang (1983) broadly concurred with this opinion, remarking the important influence imposed on the climate patterns of the region by the closing of Tethys and the initiation of the Himalayan uplift during the mid-Tertiary. These events resulted in the establishment of the monsoonal system which gradually intensified as uplift continued through to the Quaternary. Wang (1983) also recorded the onset of humid tropical conditions during the Miocene on the Laizhou Peninsula west-southwest of Hong Kong and noted a possible relationship with the Miocene marine transgression. The transgression was presumably a function of the closing of Tethys.

Liu and Ding (1982) dated the earliest stage of laterite ('red clay') development as probably Pliocene. The process continued in southern China throughout the Pleistocene although it was restricted to the area south of latitude 23° to 25°N during the Late Pleistocene. At the present day laterite development corresponds closely with the tropical and warm subtropical belts of China to the south of c. 23°N.

More recently, utilising weathering rates determined in Oahu and Brazil, Ruxton (1980) suggested that many of the weathering profiles observed today in Hong Kong may exceed 200 000 years. In the absence of confirmed Tertiary deposits it is difficult to provide a more precise maximum age limit than that presented above. At least a proportion of the weathering occurred prior to c. 33 400 years BP (although this date should be regarded as a minimum age) and weathering continues of course at the present day. Yim and Li (1983) reported subaerially weathered residual deposits overlain unconformably by the series of transported alluvial and marine superficial deposits at several nearshore submarine and onshore locations in Hong Kong. The weathering presumably occurred at a time of lower sea level and prior to the deposition of the superficial deposits which have been dated in a preliminary manner using radiocarbon techniques (see section 3.2).

A more precise assessment of the rate of weathering and of the ages of the weathering profiles will be difficult to achieve in the absence of suitable time markers. Dating of the older colluvial deposits could enable an assessment to be made of the rate of decomposition of contained clasts of different rock types, assuming these to have been fresh or only slightly weathered at the time the material was deposited. The results acquired could then be applied to weathered profiles of known thickness in an attempt to refine the timescale suggested above. Specialist advice could also be sought to ascertain whether existing isotope techniques are applicable in resolving these problems.

3. TRANSPORTED SUPERFICIAL DEPOSITS

3.1 INTRODUCTION

Weathering, briefly reviewed in the previous section, reflects the complex interplay of a variety of processes but its main significance is that it prepares the rocks exposed at surface for erosion, transportation and the redeposition of the weathered detritus (Fairbridge 1968). It thus exerts a fundamental control over the development of what are broadly classified in this report as transported superficial deposits. The characteristics of these deposits are influenced by the nature of the parent material(s) and by the manner and rate of weathering, erosion and deposition.

In Hong Kong the formation of the deposits was accomplished by gravitational, fluviatile and marine action or by combinations of these processes. Berry (1957) classified the regolith into weathering residues, water-transported deposits and landslide deposits, and noted that under present conditions weathered material is being eroded more rapidly than it is being formed. Lumb (1962b) recognised alluvial deposits formed by the erosion of soils (used in the engineering sense), beach deposits derived from the resistant constituents of residual soils, and collvuial deposits comprised of landslide debris. Lumb further divided the alluvial deposits into those laid down by streams and those deposited in the marine environment, noting the latter to become finer and thicker in a seaward direction.

The present status of Quaternary geology in Hong Kong was outlined briefly in the context of the general stratigraphy of the Territory by Bennett (1984). The main developments of the geologically recent superficial fluviatile and onshore marine deposits were first systematically mapped by Brock <u>et al</u>. (1936). They were subsequently examined by several workers during the course of research into engineering and agricultural problems (e.g. Fanshawe 1962; Grant 1960; Guilford and Chan 1969; Lumb 1977; Lumb and Holt 1968; and see also Lumb 1962c). In 1971 Allen and Stephens refined the earlier mapping of these deposits and it is unlikely that future work will result in major changes to their gross distribution as shown on the 1:50 000 scale map. Allen and Stephens recognised two classes of alluvium and a number of beach deposits.

Since 1971 site investigation studies onshore and offshore have accumulated considerable information on the fluviatile and marine deposits, but little is yet published. Their systematic geological study largely awaits the remapping programme and future research which should aim to coordinate and synthesise the available data in conjunction with the new observations. Note may be made here, however, of the contributions by Kendall (1976), Yim (1983a,b) and

Yim and Li (1983)* which provide a useful, but preliminary working model for the stratigraphy and depositional environment of the deposits. This model requires further critical testing.

Allen and Stephens (1971) undertook the first Territory-wide differentiation of the mass wasting deposits, although information is lacking in some areas, particularly on Hong Kong Island. Greater attention has since been paid to these deposits, which in Hong Kong are generally known as colluvium. Colluvium may be defined, following Fairbridge (1968), as the heterogeneous material accumulated on the lower parts or base of slopes by gravity, soil creep, sheet erosion, rainwash and mudflow. Colluvium may intermingle with and contribute to stream-transported detritus and the marine deposits. Criteria for its recognition were presented by Huntley and Randall (1981).

The above definition clearly indicates that colluvium is a sack term. Its use has had undoubted advantages, notably those of brevity and convenience, and it has focussed attention on this important class of deposit. It is arguable, however, that use of the term has also led to its variability being neglected and to insufficient attention being paid to the processes by which the deposits were formed. It is hoped that the remapping programme will be able to redress any such imbalance, bearing in mind the 'regional' bias of the work, and that it will permit a distinction to be made between deposits formed by different processes and/or possessing different morphological - lithological characteristics, as has been attempted on some of the US Geological Survey maps (e.g. Van Horn 1972a,b). The identification and classification of a specific colluvial deposit may be rendered difficult, however, because the depositional processes which gave rise to it are complex; they do not act or occur in isolation but form part of a broader spectrum. Deposits formed by gravitational processes, for example, may involve repeated debris falls, hill wash,

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* See also the Abstracts and Proceedings (in preparation) of the Meeting on the Geology of Surficial Deposits in Hong Kong, organised jointly by the Geological Society of Hong Kong and the University of Hong Kong, 19 - 21 September 1983.

debris flow and fluviatile reworking, while deposits of gravitational and fluviatile origin and the parent saprolite can interface with and contribute to the marine environment.

Early attention was paid to some of the colluvial deposits, notably by Grant (1960) and Berry and Ruxton (e.g. Berry 1957; Berry and Ruxton 1960). The most recent and comprehensive though unpublished overview of the distribution and general character of the deposits, however, is afforded by the GCO Geotechnical Area Study (GAS) Programme maps and reports. Outlines were given by Burnett and Styles (1982) and Styles (in press). Without doubt the most intensively studied of the colluvial deposits are those occurring in the Mid-levels area of Hong Kong Island (Hong Kong Government 1982). This study resulted in a classification of the deposits based on their physical characteristics and will be considered further in section 3.3. Its findings are currently gaining acceptance and attempts are being made to apply it throughout the Territory (e.g. Lai and Taylor 1983).

For the purposes of this report the transported superficial deposits are grouped into two categories, one comprising the fluviatile and marine deposits, the other the mass wasting (colluvial) deposits. The mass wasting deposits result from "a general process of gravity-controlled subaerial .... slow to sudden, downward or downward and outward fall, slide, flow, creep or subsidence of small-to-large masses of dry-to-wet .... rock or rock materials" (Fairbridge 1968). Both categories of deposit are removed to a greater or lesser extent from their source area and parent residua.

3.2 FLUVIATILE AND MARINE DEPOSITS

3.2.1 Distribution and depositional environment

Fluviatile (alluvial) sediments floor the lower sections of the larger valleys and form fans at the mouths of many streams. More restricted alluvial developments occur in upland valleys and in shallow depressions on plateaux in volcanic terrain. The upland valleys may also be floored with debris derived mainly from the mass wasting of the valley sideslopes and clear distinction between colluvium and alluvium in these circumstances may be hampered by reworking. Fluviatile and marine sediments constitute the extensive low-lying coastal plains which are most prominently developed in the northwestern New Territories. They also occur offshore and comprise the surficial sea-floor cover, mantling weathered bedrock and residual deposits.

The gross disposition of the onshore deposits was indicated by Brock et al. (1936) and refined by Allen and Stephens (1971). It is unlikely that the remapping programme will involve significant changes in the outcrop patterns and distribution of these deposits although differences in detail may arise, reflecting the larger scale of the new work. Some reclassification of, e.g. the upland valley alluvials may emerge but in general the new programme is viewed as an opportunity to coordinate and synthesise the available, mainly sub-surface information within the existing broader framework.

The depositional environment of the coastal plain deposits in the northwestern part of the Territory and the general characteristics of the deposits were outlined by Allen and Stephens (1971). Although true alluvial deposits occur most of the recent superficial sediments in the area were considered to have been deposited in the littoral-deltaic environment. No attempt has yet been made systematically to rationalise and compile the results of the subsurface investigations for geological purposes but the general sequences recorded there (e.g. by Ha et al. 1981; C.J. Beggs in oral presentation of Beggs 1983) accord with the findings of other preliminary onshore and near-shore sea-bed investigations at various locations throughout the Territory. These include Plover Cove (Lumb and Holt 1968; Guilford and Chan 1969), Tide Cove-Tolo Harbour (e.g. Whiteside 1983; R. Purser, pers. comm. 1983), High Island (Kendall 1976; Yim 1983a), Hong Kong Harbour (Berry 1962; Berry and Ruxton 1960) and Chek Lap Kok, Lantau (Yim and Li 1983).

At all these locations weathered bedrock and residual deposits are stated to be overlain by one or more sequences of alluvial and marine superficial deposits. The fullest successions yet described are those at Chek Lap Kok, High Island and Lei Yue Mun Bay (Yim 1983a;

Yim and Li 1983) and at Tau O (Dickson 1983) where the following units, listed in chronological order, are provisionally recognised :

(v) Upper marine deposits
(iv) Upper alluvial deposits
(iii) Lower marine deposits
(ii) Lower alluvial deposits
(i) Residual deposits

Intraformational scouring and discontinuities are reported from the High Island site, leading to the local removal of individual units, but commonly, particularly at near-shore locations, only one alluvial-marine sequence is encountered. Lumb and Holt (1968) reported marine clays overlying alluvial deposits at Plover Cove and interpreted the latter as probable floodplain deposits laid down at a time of lower sea level. In a recent examination of borehole records in the Tide Cove-Tolo Harbour area, R. Purser (pers. comm. 1983 and GAS report, in preparation) reported a similar sequence but noted recent alluvium to overlie the marine horizon at the southwestern end of the section. He interpreted a prominent and consistent silt horizon within the main 'lower' alluvial sequence as a former lake deposit and considered the restricted nature of the succession in this area to reflect the presence of a seaward bar or barrier which precluded the deposition of the full, repeated sequence. Up to 40 m of residual deposits underlying the superficial deposits were noted in this section. (Lumb (1977) reported weathering of granitoid bedrock to extend some 70 m below sealevel in Hong Kong Harbour.)

Contiguity can be demonstrated between fluviatile-marine sequences on- and offshore (e.g. Berry 1962, Kai Tak area). The alternating nature of the deposits is most satisfactorily explained as the result of marine transgression and regression during the Quaternary (see below) and the gradual drowning and subsequent silting-up of previously low-lying ground under conditions ranging from truly alluvial (valley bottom, valley flood plain deposits) to wholly marine in character. A local source for much of the marine sediment is indicated but deposits are notably thicker in the west of the Territory (Lumb (1977) reported up to 38 m off Lantau) reflecting supply from the Pearl River. Grant (1973) cited work recording that this river deposits a total load of 28×10^6 t per annum under present conditions, and considered that it contributed significantly to the Deep Bay - Yuen Long - Castle Peak deposits, although more locally derived alluvial material is present in the southern part of this sector.

3.2.2 Recognition of the deposits

Criteria for the recognition of fluviatile deposits are given in standard reference texts and include the degree of sorting and grading of the deposit, the presence or absence of stratification, the extent of rounding of the clasts, and the presence of sedimentary structures such as cross and graded bedding and channelling and washout features.

In the context of the fluviatile-marine sequences described in Hong Kong by Yim (1983a) and Yim and Li (1983), recognition depends on sedimentological, chemical and physical criteria and, importantly, on the presence of shell and plant remains, which also provide a basis for assessing the age of the deposits. In addition to the nature of the organic detritus Yim and Li noted colour (to be used cautiously), texture and grading of the sediment (the marine deposits tend to be generally finer-grained than the fluviatile material), the degree of compaction (alluvial deposits, and residual soils, are mostly better compacted than the marine deposits), and the pH and chloride content of the sediments, (although practical difficulties in interpreting these data were noted by Yim). Of seemingly greater promise is the iron content of the sediments, Yim and Li (op. cit.) indicating average iron values in the alluvium to be approximately double those in the marine sediments. In the example cited, however, the Consultants would note that the value for the alluvium is represented by only three samples and may not be statistically representative of the unit as a whole.

Yim (1983a) noted that shell debris was generally sparse in the lower marine unit and he attributed this to the possible leaching of carbonate by acidic groundwaters. As a result, recognition of this horizon may be particularly difficult. Scope exists for micropalaeontological study, especially if siliceous organisms can be identified, to confirm the depositional environment and possibly the age of these deposits.

3.2.3 Chronostratigraphy

The establishment of a tentative chronostratigraphy for the fluviatile-marine succession presented in section 3.2.1 is possible, based on a limited number of C^{14} determinations made on plant remains and shell material. The current position, based on work reported by Kendall (1976), Yim (1983a,b) and Yim and Li (1983) was reviewed briefly by Bennett (1984).

The upper marine deposits are of Holocene age (< 8 000 years BP) and their deposition reflected the prominent marine transgression during that period which also caused the sudden appearance of a diverse fauna including thirteen species of foraminifera and five species of ostracoda (Yim and Li 1983). Li and Yim (1982, unpublished report) also referred to the existence of a similar foraminiferal assemblage in the marine deposits of the Castle Peak Channel.

The underlying deposits are of Late Pleistocene age. The upper alluvium is believed to have been deposited between 8 000 and 33 400 years BP during a predominantly glacial period. However, the lower marine deposits are tentatively assigned to an interstadial during the later stages of the Dali (or Würm) glaciation (10 000 to 70 000 years BP) with a possible age of 28 000 to 30 000 years BP*. The lower alluvial deposits exceed 33 400 years BP but their lower (older) age limit is not known and the upper limit adopted should be regarded as a minimum age as it occurs near the working limit of the analytical method.

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* Work in northern China places the relatively warm period at 23 000 to 26 000 years BP during a late Pleistocene glacial phase extending from 12 000 to 35 000 years BP (Cui and Xie 1982) while Zhao and Chin (1982) noted the interstadial to have commenced _c_. 32 000 years BP and that the second of five marine formations identified in eastern China corresponds closely with it. They also demonstrated that the ages of the marine formations (back to _c_. 300 000 years BP, Riss-Mindel (or Lushan-Dagu) interglacial) correlate well with short palaeomagnetic polarity reversals in the Bruhnes normal epoch (present to 730 000 years BP).

3.2.4 Comment

The recent albeit ad hoc work undertaken on these deposits coupled with the earlier mapping, provide a useful general framework on which future investigations can build.

The remapping programme and the systematic evaluation and coordination of existing subsurface records should permit a clearer understanding of the 3-dimensional distribution and relationships of the alluvial and marine deposits, and ideally this work should be extended offshore (cf. the Tide Cove - Tolo Harbour study initiated by R. Purser of the GCO). A more detailed research study of the deposits is unlikely to be feasible, however, without the active participation of specialist researchers from other organisations, locally or overseas.

There is scope for specialist study in radiocarbon dating, sedimentology, chemistry, micropalaeontology, palynology, and possibly isotope applications and palaeomagnetism (cf. Zhao and Chin 1982). Such work would undoubtedly permit a considerably improved understanding of the deposits. However, from the broader, geological viewpoint, it is important to guard against the placing of a disproportionate emphasis on what is a relatively minor Quaternary sequence, and research priorities must be carefully considered.

3.3 MASS WASTING DEPOSITS

3.3.1 Disposition and mode of formation

Mass wasting deposits formed predominantly by gravitational rather than fluviatile processes are abundant in Hong Kong, where they are now generally referred to as colluvium.

Deposits of this type were recognised, described and locally mapped by L. Berry and B.P. Ruxton (Berry 1957; Berry and Ruxton 1960) who termed them variously soliflual, fan, landslide and slump deposits. They indicated in diagrammatic manner their distribution in the Hong Kong Harbour area, noting particular concentrations beneath the volcanic-granitoid contact, e.g. in the Mid-levels and Beacon Hill-

Kowloon Peak areas. Allen and Stephens (1971) extended the differentiation of these deposits, which by the late-1960's were more widely referred to as colluvium, throughout the Territory. They attempted a preliminary subdivision, recognising undifferentiated colluvium, boulder colluvium and landslip deposits. It is noteworthy, however, that they failed to incorporate on their map all the deposits of this category previously identified, but shown only diagrammatically on sketch maps, by Berry and Ruxton.

Increased attention was paid to the mass wasting deposits following the Po Shan landslide in 1972 (Hong Kong Government 1972). In consequence of the investigations which took place as a result of that disaster, the engineering importance of the deposits was firmly established and their limited recognition on the 1:50 000 scale map was found to be inadequate for engineeering purposes. In view of the abundance and extent of these deposits in Hong Kong (see below) their adequate study and representation during the 1:20 000 remapping programme is clearly important.

The most complete, currently available assessment of the distribution of colluvium throughout the Territory is that deriving from the GCO GAS Programme. The deposits are shown on maps at scales of 1:20 000 and, for restricted areas, 1:2 500. For the purpose of the GAS Programme the deposits were defined on the basis of their morphology, geomorphic position, the nature of the source material, the slope angle of the deposit, indications of instability, and on erosional and hydrological attributes (Styles in press). Of the c. 600 km^2 of the Territory studied to date by this programme at the 1:20 000 scale, approximately 20 percent is mantled by colluvium.

The information generated by the GAS Programme, particularly that concerning the general character and distribution of the deposits, will provide useful background for the new survey. It sbould assist the planning of the fieldwork and provide a basis for the field checking of the deposits and their geological interpretation. However, revision of the colluvial boundaries shown on the GAS maps is to be expected and modifications to the terrain classification approach will follow as the geological programme gains momentum. It was the GCO's intention at the outset of the GAS study first to delineate the deposits and review their nature and occurence, and only then to consider the problem of their overall classification. The geological survey should provide a most appropriate means of furthering and broadening the scope of these aims and of developing the existing model, giving greater emphasis to geological processes and to the geological approach considered necessary. The suggested aims of the geological study are noted later in this section.

By virtue of their origins mass wasting deposits form on and at the base of valley sideslopes, often in inherently unstable positions, and as valley-fill material, mantling the pre-existing land surface. The valley sideslope deposits form cones, more gently sloping fans and, where these features merge or coalesce, more extensive apron or sheet deposits. The valley-fill deposits may accumulate by gravity from the valley sides or by flow of material channelled along the valley and minor developments occur even at high levels and on steep gradients. A flow mechanism may perhaps be involved, for example, to account for the coarse accumulations seen in some valley sections which form upstanding ribbon-like deposits (e.g. immediately east of the prominent headland c. 2.2 km southwest of Shek Pik, Lantau). However, any colluvial deposit, whether accumulated on a valley sideslope or valley bottom may be liable to subsequent or even immediate, essentially syndepositional reworking by true fluviatile processes or by slope wash resulting from intense precipitation.

The deposits are thinnest on the upper slopes and reach their maximum development on the lower slopes. Berry (1957) noted the presence of geological as well as geomorphologic control in spawning the deposits, particularly debris derived from the undercutting of the granitoid-volcanic contact. The underlying granitoids tend to weather more readily than the volcanic rocks which are also preferentially hardened in the contact zone by thermal metamorphic effects. The resulting rock fall debris (talus) was observed by Berry to become finer grained downslope. Downslope thickening of the valley sideslope deposits was also borne out by the Mid-levels study (Hong Kong Government 1982) which differentiated between erosional and depositional zones and recorded thicknesses of 15 to 35 m in the latter where new landforms were created or existing ones modified by the colluvial material and by subsequent erosion. The study noted that the colluvium preferentially filled pre-existing depressions and valleys but also overstepped and mantled the existing interfluves. Subsequent erosion in some instances resulted in the valley-fill deposits now forming upstanding ridges and lobes; a significant post-depositional erosion history is indicated.

The disposition of the mass wasting deposits is thus fundamentally controlled by topography but is also influenced by geology and by the weathering response and characteristics of the source rocks. Although the Mid-levels study indicated that erosion subsequent to deposition had modified the local, relatively smallscale topography, the deposits examined all occur on the northern flank of the main Hong Kong Island divide. Likewise, the deposits in the Beacon Hill-Kowloon Peak sector occur on the southern flank of another major watershed. Colluvial deposits are not formed along the major divides themselves and it must be supposed that the present topography and the main drainage patterns were already established prior to the formation of the deposits, although the relief may well have been more extreme at that time to account for the large quantities of detritus now observed. Colluvial deposits capping major ridges or occurring high on valley sideslopes at the present day are unlikely unless they represent erosional remnants of now dissected but originally more extensive sheet deposits related to an older, more grossly scaled fossil land surface.

The correct interpretation of the regolith occurring on ridge crests and upper valley sideslopes at the present day is necessary in view of the implications this would have on the palaeogeography and on the age of the deposits, were they demonstrated to be substantially transported. Also, if it is accepted that the present topography and main drainage patterns were established prior to the formation of the deposits, only the most general of correlations need be expected between deposits formed in different drainage basins. This would apply even if the geological and physical conditions which obtained in the separate basins were broadly comparable.

Like Berry and Ruxton, Lumb (1962b) regarded colluvium as landslide debris, a classification also favoured by Rodin et al. (1982) who considered the Mid-levels deposits to reflect rock fall and rock-soil landslide deposits. Virtually all the Mid-levels deposit are now thought to represent a series of debris flows rather than occurring as a single event or as a continuous process.

These and other conclusion (see section 3.3.2) were reached following the examination of the Mid-levels deposits in considerable detail. This large scale, intensive, site investigation approach will not be practicable during the regionally-orientated geological remapping programme, although the broad principles of deposit recognition derived from the Mid-levels study will be relevant and should be applicable elsewhere. The prime aims of the geological survey should be the identification, delimitation and broad classification of the deposits to provide the necessary framework within the context of which more detailed follow-up studies of selected deposits can be undertaken if required (cf. the Mid-levels study), particularly of deposits which may be critical in terms of engineering development. To help achieve this aim it is considered that a broad twofold breakdown of the mass wasting deposits into slightly transported and substantially transported detritus offers greater initial promise (R. Addison in oral presentation of Addison 1983). The first category incorporates deposits produced by such processes as soil creep, slopewash, bedrock slump and smallscale earth and debris flows and slides of restricted extent. These processes result in only the limited downslope movement of saprolite and residual soil and at the scale of the remapping programme the surficial deposits produced in this way will generally be considered as essentially in situ regolith, i.e. as residual or quasi-residual weathering products of the underlying bedrock(s). Features indicative of the above processes should, however, be recorded in the field and consideration given to representing them diagrammatically on the maps, using an overprinted ornament, where they are prominent and where their scale permits.

This approach is similar to that adopted by Berry (1962) who grouped "all those surface residues and deposits which have been derived either directly from the rocks beneath or from nearby rocks by falling or sliding downslope" as 'locally derived material' - and distinct from categories which he termed bare rock and washed alluvial deposits. However, Addison (1983) envisaged a refinement of Berry's (op.cit.) locally derived category and also considered those deposits resulting from substantial transport from their source area, generally as a result of more catastrophic processes such as debris fall, debris flow and debris slide, operating on a larger, mappable scale. Based on preliminary observations in the New Territories he noted that deposits formed by these processes accumulate predominantly on more gradual slopes and on flat valley floors. The last position, however, is reached by only a few debris flows.

3.3.2 Distinguishing features and classification

Criteria for recognising colluvium and distinguishing it particularly from the residual surficial deposits were presented by Huntley and Randall (1981). They are summarised in Table 1. Central to the problem is the recognition of the transported nature of the deposits and this includes examination of the contact relationship with the underlying deposits, the nature of the clast lithology, and the structural and textural characteristics of the deposits, particularly any evidence for the disruption or rotation of adjacent clasts. Note should also be taken of the clast to matrix ratio, the degree of weathering of the clasts, and whether or not evidence for 'internal' contacts can be distinguished.

The Mid-levels deposits were subdivided into three classes based on (i) evidence of superposition, taking account of colour variations between the sub-units; (ii) differences in the clast : matrix ratios; and (iii) the degree of decomposition of the clasts. Details are given in Table 2 taken from the Mid-levels report (Hong Kong Government 1982) which noted that the degree of decomposition of the clasts or the thickness of the weathering patina was the single most useful diagnostic feature when distinguishing between the different classes. Another feature which may assist the empirical classification of the deposits and which was implicit in, but not emphasised by the Mid-levels model, relates to their degree of induration or lithification. Owing to greater load pressures and a longer time period for

Table 1 - Criteria for the recognition of colluvium

Feature	Residual Deposit	Colluvium
1. Clast Lithology		
a) foreign, present upslope		x
2, Relict Structure		
a) joints, vein in clasts	x	x
b) joints, veins persistent through matrix	x	
c) Layering		(x)
3. Macrofabric		
a) uniform	x	
b) irregular, some point contact of clasts		x
4. Microfabric		
a) gradational	x	
b) sharp		x
c) matrix composition, texture different from clasts		x
5. Stratigraphic profile		
a) boulder-free zone		x
6. Basal features		
a) soil layer		x
b) particle alignment		x
7. Springs		
a) at contacts with other soils		x
8. Geomorphology		
a) fan, lobe etc.	(x)	x

Source : adapted from Huntley and Randall 1981 effecting diagenetic changes, the older or more deeply buried deposits are likely to be more completely lithified than the more recent, near surface deposits.

The Mid-levels classification was observed to be supported by evidence from elsewhere in the Territory and its wider adoption was recommended by Lai and Taylor (1983). However, its application depends on detailed surface and subsurface investigations and it is essentially geared to site investigation studies. It is less immediately and directly applicable to the smaller scale, more widely ranging, 'regionally' orientated survey which will be central to the geological remapping programme. The prime aims of this work and the broad categories of mass wasting deposits that are likely to emerge from it were indicated in section 3.3.1. Particular emphasis will be given to identifying and defining those deposits which can be demonstrated to have undergone substantial transport. Detail of the type acquired, by the Mid-levels study and noted in the preceding paragraphs and tables will be gained more slowly. Some scope will exist during the routine fieldwork associated with the remapping programme, although this will depend upon time constraints and upon the level of information available for particular deposits, in the way of natural and artifical exposures and subsurface data. Other data will only be obtained in more piecemeal fashion over a period of time, for example by the monitoring of site investigations being carried out in geologically important areas (as identified during the remapping programme) or by commissioning special research studies to examine particular deposits in detail (cf. the Mid-levels study).

3.3.3 Age and conditions of formation

The formation of the mass wasting deposits was noted in section 3.3.1 to reflect both topographic controls and the underlying geology, particularly the weathering response of the source materials. An important factor not yet considered, however, is climate. The present day represents a phase when erosion dominates and although landslides occur (showing a correlation with periods of particularly heavy rainfall) the scale of formation of the mass wasting deposits was clearly considerably greater during the relatively recent past than

Table 2 - Definitions of colluvium classes in Mid-levels

CLASS 1 (oldest)

Matrix	- stiff to very stiff, mottled dark red and yellow brown slightly clayey sandy SILT, with some gravel in the east.
Cobbles and Boulders	- commonly comprising 75 to 100% but may be as low as 25% sub-rounded minor angular, mainly highly to completely decomposed, some moderately decomposed, no patinas.
	(Type location, University Area, described in exposure log EL2B, reference 27)

CLASS 2 (intermediate age)

Matrix	- firm to stiff, mottled dark red and yellowish brown, clayey sandy SILT, with some gravel in the east.
Cobbles and Boulders	- commonly comprising 0 to 50% and up to 80%, subangular to sub-rounded, mainly moderately to highly decomposed, occasionally slightly decomposed. Patinas commonly 30 to 60 mm thick and may be up to 100 mm thick.
	(Type location, Central area, described in exposure log EL2H, reference 10)

CLASS 3 (youngest)

Matrix	- soft to firm, uniform pale brown to yellowish brown, slightly clayey sandy SILT, with some gravel in the east.
Cobbles and Boulders	- commonly comprising 25 to 50% in the west, 50 to 75% and up to 100% in the east, angular to subrounded, mainly slightly to moderately decomposed with patinas generally a few mm and up to 10 mm.
	(Type location, exposures in cuttings along Lugard Road)

Source : Mid-levels study, Hong Kong Government 1982.

it is today (cf. P.A. Randall in oral presentation of Taylor and Randall 1983).

In Hong Kong the formation of the deposits is ascribed in general terms to cyclical fluctuations in climate and sea level during the Pleistocene. The accumulation of these deposits during this period may also have been aided by prolonged preparation of the bedrocks under favourable climatic conditions during the Tertiary, when the landscape assumed its present general characteristics following early to mid-Tertiary earth movement associated with the opening of the South China Sea. Only relatively limited and localised deposition of new 'cover' rocks took place during this period in southern China.

The development and deposition of each class of colluvium recognised during the Mid-levels study was considered in terms of one or, in the case of the Class 2 deposits, possibly more glacial-interglacial cycles (Hong Kong Government 1982). The study noted, however, that it was not possible to assign actual ages to the different classes (see below). Deposition was correlated with the immediate post-glacial periods and was ascribed to increasing precipitation and the rise in sea level and water table as the ice caps retreated. The climate became less seasonally extreme, and was ameliorated by the marine transgression. These changing conditions were considered to have facilitated the mass movement of material downslope. It may also be supposed that erosional activity at the end of a glacial period was more intense, given the lower sea level (lower base level) and relatively more exaggerated relief and a possibly sparser vegetation cover.

Recent Chinese research has demonstrated good correlations between the marine transgressions, palaeomagnetic reversals and the interglacial and interstadial periods in eastern China (Zhao and Chin 1982). The transgressions occurred at c. 10 000 years BP (Holocene transgression); 30 000 to 40 000 years (Würm or Dali interstadial); 70 000 to 100 000 years (Würm-Riss or Dali-Lushan interglacial); c. 200 000 years (Riss or Lushan interstadial); and c. 300 000 years (Riss-Mindel or Lushan-Dagu interglacial). Mean sea temperatures during the Dali interstadial and the Dali-Lushan interglacial were reported to be comparable with those obtaining at the present day off the Fujian coast, based on micropalaeontological data. Zhang (1983) considered the mean annual temperature in southern China during the Late Pleistocene to be some 5°C cooler than at present. He presented data showing a mean of c. 20°C in the vicinity of Hong Kong (range 5° to +25°C) and reported rainfall to have been of the order of 800 mm p.a. or some 60 percent of present-day levels. If it is assumed that at least some of the major colluvial deposits formed during this period it is somewhat difficult to reconcile this relatively low average rainfall value (by comparison with present values) with the association observed today between the incidence of landslides and periods of intense rainfall. It should be noted, however, that Zhang's figure is an average for the period and maxima during the Dali-Lushan interglacial and the Dali interstadial may well have been significantly higher and the rainfall patterns more extreme.

Lai and Taylor (1983) attempted to build upon the model developed by the Mid-levels study and apply it more widely throughout the Territory. They, too, related each class of colluvium to climatic and environmental changes during the Tertiary but proposed tentative ages for each class. Class 1 deposits were considered to have formed more than 128 000 years BP and probably in the Middle to Early Pleistocene; Class 2 colluvium was assigned a Late Pleistocene age (12 000 to 128 000 years BP); and the Class 3 deposits were assigned to the Holocene.

These age assignments should be regarded with caution at the present time. They are tentative if not speculative, and do not obviously accord, for example, with the ages of the marine transgressions reported by Zhao and Chin (1982) for eastern China, nor with the ages accorded to the local alluvial-marine sequences (Yim and Li 1983). A more straightforward but equally simplistic and speculative application of the Mid-levels model would be to relate the formation of the different classes directly to the marine transgressions reported by the Chinese workers and correlated with the global sequence of Quaternary events, i.e. class 1 c. 100 000 years BP; class 2 c. 40 000 years BP; and class 3 c. 10 000 years BP. This scheme, however, does not necessarily take into account the possible polycyclic nature of the Class 2 deposits.

A minimum age for at least some of the colluvial deposits is indicated by recent work associated with the MTR Island Line extension. Colluvium is reported to underlie the upper marine - upper alluvial deposits in the Wanchai section at a depth of -8 mPD and some 30 m offshore from the original shoreline (A.J. Willis in oral presentation of Willis and Shirlaw 1983). The colluvium was deposited at a time of lower sea level prior to the Holocene transgression, i.e. at some stage during the Late Pleistocene Dali Glaciation. The 'upper alluvial' deposits which post-date the colluvium at this site have been tentatively dated elsewhere at between 8 000 and 33 400 years BP (Yim and Li 1983).

3.3.4 Comment

It will be evident that the satisfactory dating of the mass wasting deposits and an understanding of the climatic and environmental conditions applying at the time of their formation require considerable further investigation. At present reliable ages for the deposits are lacking. If the catchment-bounded nature of the deposits noted in section 3.3.1 is accepted then there would not appear to be any *a priori* reason why colluvium possessing similar physical characteristics (i.e. belonging to the same class) but occurring in different depositional areas need be of the same age. It may be considered more likely that the variations between the different classes reflect rather the effects of diagenesis and possibly localised overpressures due to loading, and need only be age-related in a general and relative way. The general applicability of the three-class concept in chronostratigraphic terms remains to be effectively demonstrated.

Further study of the interface between the mass wasting deposits and the layered fluviatile-marine sequences may permit some advances to be made, particularly if the colluvium interfingering with or underlying the layered deposits can be assigned to a particular class and if the chronostratigraphy of the latter beds can be further improved and refined. However, the limitations of the C^{14} method, particularly insofar as the lower marine-lower alluvial beds are concerned, should be noted. There would appear to be scope for applying palaeomagnetic techniques (cf. the Chinese work) to establish a magnetostratigraphy for the fluviatile-marine deposits and specialist advice could usefully be sought to ascertain whether the method could also be applied directly to the different classes of the mass wasting deposits. The oxidised nature of the material comprising the deposits may well preclude the application of palynological and palaeobotanical methods although in theory there should be scope for discovering plant and pollen remains in the deposits which could shed useful light on the palaeoclimate and possibly the age of the deposits.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 GENERAL

The investigation of rock weathering and of the superficial deposits _sensu stricto_ will form only part of the wider tasks involved in the remapping programme. A considered approach to these aspects of the programme will, therefore, be necessary. It is recommended that the main aims of the work should be :

(i) to establish a broad framework for the classification of the residual and transported deposits (i.e. distribution, general character, relationships);

(ii) to acquire such additional detail as is feasible given the publication scale, the time available, and the nature and purpose of the end-product.

There will be scope throughout the programme for collaboration with outside researchers to examine more fully the topics considered by this report. Full use should also be made of the available in-house experience gained from the GAS Programme and of the existing in-house data (e.g. GAS maps, GEOTECS data and Data Bank records). However, significant advances in the study of the superficial deposits and weathering processes will depend, as does the study of the solid (bedrock) geology, on the availability of good sections. An opportunistic approach will be particularly necessary in Hong Kong if full advantage is to be taken of major temporary exposures revealed during the course of engineering works. Generally, it will not be feasible for the mapping geologists to respond adequately to such opportunities, particularly where temporary sections are opened-up outside the areas currently under systematic study. Geologically-trained staff within the GCO should be made available in such circumstances to meet this need and to monitor potentially useful developments, to avoid further loss of valuable data.

4.2 WEATHERING

Weathering studies carried out to date concentrated mainly on the granitoids and were field rather than laboratory orientated. Two aspects meriting further investigation are thus immediately identifiable : an assessment of the weathering modes and characteristics of the non-granitoid rocks and the attachment of greater emphasis to the laboratory investigation of the physical, chemical and mineralogical changes accompanying weathering, involving an attempt to define more precisely the rate of weathering and the conditions under which it occurred.

For the reason summarised at the start of section 4.1, the remapping programme along is unlikely to afford adequate opportunity for a detailed study of weathering. However, the recommended attachment to the programme of an engineering geologist should permit the fuller documentation than would otherwise be possible of the various changes affecting the main rock units during the weathering process. This input to the programme will require the careful selection of representative sections for study and sampling, and will involve a considerable laboratory involvement. The participation of outside researchers, particularly to evaluate the chemical and mineralogical changes taking place, can be envisaged. The information gained should provide useful background on the general engineering response of the weathered variants of the main rock units mapped and should thus be of direct benefit to a variety of engineering and geotechnical applications.

The remapping should permit representation of the gross distribution of bedrock outcrop, residual and transported deposits. It may be possible to display in a general manner on the superficial geology maps the weathering grade or ranges of the outcrop areas delimited and the relative abundance of relict bedrock material present in areas mainly underlain at the surface by residual deposits (see section 2.3). This information should assist the engineer in anticipating problems that are likely to be encountered during site investigation. It will not of course remove the need for site investigation at a scale appropriate to the task at hand.

The environmental conditions responsible for the development of often thick in situ weathering profiles and the age of the profiles themselves remain imperfectly understood. Estimates for the maximum age of the profiles in Hong Kong range from c. 200 000 years to c. 1.8 Ma (late Pliocene). The climatic conditions throughout the Tertiary and Quaternary in southern China are believed to have been mainly humid, tropical to subtropical and generally conducive to chemical decomposition of the bedrocks and the development of the extensive 'red clays'. Some possibility of quantifying weathering rates may be gained from the study and measurement of the weathering patinas of clasts in the mass wasting deposits, provided of course that the age of the host deposit itself can be ascertained. The possibility of applying isotope techniques to help resolve the ages of the residual and the transported superficial deposits, and to help elucidate the palaeoclimatic conditions under which the deep weathering took place or the deposition of the transported deposits occurred, merits examination.

4.3 TRANSPORTED SUPERFICIAL DEPOSITS

Two major groups of transported superficial deposits can be established for geological mapping purposes, the layered fluviatile-marine sequence and the mass wasting deposits. The latter may be broadly subdivided into slightly transported and substantially transported categories.

The overall distribution of the fluviatile-marine deposits onshore is known and the remapping programme should aim to collate and synthesise the available subsurface data, where possible extending the work into adjacent offshore areas to permit a fuller understanding of the deposits both vertically and laterally.

Recent work, mainly offshore, has allowed the recognition of a general stratigraphy which requires critical scrutiny. Further refinement of the model may be attempted using radiocarbon and possibly palaeomagnetic methods, in addition to the more conventional techniques of palaeontology, palynology, sedimentology and chemical analysis. Most of these methods are specialised and external expertise will be required.

Two main subdivisions of the mass wasting deposits for mapping purposes are noted in the report. The 'slightly transported' category will be essentially residual or quasi-residual at the mapping scale, although internal detail should be recorded wherever possible and local, smallscale landslips and virtually in situ boulder fields, etc. may be represented diagrammatically on the superficial geology maps. However, in the context of the mass wasting deposits the main aim of the survey must be the differentiation and delimitation of the 'substantially transported' deposits, possibly further subdividing them on the basis of depositional process or general composition or character. A detailed, large scale approach (cf. the Mid-levels study) will not be practicable or readily applicable during the present 'regionally orientated' survey but the detailed description of individual deposits along the lines of the Mid-levels work, particularly those deposits critical in terms of engineering development, should remain a long term objective, once a broad reference framework is established throughout the Territory.

The mass wasting deposits were formed on a considerably larger scale in the past but their age and the environmental conditions which gave rise to them remain only vaguely known. The deposits are essentially catchment-bounded except on the smallscale and formed after the establishment of the main drainage systems and the gross topography. In view of the lack of contiguity between deposits in different drainage basins and even within individual catchments, it is unlikely that conventional lithostratigraphic procedures and correlations can be effected, other than on the most local of scales. The use of such procedures is not recommended, to avoid erecting a large number of areally insignificant, localised units. Likewise, chronostratigraphic correlation cannot necessarily be inferred even if the internal characteristics of individual deposits are comparable.

Although the mass wasting deposits continue to form on a reduced scale at the present day the older deposits pre-dated the upper marine and upper alluvial horizons. Others may interfinger with and have contributed to those horizons, and possibly also to the lower alluvial and lower marine horizons, by a process of syn and post-depositional reworking. A Late Pleistocene-Holocene age for the mass wasting deposits is indicated. A general association with marine transgression during the interglacial/interstadial and post-glacial (Holocene) periods was argued for the Mid-levels deposits.

Careful examination of the relationships between the distal parts of the mass wasting deposits and the alluvium derived from them by local reworking or by independent deposition from an outside source is suggested, in an attempt to date the former more certainly. This will clearly need to be linked to the efforts, noted previously, to refine the stratigraphy of the fluviatile-marine deposits.

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