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Dredged Sand and Gravel for Construction Purposes—an Assessment Procedure and Hong Kong Case Study

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ABSTRACT

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This paper discusses important features of various methods used to describe and specify sand and gravel with a view to its being used for construction purposes. The paper presents the results of work done in Hong Kong to develop a scheme that might have general application for assessing onshore or offshore sand and gravel deposits in any country.

The need for such a scheme became apparent with recent moves by the Hong Kong Government to more clearly specify sand in its Unified General Specification, and also with the recent discoveries of large resources of high quality granular materials in Hong Kong waters which might be suitable for various construction uses.

A conclusion to the work on seabed materials that ensued and a key aspect of the assessment scheme which resulted, is that following detailed description of all the samples, selected Type Samples from different target geological deposits should be tested for compliance with particular specifications/standards. It is contended that primarily in this way can an inventory be compiled of those geological deposits that will satisfactorily provide resources for particular purposes. The alternative approach involving an initial detailed classification of the materials is not advocated.

ADDITIONAL INDEX WORDS: *Concrete aggregate, reclamation fill, soil description, laboratory testing, material specification, natural resources.*

INTRODUCTION

Sand and gravel is a widely used natural material. The term as used herein excludes artificially crushed rock and man-made materials. On first impression apparently similar materials may be used in 'low grade' situations such as for fill, in 'medium grade' situations such as for concrete aggregate, and in 'high grade' very specialised situations such as for making glass. The characteristics which make sand and gravel specifically suitable for various particular uses to which it is put can be broadly divided into two kinds.

Firstly there are those uses that depend on the fact that sand and gravel is non-cohesive, durable and highly permeable. Use in the construction industry generally falls into this category. Secondly there are those uses which depend on the physical or chemical properties of the material of which the grains are made. Specialised uses such as glass making and moulding sands are examples.

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This paper is primarily aimed at possible uses for sand and gravel in the construction industry, such as for concrete, mortars, filters and general granular fills.

In order to determine if a certain sand and gravel is suitable for a particular use it is necessary first to determine what are the desired characteristics for the intended use, and second to examine and describe the material so as to compare the actual material with the requirements. These two stages of specifying and of describing are quite distinct. In fact if a sufficiently full description of the material is made it will probably contain enough information about the sand and gravel for that description to be used thereafter to determine the materials suitability for a number of different uses.

Unlike many other economic natural deposits such as metallic ores which in comparison are more valuable and which undergo considerable processing before use, sand and gravel is a relatively cheap commodity and it is not usual for it to be very extensively processed before use. This

Table 1. *Descriptive geological terminology of sands.*

Material Terms	Generic Terms
Quartz sand	River sand
Arkosic sand	Beach sand
Iron sand	Desert sand
Basalt sand	Marine sand
Coral sand	Glacial sand
Shell sand	

fact together with the very wide range of uses for sand and gravel means that the *in situ*/natural characteristics essentially determine its use. Therefore, on discovering a new deposit or source of sand and gravel it is important to describe its characteristics as fully as possible in order to determine its potential as a reliable resource.

In Hong Kong, for example, there are currently about 20 million tonnes of sand and gravel used annually in the construction and concrete industry (EARLE, 1990; CARBRAY, 1988). A very much smaller amount is imported for minor specialist uses. In addition to the sand to be used in the concrete industry there is a massive need for an extra 700 million m^3 of granular fill for use as prime reclamation material over the next ten years. This material must be located, appraised, won from the seabed and placed within this timeframe.

This paper therefore draws on the Hong Kong case study which, concentrates on the use of sand and gravel for the construction industry. It aims to address the need to fully describe and assess sand and gravel, wherever found, in order that its potential and suitability for various uses in industry can be ascertained.

The process of soil and rock description and specification is becoming well established throughout the world and the means by which this can be efficiently done for sand is presented and discussed below. There are, however, minor variations in the existing systems, and this paper presents and advocates a consensus scheme. A practical example of the use of this scheme applied to a Hong Kong source material is included.

DESCRIPTION OF SAND AND GRAVEL

Definition of Sand and Gravel

"Sand" and "gravel" are both everyday and technical terms, with both everyday and technical definitions. This can lead to some confusion, especially when considering the uses of such material if, as is often the case, the description and classification of the material is done by a person other than the end user/specifier. In Hong Kong, as in many other countries, there are also legal connotations because of the existence of "Sand Ordinances" which regulate the extraction and transportation of sand. Some examples of popular definitions of sand are given below.

(1) Everyday/common parlance: Naturally occurring, loose detrital material consisting of grains which are smaller than gravel but which are visible to the naked eye (*e.g. Oxford English Dictionary*).
(2) Everyday-technical: As above but with the addition that the grains are essentially composed of quartz (*e.g. Chambers Technical Dictionary*).
(3) Legal: Often not specifically defined, as is the case in Hong Kong Laws; so presumably the same as (1) and (2).
(4) Geological: Using (1) and (2) as a start, the definition is expounded to include various types of sands which are distinguished either by terms which more fully describe the material or by terms which describe the environment or mode of its formation. Table 1 provides examples of commonly used terminology.
(5) Specific: Related to a particular use. There is a whole range of such specifications each of which concentrates only on those characteristics which are of importance to that particular use. These definitions can rarely be used for more than one purpose.

Individual Characteristics

The general principle to be borne in mind when describing sand and gravel is to make the description as full as possible. This applies not only to the occasions where the end use and purpose of the description are not known but also to cases when the description is being made for a specific use. Many specific uses require selective partial descriptions of certain characteristics to be made (such as the shell content for use as concrete aggregate). This should be avoided as a general practice since the description might be used at a later date by someone else, to whom any selectivity built-in to the partial description may not be evident.

The sub-paragraphs below are not exhaustive but they propose a scheme of description of sand and gravel which can be easily and universally

Table 2. *Order and content of a full description for sand and gravel.*

Component	Terminology	
1. Origin (of material)	Land won/marine dredged Processed/unprocessed	
2. Class (of material)	Crushed rock Gravel—Natural/crushed Sand—Natural/crushed	
3. Mass (description)	Cementation	Indurated/non-cemented Poorly/well-cemented
	Compaction	V dense/dense Loose/V loose
4. Material (description)	Colour	Hue Value Chroma
	Grading	Well/poorly Uniform/gap
	Secondary constituent	Clayey/silty Sandy/gravelly
	Composition	Quartz/arkose Shelly/coral Calcareous/lithic
	NAME	CLAY/SILT SAND/ GRAVEL (c, m, f) FINES
5. Particle (description)	Texture	Glassy/smooth Rough/honeycombed
	Shape	Spherical/angular Flaky/elongate

applied and was found, for instance, to be relevant to Hong Kong. The system of description proposed is simple, standardised, uses well known and used terminology, and relates strictly to a series of clearly defined phraseology; each descriptor being approached in a particular order to build to a full description. This systematic approach to the compilation of a full description follows that already widely used in engineering geology for rocks and soils.

The proposed order of description and components to be covered in such a description are presented in Table 2. These components are more fully described in the following paragraphs and an example of how the system may be used as a typical checklist for multiple description of samples is shown in Figure 1.

Origin and Class of Material

These components of the description are very important for completeness and subsequent reference by other parties but are unfortunately usually not recorded in most systems.

Table 3. *Cementation of materials.*

Term	Description
Indurated	Bound together by pressure or clay, coherent, crumbles on water immersion.
Non-cemented	Free running, unbound, non-coherent.
Poorly cemented	Weakly bound by intergranular cement, hand specimens can be broken by hand.
Well cemented	Strongly bound by intergranular cement, hand specimens cannot be broken by hand.

Mass Properties

The next component of the description, *i.e.* mass, relates to the character of the *in situ* mass of the material, if this is known. For most natural granular geological deposits this relates to their degree of cementation of compaction. The suggested terminology and definitions for such descriptions are given in Tables 3 and 4.

Material Descriptions

The next and most important component of the full description follows in an orderly sequence and this relates to the actual nature, composition, appearance and name of the material fragments. The range of terms proposed and their now well accepted definitions are given in Tables 5 to 8.

A note of the colour is a basic part of a description although there are only a few uses where this will be important, and even then the colour may be described elsewhere by virtue of being included in, say the metallic oxides in a chemical analysis, *e.g.* for use as a glass sand. Standard colour charts such as those of Munsell and accepted phraseology (Table 5) are available and the description should be in these terms. No full description is complete without a colour photograph of a representative number of the samples and these should be taken alongside both a standard colour chart and a ruler for scale.

The particle size distribution or grading of the grains in a granular material determines the way in which the grains can be packed together and as such dictates the density to which the material can theoretically be compacted. This is important in most uses, particularly in the construction in-

Figure 1. Scheme of description of sand, gravel or fine aggregate.

Samples:		Location: No:	Stanley Beach 1-1				
Component	Term						
Origin	Land won/marine dredged		x/	/	/	/	/
	Processed/unprocessed/*in situ*		/x/	/ /	/ /	/ /	/ /
Class	Crushed rock						
	Gravel—Natural/crushed		/	/	/	/	/
	Sand—Natural/crushed		x/	/	/	/	/
Mass	Cementation	Indurated/non-cemented	/	/	/	/	/
		Poorly/well cemented	x/	/	/	/	/
	Compaction	V dense/dense	/	/	/	/	/
		Loose/V loose	x/	/	/	/	/
Materials	Colour	Hue	Pale				
		Value					
		Chroma	Brown				
	Grading	Well/poorly	/x	/	/	/	/
		Uniform/gap	x/	/	/	/	/
	Secondary constituent	Clayey/silty	/x	/	/	/	/
		Sandy/gravelly	/	/	/	/	/
	Composition	Quartz/arkose	/	/	/	/	/
		Shelly/coral	/	/	/	/	/
		Calcareous/lithic	/	/	/	/	/
	NAME	CLAY/SILT	/	/	/	/	/
		SAND/GRAVEL (c,m,f)	x/(f)	/	/	/	/
		FINES					
Particles	Texture	Glassy/smooth	/	/	/	/	/
		Rough/honeycombed	x/	/	/	/	/
	Shape	Spherical/angular	/x	/	/	/	/
		Flaky/elongate	/	/	/	/	/

Remarks: *e.g.* The Stanley Beach sample 1-1 may be classified as an unprocessed natural sand. It is poorly cemented and loose *in situ* and may be described as a pale brown poorly and uniform graded silty quartz (fine) SAND comprising mainly rough textured, angular shaped particles.

dustry, and so the grading is usually a basic part of most specifications of sand and gravel.

It is worth noting that "grading" is a term used by engineers and other specialists to describe the fact that there is a range of grain sizes; *i.e.* that the sizes grade from small to large. Well graded meaning that there is a wide range of grain sizes. Geologists, on the other hand, use the term "sorted". Geological environments process detrital material by concentrating material of particular sizes. Therefore they "sort" a mixture of grain sizes to produce nearer a single-sized material. "Well sorted" is therefore "poorly graded", and "well graded" is "poorly sorted". Grading is generally

Table 4. *Compaction/relative density.*

SPT N Values (blows)		Relative Density (%)	Terminology	Description
			Very loose	Excavation by spade, peg may be pushed in
4	—	15	—	
			Loose	Excavated by spade, peg may be tapped in
20	—	50	—	
			Dense	Excavated by pick, peg may be hammered in
50	—	85	—	
			Very dense	Excavated by mechanical digger, cannot hammer peg in

unimportant in those uses of sand which depend on the material composition.

An elaboration of the grading description is possible using the secondary constituent descriptor. This descriptor may be defined in quantitative terms by the proportion of a particular secondary constituent to the material as shown in Table 7. This link between a verbal description and a highly defined and standardised wordage is useful and powerful in that it facilitates a description capable of translation into triangular graphical plots of 2 levels of dissemination (and vice versa) as shown in Figures 2 and 3.

With respect to the material composition, for situations where sand and gravel is used primarily for its bulking characteristics, it is essential that the material is durable; this is, however, often assumed rather than actually specified by the user. For the type of use where it is the composition of the grains that is the main interest to the user then this will undoubtedly form the main part of the specification.

Sand and gravel, being a naturally formed detrital material has to be fairly durable in order to have survived the geological processes of erosion, transportation and deposition, and so most sand and gravel deposits are composed of quartz, it being the most common rock forming mineral which is stable under normal earth surface conditions. Immature sands and gravels (*i.e.* those in which the detrital material has not been transported very far) contain more broadly varied composition depending on the original rock type from which they were derived. The non-quartz grains might be monomineralic, such as feldspar or amphibole, or they may be lithic fragments, such as small pieces of the original parent rock, for example grains of granite (a quartz-feldspar crystalline aggregate). The extent to which there is a non-quartz component to a sand and gravel will depend on two main factors. First, the nature of the source rock clearly determines what material is available to produce the grains. The bedrock in a granite hinterland is 30–50% quartz and hence has great potential for producing sand (*e.g.* much of Hong Kong). A basalt hinterland on the other hand will produce a basalt sand that has no quartz in it (*e.g.* some beaches in Iceland and Hawaii). Second, the nature of the geological environment such as a beach, or a very mature environment such a the lower reaches of a river, will tend to have a high quartz content because many of the other initial constituents are less durable and have eroded or weathered away.

Table 5. *Description of colour.*

Hue	Value	Chroma
Pale	Reddish	Red
Dark	Pinkish	Pink
Mottled	Yellowish	Yellow
	Brownish	Brown
	Greenish	Olive
	Bluish	Green
		Blue
		White
		Grey
		Black

Table 6. *Grading of material.*

Term	Description
Well graded	Wide and full range of particle sizes.
Poorly graded	Comprising essentially one or two main particle sizes.
Uniform graded	Essentially single sized.
Gap graded	Comprising essentially a fine and coarse component, but missing the intermediate size.

Table 7. *Secondary constituents.*

Term	Proportion
Clean (say sand)	0–5% secondary constituent
Clayey, silty, sandy, gravelly	5–15% secondary constituent
Very clayey, very silty, very sandy, very gravelly	15–35% secondary constituent

Apart from the reworking and concentrating of parent rock material to produce a sand and gravel there is also the possibility of new material being added during the processes of erosion, transportation and deposition. The commonest of these is the addition of other, perhaps finer sediment, which has been undergoing a separate evolution nearby and which is brought into contact with the sand and gravel. The resulting material might be a muddy sand for instance. This type of mixing can occur when there is a change in environment such as when there is a marine transgression or progradation of deltaic facies and alluvial sediments become reworked in a marine environment [*e.g.* the basal Holocene marine sands which occur as moribund banks offshore Hong Kong (EVANS, 1988)]. Another important addition of material to a sand is the inclusion of shells, particularly marine shells. In many ways the presence of shells and shell fragments is more of a potential problem to a sand user than the presence of fines because the fines can be easily removed by washing and screening, whereas the shells cannot. A quantification of the shell content of the deposit is therefore required for some users. It is worth noting that the method of measuring the shell content usually commences with a sub-sample of the original material obtained by sieving. This means that the shell determination is carried out on the material retained on a certain sieve size and not on the whole sample. Shell content determination by BS 812 (BRITISH STANDARDS INSTITUTION, 1985) for aggregate is an example where the shell content is determined, but only on the fraction greater than 5 mm. This should be borne in mind when assessing shell content measurements.

It is recommended that as sound general practice the composition of the grains should always be assessed and preferably measured as part of a statistical grain count. Grain size is the fundamental characteristic of sand and gravel for it is this which dictates the mass behaviour and defines the material name. The range and distribution of grain sizes and the names associated with each are slowly becoming well understood

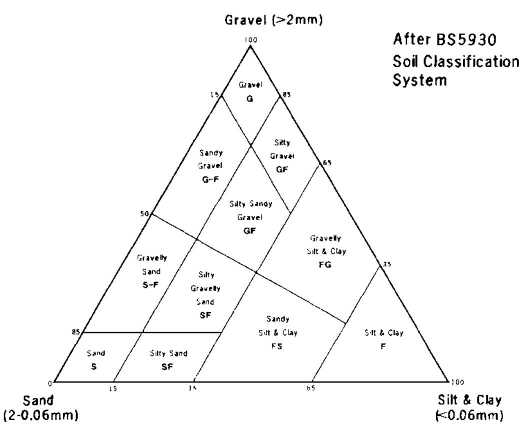

Figure 2. General soil classification.

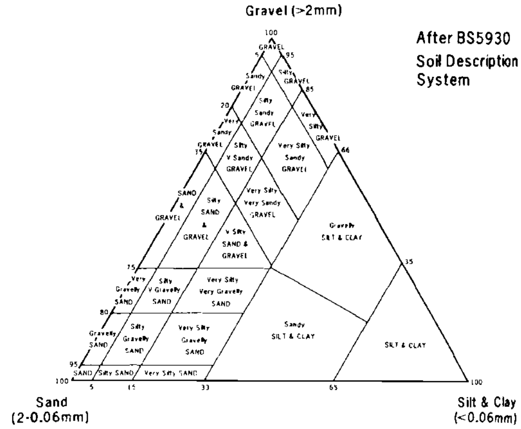

Figure 3. Detailed soil classification.

Table 8. *Grain size/material name.*

Name		Size in Millimetres
BOULDERS		200
COBBLES		60
GRAVEL	Coarse	20
	Medium	6
	Fine	2
SAND	Coarse	0.6
	Medium	0.2
	Fine	0.06
FINES	SILT	0.002
	CLAY	

Table 9. *Texture of particle surfaces.*

Term	Description
Glassy	Conchoidal fracture
Smooth	Water worn or sand blasted
Rough	Pitted, angular
Honeycombed	Visible pores or cavities

Table 10. *Shape of particles.*

Spherical	More or less sphere shaped
Rounded	Non-spherical but with rounded edges
Flaky	Thin and flake-like, angular edges
Elongate	Long and slender, angular edges

and used and are defined in Table 8. Grain size is normally measured by a standard sieving method. It is important to note that for non-spherical grains it is the length of the intermediate axis, not the longest axis that determines the sieve size on which it will be retained.

Particle Characteristics

The two most important descriptors of the individual fragments or particles comprising the sand are their surface texture and overall shape.

The texture is a measure of the grain surface roughness and is usually made subjectively, possibly by comparing the appearance of the grains with a standard illustration or by reference to standard definitions (Table 9). Clearly, as the irregularities of the grain surface become larger, they eventually determine the shape. However, in most cases, particularly with coarser sand and gravel, it is useful to distinguish between shape/sphericity and roughness/angularity.

The shape (sphericity) refers to the overall outline of a grain rather than the roughness of the surface. The shape can be measured, in two dimensions, by the ratio of the inscribed circle to the escribed circle—the ratio being equal to one for a circular outline and tending towards zero as the grain becomes more elongate. Rather than attempting to carry out a three dimensional measurement of grains it is usually sufficient to statistically assess the material in two dimensions provided the grains are randomly orientated with respect to the sampling plane. Where the three dimensional shape can be seen, as is often the case with coarser material, then a subjectively assessed term can be used. Definitions of the terms used to describe particle shape, such as flaky, are given in Table 10.

It is often possible, from a detailed geological examination, to establish the environment of deposition of a sand and gravel. While this may only be of passing interest to the user of the material it will very often give some indication of the lateral and vertical variation in the deposit which might be expected. This is important to the extractor because it will indicate the persistence of the deposit, and it is important to the user because he will need to know the intensity of sampling (and description) necessary to reliably characterise the material in the deposit. It may also indicate to the user and to the person making the description that certain undesirable characteristics may be present and hence need for these to be looked for, described and tested.

Typical environments are given in the "generic terms" in Table 1. It should also be remembered that a study of the nearby geological materials and the local geology will give important indications of the nature of the deposit.

CLASSIFICATION AND SPECIFICATION OF SAND AND GRAVEL

A user of sand and gravel "specifies" the type of material required in order to ensure that its performance will meet expectations. This "specification" can either be in terms of the way the material should perform on the job or in terms of the raw material characteristics. The latter method is mostly employed for construction-related uses, although there may well be cases when a combination of the two is needed in order to ensure that the correct thing is done with the correct material.

Having established from experience what material characteristics are required, the user describes these in detail and this forms the basis of a "specification". It is important to remember that because a "specification" only details those characteristics which a particular user is interested in, it does not include a complete description of the sand and gravel. Therefore, it is possible for a sand which meets the specification for making glass, for instance, also to meet the specification for making concrete. Equally, a marine sand which meets the specification for use as fill material may not meet the specification for making, say, structural concrete. It should be noted in passing that processed natural material (*i.e.* crushed and screened) and artificial material (PFA *etc.*) can also satisfy some specifications and are then used

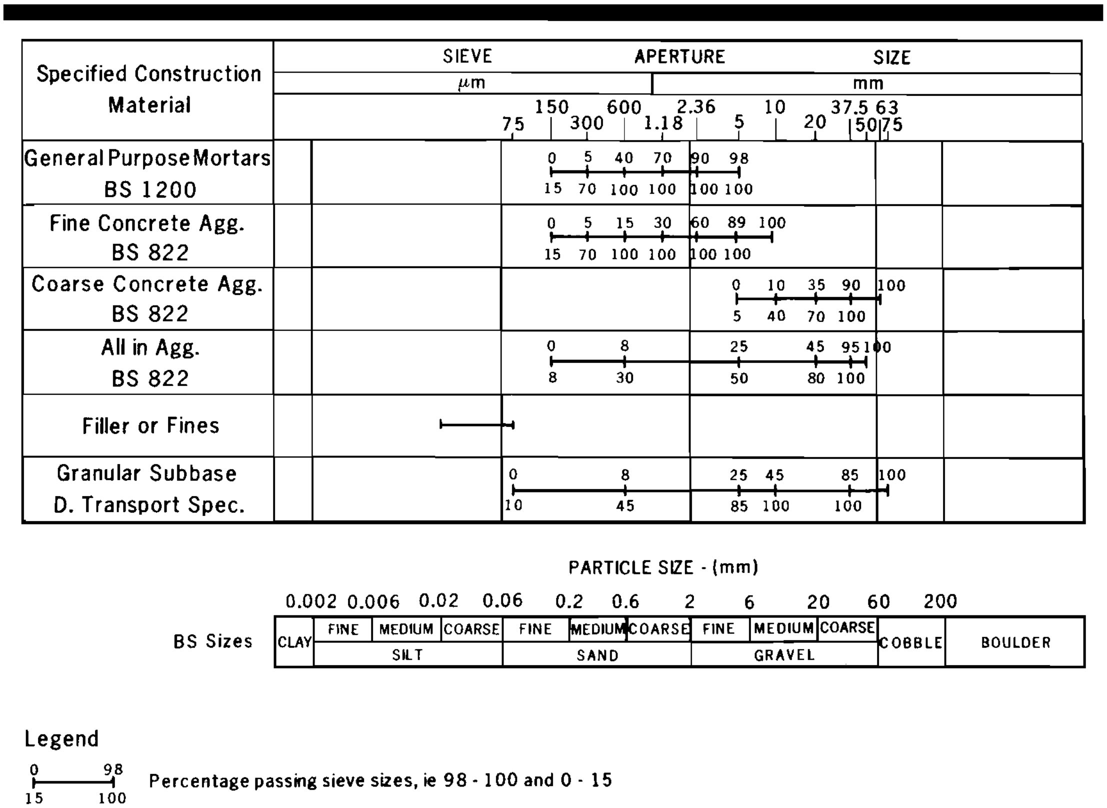

Figure 4. British Standard grading specification.

if the supply and economics situation are favorable.

Having described the individual characteristics of a sand and gravel some specialists feel that it is useful to then classify it as falling into one of a number of groups within each of which there is a small range of individual characteristics but a uniformity of general character. The "Classification and Description of Aggregate Materials" (CADAM) classification developed by the Geological Society of London (COLLIS and FOX, 1985) is an example of such a system. CADAM was specifically developed for aggregate materials in the United Kingdom but its relevance to other uses and other parts of the world is perhaps slight. In fact, it is arguable that the classification of a sand and gravel is only useful if the classification is aimed at a specific use and, if this is the case, then there will almost certainly be an existing specification for such use, in which case it is probably simpler to use that specification as the basis of the particular classification system. It should be remembered that "classification" is inevitably a down-grading of the full description, and unless there is particular need it is perhaps not necessary. There is nevertheless always a need to refer to the material in question in reports, discussions, *etc.* and this can conveniently be achieved by a "classification". However, unless contemplating a specific end use there would appear to be no great merit in formalising this classification beyond the use of a few standard words of English. Therefore it would be sufficient to refer, for instance, to a "fine brown quartz sand", or a "grey muddy shell gravel", *etc.*, in reports, it being quite clear that one must resort to the full description to determine if the material is suitable for a specific use.

A purely geologically based classification has already been referred to where the use of "generic terms" is used to classify deposits of sand and gravel. However, this type of "classification" is better regarded as part of the description even though it is qualitative and inferred.

Although a formal classification is therefore not

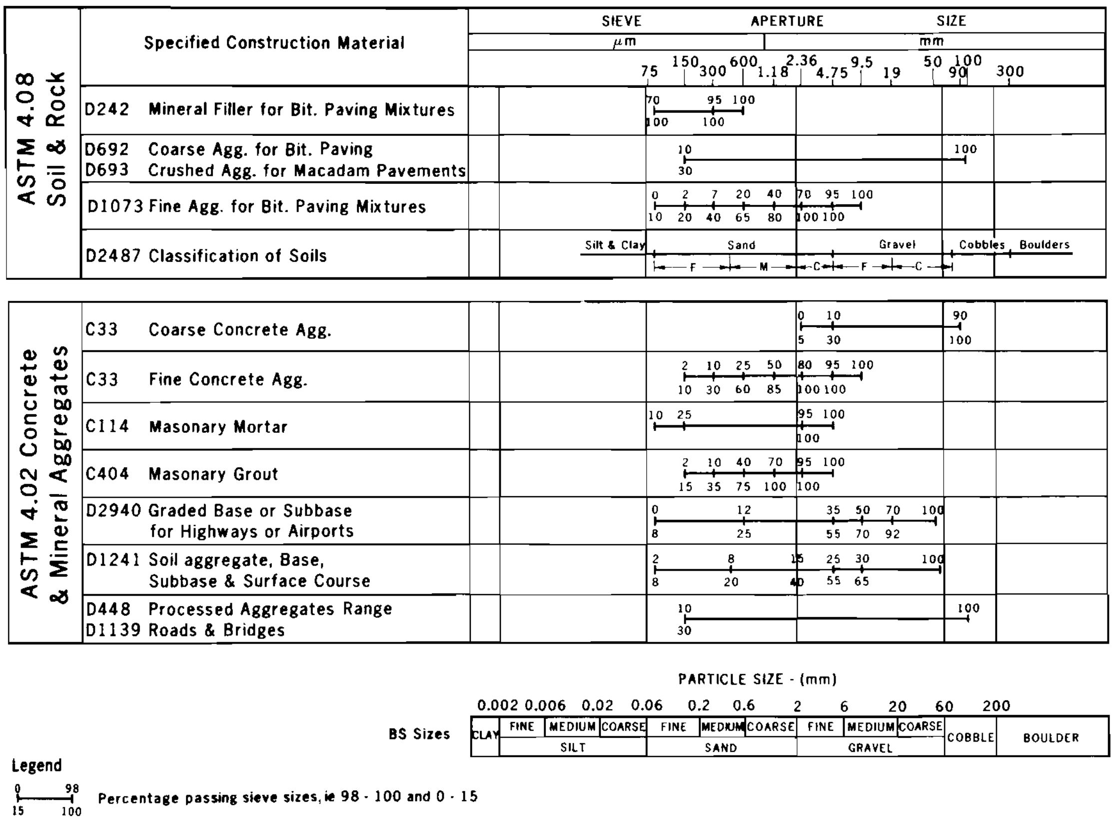

Figure 5. ASTM Standard grading specification.

advocated here, there is inevitably a need to use the terms "sand", "gravel", "fine", "coarse", *etc.*, and the criteria adopted here are those of BS 5930 and BS 1377 (British Standards Institution, 1981 and 1975 respectively). This convenience should not lead to confusion since detailed specifications do not in general specify "sand" or "gravel" but instead specify the gradings. Other terms can be added as thought appropriate provided there is always a reference to the dominant grain size and the dominant material of which the grains are made.

Specifications for Concrete and Mortars

In financial terms on a global basis the use of natural sand and gravel as aggregate for concrete is very important in the construction industry and as a result there are a number of different international standards cited in specifications around the world. The two main systems are the British Standards Institution (BS) and the American Society for Testing Materials (ASTM). A summary of the required grading limits laid down by these systems is presented in Figures 4 and 5. Many countries use one or other of these systems; in Hong Kong, for instance, the BS system is generally used.

In addition to the grading, the standards require that for each particular aggregate category the following characteristics are also all within certain specified limits:

Aggregate crushing value
Aggregate impact value
Water absorption
Flakiness index
Magnesium or sodium sulphate soundness
Aggregate abrasion value
Los Angeles abrasion test value
Shell content
Chloride content

Table 11. *Specification of concrete aggregates for particular uses—British Standard Institution (BS 882:83).*

	Gradings	Flakiness (+elongation)	Shell Content %	10% Fines (heavy duty) kN	AAV (heavy duty) kN	Fines Content (−75 μm) %	Chloride Content (Wt % agg)	Sulphate Content (wt % cement)	Water Absorption %
Fine Concrete Aggregate	Yes Fig. 4		no requirement				<0.06	<4 (of cement mass)	<3
Coarse Concrete Aggregate	Yes Fig. 4	35 (<50)	20 (5–10 mm)	50 (150)	45 (25)		<0.06	<4 (of cement mass)	<3
Filler of Fines	<75 μm								
All in Aggregate	Yes Fig. 4		8 (>10 mm)			3			
Granular Subbase	Yes Fig. 4			<50		<10			
Road Base	Yes Fig. 4	>35		<50	AIV >30	<8			
General Purpose Mortars	Yes Fig. 4								

Sulphate content
Fines content

Tables 11 and 12 set out these specifications as required in the British and American standards respectively.

It is to be noticed that not only are there characteristics required which were not mentioned in the section above (*e.g.* water absorption) but also that some of those which were mentioned, such as shape, are required by this standard specification in different and more detailed form (*e.g.* flakiness and elongation).

When used to make concrete for road pavement

Table 12. *Specification of concrete and mineral aggregates—ASTM Standards (also AASHTO).*

	Gradings	Organic Impurities %	Clay Lumps % / Lightout Particles %	$MgSO_4$ Soundness % Loss	Na_2SO_4 Soundness % Loss	Fines Content (−75 μm) %	Los Angeles Abrasion % Loss	Elongate Particles %	Plasticity Index
Coarse Concrete Aggregate	Yes Fig. 5		5 / 0.5	18	12	1	50		
Fine Concrete Aggregate	Yes Fig. 5	0	3 / 0.5	15	10	5			
Masonary Mortar	Yes Fig. 5	0	1 / 0.5	15	10				
Masonary Grout	Yes Fig. 5	0	1 / 0.5	15	10				
Graded Base or Subbase	Yes Fig. 5								
Soil Aggregate Base Subbase & Surface Course	Yes Fig. 5						50		
Processed Aggregates	Yes Fig. 5		3.0 / 1.0	18	12		40	10	
Mineral Filler	Yes Fig. 5	0							<4
Fine Agg for Bit Mixtures	Yes Fig. 5			20	15				<4

the skid resistance also becomes a factor in specifications.

Specifications for Granular Sub-base

With the large amount of crushed quarry rock available in Hong Kong it is unlikely that any significant quantity of natural local sand and gravel will be used for granular sub-base. However, specifications for such material are worth noting since they are relatively simple compared with those for concrete. The main characteristic of interest as shown in Table 11 is the grading, the acceptable range of which is shown in Figure 4.

Specifications for Fill

The term "fill" covers a wide range of uses, some of which require 'higher quality' material such as sub-base for roads, while others can accommodate a 'lower quality' material as in general fill for, say, reclamation works. All of these types of fill are generally specified individually for each use. General guidelines are, however, available, *e.g.* for subbase (DEPARTMENT OF TRANSPORT, 1986) and for reclamation using dredged material (FORD, 1988). Individual specifications for fill generally concentrate on ensuring that the material is lean, hard, sound, durable, nonplastic, freedraining and capable of being effectively compacted; which usually means ensuring that the grading is within certain limits.

GRANULAR MATERIALS IN HONG KONG

A detailed description of natural sand and gravel currently in use in Hong Kong for the production of concrete is given in EARLE and EVANS (1988), CARBRAY (1988), BRAND *et al.* (1984) and EARLE (1990). Locally derived sand and gravel is not used nowadays for the production of concrete as these materials are freely imported from the Peoples Republic of China for this purpose. These imports are usually poorly described, ill-specified and merely classified to include "river sand" and "marine sand". The former is mostly used as fine aggregate for concrete and the later for mortars and plasters.

An increasing amount of marine won local sand and gravel is now, however, being used for fill material either in specialised uses, or the majority of it as general fill for reclamations. This latter use has been given considerable impetus by the recent announcement of the massive new Hong Kong Port and Airport Development Strategy plans.

The construction of major reclamations over the next 15 years will require the supply of approximately 350 million m^3 of marine granular fill material. In addition, it will be necessary to dispose of a similar quantity of marine mud that will be dredged both from the reclamation sites and as overburden from marine borrow areas. The largest demand for fill is likely to occur during the three years from 1992 to 1994. Apart from the New Airport, the Port Peninsula and the Castle Peak developments, the designers and planners of most of the Territory's several other major reclamations have expressed a strong preference for using marine won granular fill. To meet these requirements it will be necessary to develop a number of major marine borrow areas.

Present indications from offshore site investigations suggest that there is likely to be sufficient marine materials of a range of types to meet the estimated demand for major reclamations over the next 15 to 20 years. However, detailed site investigation information is available for only a few of the marine borrow areas. The other potential borrow areas have so far only been covered by reconnaissance level investigation carried out by the Geotechnical Control Office (GCO) of the Hong Kong Government. Although further investigations are now being carried out by the GCO and others, it will still be necessary to prove most of the potential borrow areas to a level at which firm exploitation allocations and dredging plans can be made. This will involve a major offshore site investigation which will provide sufficient data not only for fill management purposes but also for dredging contractors tendering for future major projects. A major aspect of this site investigation work will of course involve the accurate logging and description of the potential source materials, their thorough testing and then an assessment of their properties and capabilities to both perform as, and satisfy the specifications for, a range of construction materials.

Local Hong Kong Resources

In order to meet the future huge demand for sand and gravel for use in a wide range of situations and projects a major offshore exploration programme has been mounted to cover systematically the territorial waters of Hong Kong. The first two reconnaissance level phases of this work are complete and the results are fully described by CHOOT (1988) and THORLEY *et al.* (1990). A second stage detailed investigation which will es-

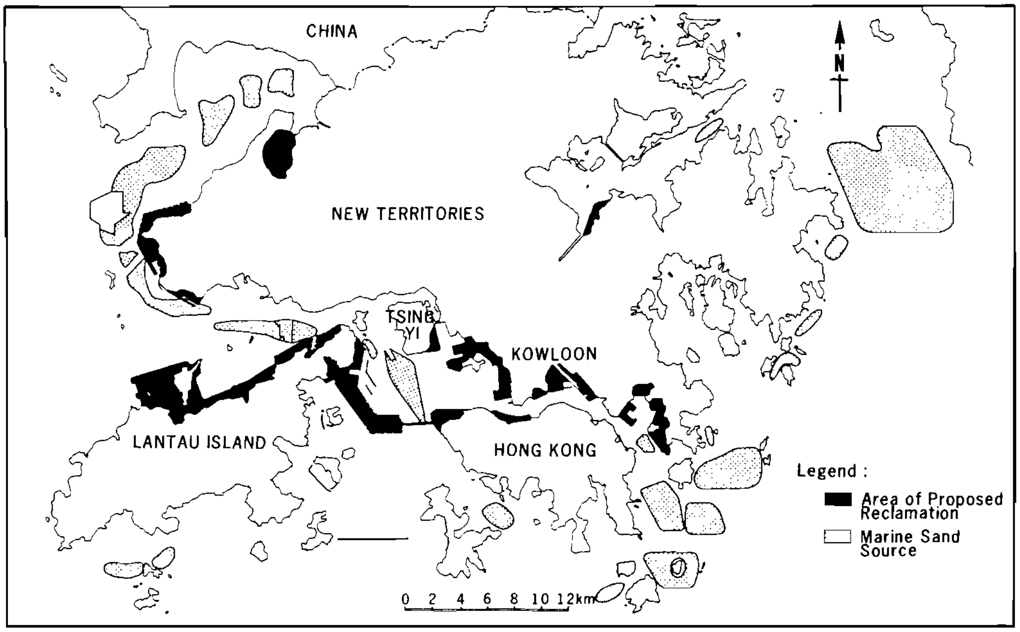

Figure 6. Location of Hong Kong's main offshore sand resources (after WHITESIDE, 1991).

tablish the extent of the economic reserves is now underway (WHITESIDE, 1991); Figure 6 shows the location of the thus far located offshore sand resources.

An understanding of the geology of the seabed has been concurrently progressing, mainly through the work of the Hong Kong Geological Survey, whose work in this field is reported on in publications by STRANGE and SHAW (1986), LANGFORD *et al.* (1989), and JAMES and SHAW (1990).

In summary Hong Kong's sand and gravel deposits can be divided into three main types:

(1) **Beaches.** The exposed present day beaches are the most obvious examples, but recent findings in the offshore sand search has indicated that substantial volumes of buried beach deposits exist (WHITESIDE, 1988). Present day beaches are not likely to provide sources of exploitable sand as they are fully needed for recreational purposes. They are in any case likely to need replenishing rather than to be available as a sand and gravel resource. The beach sands are characteristically subrounded, medium grained and low in fines, quartz rich and slightly shelly, the shells being, however, usually small fragments.

(2) **Marine Seafloor Sands.** These have recently been studied in some detail (EVANS, 1988), JAMES and SHAW (1990) as part of the offshore fill search. They tend to occur in close association with or under relatively thin cover of marine mud, and to be in the form of very low banks. They are characteristically muddy, often to the extent of greater than 35% fines (<0.06 mm), their sand fraction is generally of fine to medium grain size, and there can be substantial quantities of shells, many of which will be unbroken. The shell content of individual sieve sizes tends to increase with size.

(3) **Alluvial Sands.** These paleo-braided river channel, valley floor deposits now covered by Holocene muds have for a long time been presumed to exist, but recently their extensive occurrence has been proved by the offshore fill search. Being the buried deposits of ancient river channels which eroded weathering granite terrains they tend to occur in systematic but irregular lenticular deposits. The deposits are characteristically free of fines, brown in colour and dominantly comprising medium to coarse grained subangular quartz but with significant lithic clasts.

Possible Uses

In the Hong Kong construction industry the main potential uses identified so far for the marine and alluvial sands described above are:

(1) Aggregate for concrete, both structural and as road pavement
(2) Fine sand for mortars and plasters
(3) General fill material for use in reclamations
(4) Specialised fill for filters, sub-base, *etc.*

It is important to remember, however, that in the sand and gravel industry it is normal for the raw material to be washed and screened, and therefore in assessing potential uses for materials the presence of undesirable gradings, size fractions or certain chemical contaminants, *e.g.* chlorides, are not necessarily a problem since they can be adjusted in processing. This type of processing does, however, increase the cost and so will probably be restricted to uses where higher unit costs for a particular material are acceptable.

Assessment of the Tsing Yi Alluvial Sand Deposit

As an example of the type of assessment that is required for each sand deposit discovered the following paragraphs briefly describe the setting, sampling, testing and evaluation of the alluvial sands that have been located south of the island of Tsing Yi in Hong Kong harbour.

The general position of the seabed sand deposit may be located on Figure 6 as lying south of Tsing Yi island and immediately northwest of Hong Kong island.

Greater detail of the location is given in Figure 7 which also shows the exploratory seismic lines run as well as the deep marine boreholes and shallow vibrocores sunk. The typical geology of the deposit is depicted in Figures 8 and 9 which show the proven cross-sections numbered 3-3 and 4-4. The irregular fresh and more planar weathered upper bedrock surfaces are overlain by a clayey alluvium which in turn is overlain by a subaerially river laid granular alluvium spread. Onset of marine inundation from the south then gave rise to disconnected intertidal deposits containing organic material. Reworking of the upper surface of the alluvial sands is thought to have then given rise to layer of silty marine sands in places. The Holocene transgression then reached its peak and the southern end of the Hong Kong valley network was flooded by the sea, giving rise to an extensive blanket of modern marine mud layers.

In order to assess the potential and general usefulness of the buried alluvial sands as a source of granular fill or even as a source of concrete fine aggregate, a sampling and laboratory testing programme was conducted. The alluvial sand samples tested, the range of testing scheduled, and the test results are all shown in Table 13. Reference is made to Figure 7 for the location of the holes from which the samples were taken. Comparison of the test results for the alluvial sands with the values specified for various uses of sands as presented in Tables 11 and 12 give rise to the following comments and conclusions.

With respect to gradings, Figure 10 shows that the alluvial sand materials fall almost entirely within the Sand (S) and Gravelly Sand (S-F) fields of Figure 2, indeed with respect to the more definitive fields of Figure 3 the sands relate primarily to those defined as SAND, Gravelly SAND, or Very Gravelly SAND. The rather low silt (−150 μm) contents are an advantage and the grading thus leads to the indication that the materials would fall within the specifications for mortars, masonry grout and concrete or bituminous fine aggregates. They would also of course come within the very general requirements for granular fill.

The negligible shell content is a useful asset even although there is in fact no requirement on maximum shell content for fine concrete aggregates in the British Standards. These visually determined shell content values are verified up by the very low acid soluble percentage values on chemical testing.

A maximum water absorption of 2–3% is implied in the British Standards for concrete aggregates and again the average value of under 1% for the alluvial sands is within specification. Similarly the absence of clay lumps and light particles is encouragement that the materials would pass the ASTM concrete aggregate, mortar and grout specifications.

Concerning soundness, the alluvial sands, being primarily quartz grains, tested well against loss on treatment with $MgSO_4$. Indeed the average value of about 5% loss is well within the American Standards specified value of 15% loss for fine aggregates, mortars and grouts.

The organic matter content of the sand tested generally at 0.1% by mass which is also likely to be acceptable to both the British and American Standards.

With respect to the chemical tests the very low values of chloride ion content of the samples is

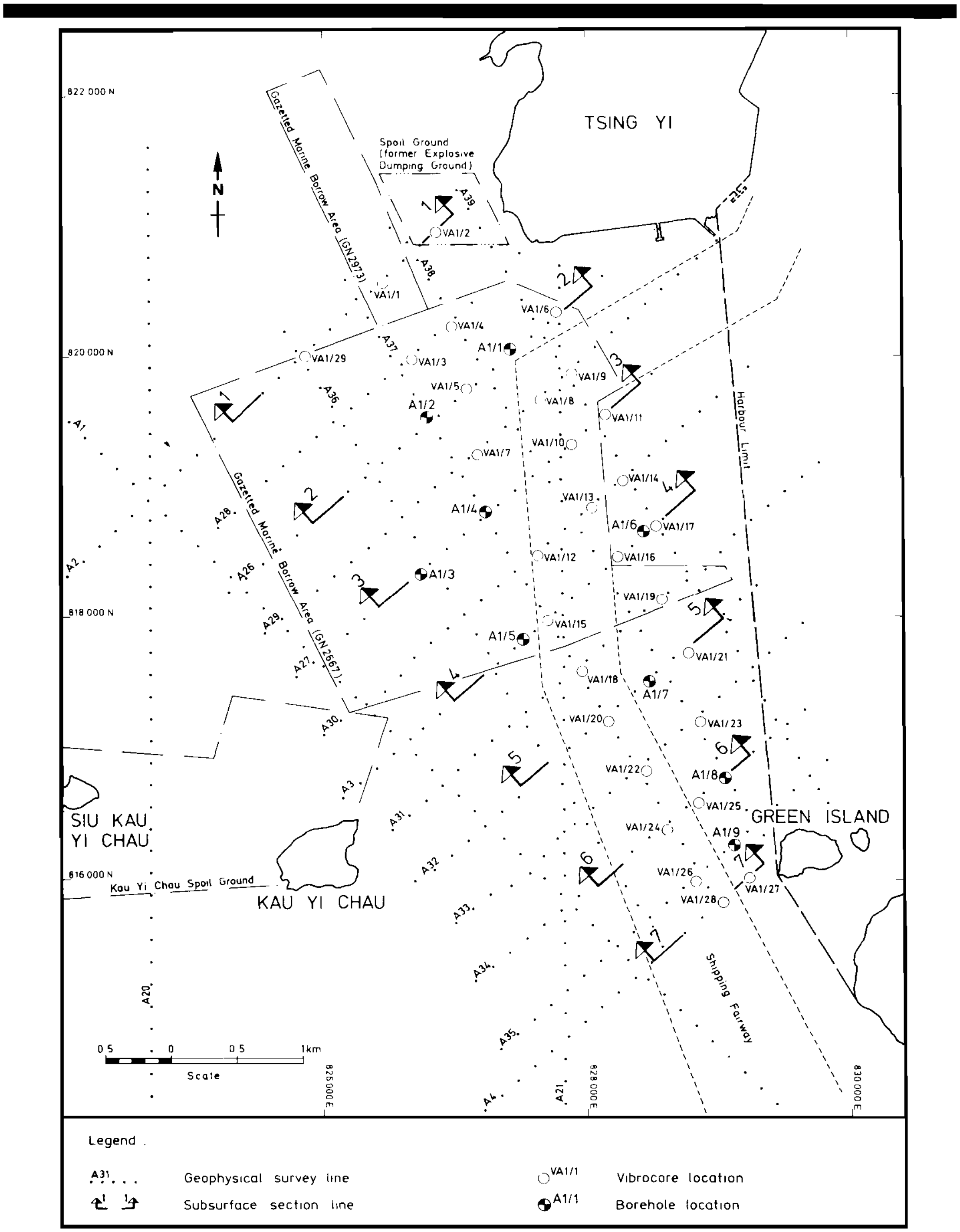

Figure 7. Target source area south of Tsing Yi (after CHOOT, 1988).

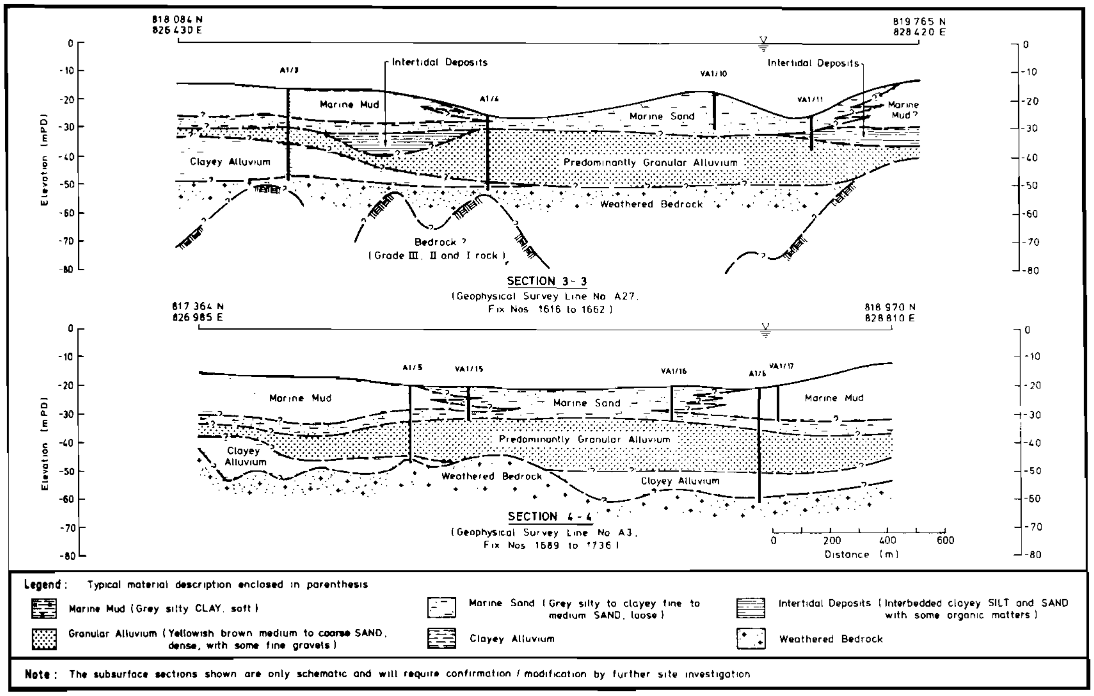

Figure 8. Subsurface sections 3-3 and 4-4 from Tsing Yi target source area (after Choot, 1988).

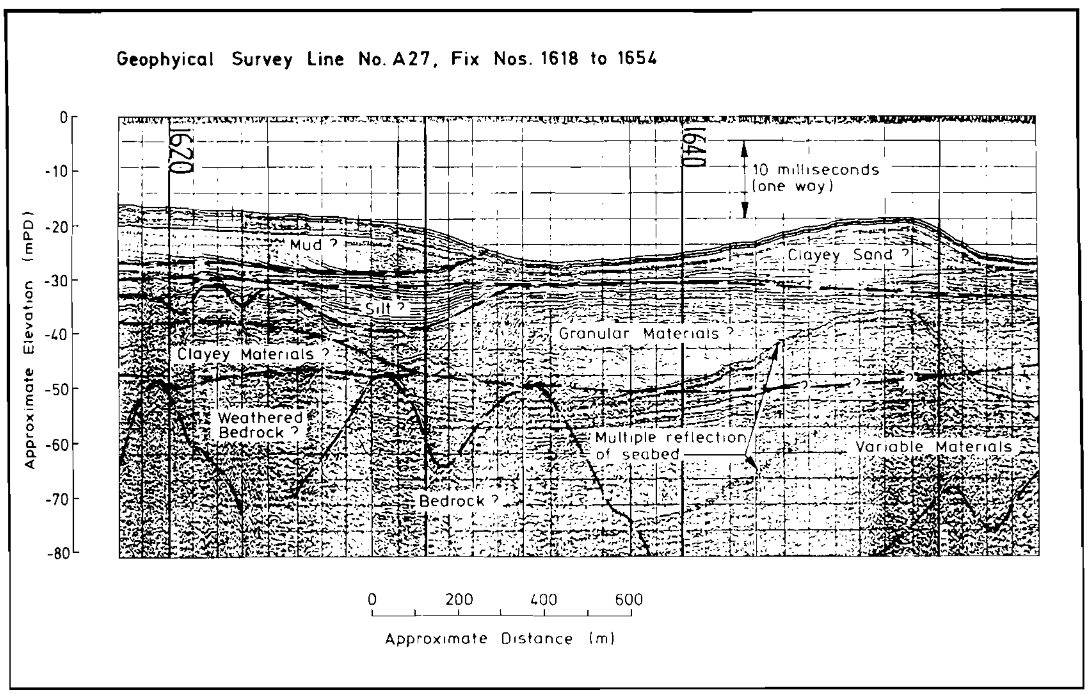

Figure 9. Interpreted seismic record along section 3-3 (after Choot, 1988).

Table 13. *Laboratory test results on samples of Tsing Yi alluvial sands.*

Borehole No.	Depth (m)	pH	Sulphate (as SO_3) % by mass	Chloride (as Cl^-) % by mass	Organic Matter % by mass	Acids Soluble Material % by mass	Dissolved Silica Content Sc (mmol/L)	Reduction in Alkalinity Rc (mmol/L)	Mg SO_4 Soundness % loss	Gradings % 150 μm & 2.36 mm silt/sand/gravel	Relative Density			Water Absorption %	Shell Content %
											Oven Dried	Saturated Surface Dried	Apparent		
A 1/1	7.0–7.45	8.3	0.11	6.7	0.3		0.0 1.0 0.7	27.7 40.2 42.8	3.36 (8.00–8.45)	<1/60/40			2.65		
A 1/1	10.50–10.95	8.3	0.02	3.6	0.1	1.16	9.0 5.0 9.3	15.1 30.2 25.2	0.76 (11.0–11.45)	<1/70/30		2.67		0.9	<0.01
A 1/1	16.00–16.45	8.0	0.02	4.2	0.1	0.85	5.0 8.7 5.7	27.7 22.6 22.6	4.61	<1/82/18		2.67		0.7	<0.01
A 1/1	21.00–21.45	7.8	0.01	1.3	0.1		15.7 13.0 12.7	10.1 7.6 15.1	3.87	0/71/29			2.65		
A 1/1	27.00–28.00	6.8	0.06	7.2	0.1		6.0 12.3 13.7	15.1 25.2 15.1	6.12	<2/92/6			2.64		
A 1/4	5.00–5.95	7.9	0.07	8.1	0.1		10.7 12.7 12.0	10.1 17.6 12.6	4.90	<4/90/6					
A 1/4	10.50–10.95	7.6	0.02	8.2	0.1	0.92	11.7 11.0 9.7	22.6 20.1 22.6	8.30 (10.00–10.45)	<1/100/0		2.65		0.6	
A 1/4	14.50–14.95	6.4	0.07	9.1	0.1	2.34	12.3 10.3 3.0	30.2 22.6 30.2		<2/92/6	2.59	2.61	2.64	0.8	<0.01
A 1/4	19.00–19.45	4.6	0.10	7.9	0.1	1.20	15.7 13.3 17.3	20.1 17.6 15.1		<2/93/5	2.58	2.61	2.67	1.2	<0.01
A 1/5B	12.00–12.45	8.0	0.10	8.2	0.2		14.3 11.7 16.0	30.2 25.2 17.6	8.86	<17/76/7					
A 1/5B	15.00–15.45	7.8	0.04	8.7	0.1	1.21	12.3 4.7 12.7	35.2 15.1 15.1		<8/89/3	2.56	2.60	2.66	1.5	

Table 13. *Continued.*

Borehole No.	Depth (m)	pH	Sulphate (as SO_3) % by mass	Chloride (as Cl^-) % by mass	Organic Matter % by mass	Acids Soluble Material % by mass	Dissolved Silica Content Sc (mmol/L)	Reduction in Alkalinity Rc (mmol/L)	Mg SO_4 Soundness % loss	Gradings % 150 μm & 2.36 mm silt/sand/gravel	Relative Density: Oven Dried	Relative Density: Saturated Surface Dried	Relative Density: Apparent	Water Absorption %	Shell Content %
A 1/5B	17.50–17.95	7.0	0.05	8.1	0.1	3.15	17.3 9.3 16.0	25.2 17.6 25.2		<8/85/7	2.61	2.63	2.65	0.4	<0.01
A 1/5B	23.00–23.45	7.0	0.03	4.4	0.1	1.00	14.7 13.7 14.7	10.1 7.6 17.6	5.81	<2/84/14		2.64		0.4	<0.01
A 1/6	15.50–16.00	8.2	0.06	8.6	0.1	1.03	10.7 9.7 8.7	25.2 22.6 25.5		<2/90/8	2.56	2.59	2.66	1.5	<0.01
A 1/6	20.00–20.45	8.3	0.04	6.8	0.2	1.17	10.7 13.3 9.7	23.0 20.4 20.4	9.63	<1/87/12		2.67		0.6	<0.01
A 1/6	23.0—23.45	8.0	0.02	6.8	0.1		10.0 10.7 12.3	10.2 15.3 20.4		<1/67/32	2.60	2.62	2.66	0.9	
A 1/7	22.50–22.95	7.8	0.06	6.5	0.1		13.0 12.7 14.0	2.5 10.1 7.6		<1/79/20	2.61	2.63	2.66	0.7	
A 1/7	27.50–27.95	7.4	0.05	7.1	0.1		12.0 9.0 6.3	10.1 12.6 15.1	6.98	<1/84/15					
A 1/8	15.50–15.95	7.2	0.09	6.0	0.3		9.0 0.0 7.7	27.7 20.1 25.2		<7/57/36	2.59	2.62	2.67	1.2	
A 1/8	19.50–19.95	7.9	0.04	10.4	0.1		5.3 8.0 9.7	22.6 22.6 20.1	4.77	<2/88/10					
A 1/8	22.50–22.95	7.7	0.01	6.7	0.1		8.0 8.3 5.7	27.7 22.6 35.2		<2/88/10	2.62	2.63	2.65	0.4	
Test Method			BS 1377: 1975	BS 812: 117: 1988	BS 1377: 1975	BS 812: 119 1975	ASTM C289		ASTM C88-56T 4C	BS 1377 & BS 812: 1975	BS 812 Pt2: 1975				BS 812 Pt 106: 1985

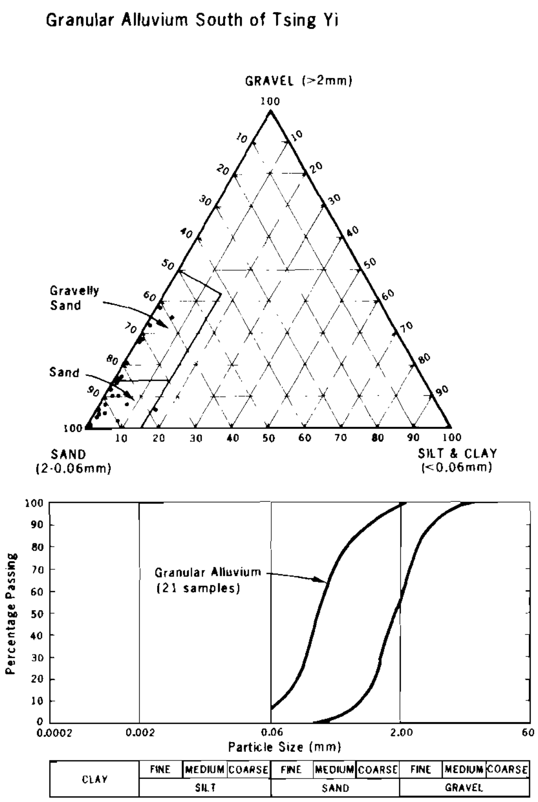

Figure 10. Particle size distributions of granular alluvial from Tsing Yi.

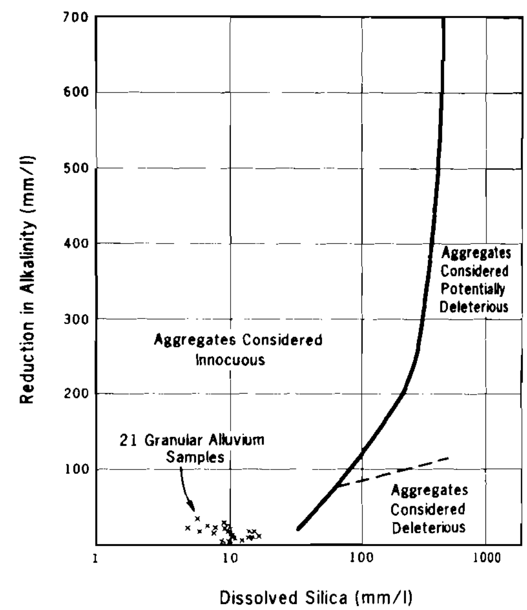

Figure 11. Potential reactivity of granular alluvial sands from Tsing Yi.

clearly also going to be acceptable/conducive to meeting the overall specified <4% by mass of cement specification.

The standard (chemical) test to ascertain the likely potential reactivity in concrete of the sands samples, *i.e.* ASTM C289, results in data which when plotted on the relevant graph demonstrates the material to be considered clearly innocuous. This plot of results is presented as Figure 11. The innocuous category into which the sands fall is not surprising and is supported by petrographic examination of the constituent sand particles which reveals that an estimated 90–95% of the grains are natural quartz of an unstrained, normal or low temperature stable type.

In conclusion the limited alluvial sand deposits south of Tsing Yi are assessed to be suitable for use as fine concrete or bituminous aggregate, masonry mortar, masonry grout and other less rigorously specified materials such as granular fill for reclamation and possibly subbase.

CONCLUSIONS AND RECOMMENDATIONS

There are large deposits of different types of sand and gravel in Hong Kong, essentially in the offshore area. These deposits may be suitable for a variety of uses and so their characteristics should be determined in order to assess their potential for selected uses.

Before and as part of making such assessments, however, it is important that the borehole samples of the materials constituting each deposit are fully and systematically described using a system such as that described.

The suitability of the deposit for particular uses is then determined on the basis of the description and the laboratory test results by the fact that the material satisfies a specification drawn up by the end-user. Although a number of different classification schemes have been proposed around the world in order to give an indication of the general suitability of sand and gravel for various purposes, there is always the need to compare the material's characteristics with a particular specification. There would, therefore, appear to be no great merit in a material classification of Hong Kong's deposits. Rather, it is proposed that once the deposits have been identified as specific geological deposits, typical, or "Type Samples" be checked for compliance with a range of specifications for a number of different potential uses. In this way the extent of different geological deposits can be determined and, as a clearly separate exercise the resources available for specific uses can be determined. An example of what could be "Type Samples" of the Alluvial Sand deposit at the Tsing Yi location have been tested for compliance with some important specifications and the results are detailed above. These limited tests clearly indicate that the alluvial sand and gravel could be suitable for fine aggregate for structural concrete, bituminous road pavement, as general fill, and for masonry mortars and grouts.

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□ RÉSUMÉ □

On discute ici les grandes lignes des diverses méthodes utilisées pour décrire les sables et graviers destinés à la construction. Un travail réalisé à Hong Kong développe un schéma qui peut être appliqué à l'évaluation des dépôts de sables et graviers littoraux et au large dans n'importe quel pays. Le besoin d'un tel schéma est devenu apparent par les récentes positions du gouvernement de Hong Kong pour définir le sable dans sa "description générale unifiée", et avec les nouvelles découvertes d'importantes ressources en granulats de haute qualité pour la construction, dans les eaux de Hong Kong. La conclusion qui s'ensuit et un aspect clé du schéma directeur qui en résulte est que la description détaillée de tous les échantillons, échantillons-types sélectionnés issus de différents types de dépôts, devrait être testée conformément aux normes/spécifications particulières. Il est affirmé qu'on peut compiler un inventaire à partir de ces dépôts géologiques qui pourrait fournir de manière satisfaisante des ressources dans des buts particuliers. L'autre approche qui implique une classification détaillée préalable n'est pas retenue.—*Catherine Bousquet-Bressolier, Géomorphologie EPHE, Montrouge, France.*