British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

DFID
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RIVER MINING:

AGGREGATE PRODUCTION AND SUPPLY IN DEVELOPING COUNTRIES

Economic Minerals and Geochemical Baseline Programme
British Geological Survey Commissioned Report CR/03/029N

UNIVERSITY of EXETER
CAMBORNE SCHOOL OF MINES

BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT CR/03/029N

Aggregate production and supply in developing countries with particular reference to Jamaica

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Key words

Aggregates, sand and gravel, limestone, Jamaica.

Front cover

Aggregate production from river mining, Jamaica Pre-mix processing plant, Yallahs River, St. Thomas, Jamaica.

Bibliographical reference

SCOTT, PW; EYRE, JM; HARRISON, DJ; STEADMAN, EJ.. 2003. Aggregate production and supply in developing countries with particular reference to Jamaica. *British Geological Survey Commissioned Report*, CR/03/029N. 55pp.

ISBN 0 85272 457 8

Keyworth, Nottingham British Geological Survey 2003

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Preface

Throughout the developing world river sand and gravel is widely exploited as aggregate for construction. Aggregate is often mined directly from the river channel as well as from floodplain and adjacent river terrace deposits. Depending on the geological setting, in-stream mining can create serious environmental impacts, particularly if the river being mined is erosional. The impacts of such mining on farmland, river stability, flood risk, road and bridge structures and ecology are typically severe. The environmental degradation may make it difficult to provide for the basic needs (water, food, fuelwood, communications) of communities naturally located in the river valleys.

Despite the importance of this extractive industry in most developing countries, the details of its economic and environmental geology are not fully understood and therefore do not adequately inform existing regulatory strategies. The main problem is therefore a need to strengthen the general approach to planning and managing these resources. Compounding the problem is the upsurge of illegal extractions along many river systems. There is therefore a need to foster public awareness and community stewardship of the resource.

The project 'Effective Development of River Mining' aims to provide effective mechanisms for the control of sand and gravel mining operations in order to protect local communities, to reduce environmental degradation and to facilitate long-term rational and sustainable use of the natural resource base. This project (Project R7814) has been funded by the UK's Department for International Development (DFID) as part of their Knowledge and Research (KAR) programme. This programme constitutes a key element in the UK's provision of aid and assistance to less developed nations. The project started in October 2000 and terminates late in 2004.

Specific objectives of the project include:

- Resource exploration and resource mapping at the project's field study sites (Rio Minho and Yallahs rivers in Jamaica)
- Analysis of technical and economic issues in aggregate mining, particularly river mining
- Determination and evaluation of the environmental impacts of river mining
- Evaluation of social/community issues in the context of river mining
- Investigation of alternative land and marine aggregate resources
- Review of the regulatory and management framework dealing with river mining; establishment of guidelines for managing these resources and development of a code of practice for sustainable sand and gravel mining.

The 'Effective Development of River Mining' project is multidisciplinary, involving a team of UK specialists. It has been led by a team at the British Geological Survey comprising David Harrison, Andrew Bloodworth, Ellie Steadman, Steven Mathers and Andrew Farrant. The other UK-based collaborators were Professor Peter Scott and John Eyre from the Camborne School of Mines (University of Exeter), Dr Magnus Macfarlane and Dr Paul Mitchell from the Corporate Citizenship Unit at the University of Warwick, Steven Fidgett from Alliance Environment and Planning Ltd and Dr Jason Weeks from WRc-NSF Ltd. The research project is generic and applicable to developing countries worldwide, but field studies of selected river systems have been carried out in Jamaica and review studies have been undertaken in Costa Rica. Key participants in these countries have included Carlton Baxter, Coy Roache and Larry Henry (Mines and Geology Division, Ministry of Land and Environment, Jamaica) and Fernando Alvarado (Instituto Costariccense de Electricidad, Costa Rica).

The authors would like to thank the many organisations in Jamaica and Costa Rica who have contributed to the project. In addition to the collection of data, many individuals have freely given their time and advice and provided the local knowledge so important to the field investigations.

This report forms one of a series of technical Project Output Reports listed below:

- *Geology and sand and gravel resources of the lower Rio Minho valley and Yallahs fan-delta, Jamaica, 2003*. AR Farrant, SJ Mathers DJ Harrison, British Geological Survey.
- *Aggregate production and supply in developing countries with particular reference to Jamaica, 2003*. PW Scott, JM Eyre (Camborne School of Mines) and DJ Harrison, British Geological Survey.
- *Assessment of the ecological effects of river mining in the Rio Minho and Yallahs rivers, Jamaica, 2003.* J Weeks, WRc-NSF Ltd.
- *Scoping and assessment of the environmental and social impacts of river mining in Jamaica, 2003*. M Macfarlane and P Mitchell, Warwick Business School, University of Warwick.
- *Alternative sources of aggregates, 2003*. DJ Harrison and EJ Steadman, British Geological Survey.
- *Alluvial mining of aggregates in Costa Rica, 2003*. Fernando Alvarado Villalon (Costa Rican Institute of Electricity), DJ Harrison and EJ Steadman, British Geological Survey.
- *Planning guidelines for management of river mining, 2003*. S Fidgett, Alliance Environment and Planning Ltd.

Details of how to obtain these reports and more information about the 'Effective Development of River Mining' project can be obtained from contacting the Project Manager, David Harrison at the British Geological Survey, Keyworth, Nottingham, UK, email: djha@bgs.ac.uk

Acknowledgements

The authors acknowledge with thanks the considerable help received from the staff of the Mines and Geology Division, Ministry of Mining and Energy, Jamaica, especially Coy Roche (Commissioner of Mines), Larry Henry (Deputy Commissioner of Mines), Carlton Baxter (Head of Economic Geology) and Paul Manning (formerly Head of Industrial Minerals). Quarry owners in Jamaica are thanked for allowing visits to their quarries and plant and for providing detailed information on their operations. The following organisations in Jamaica are also thanked for useful discussion and providing information: Caribbean Cement Company Ltd, JAMPRO, Mining and Quarrying Association of Jamaica, National Works Agency, Natural Environment and Planning Agency, University of Technology (Wycliffe Graham), Jamaican Bureau of Standards, and the National Investment Bank of Jamaica.

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Summary

The technical and economic issues for aggregate production and supply in developing countries are discussed in comparison with the mature industry in developed nations. The main data come from fieldwork in Jamaica, supported by knowledge of the aggregate industry in the UK, USA, and other developing countries. The report is part of a project examining the problems created by extraction of sand and gravel from active river systems. A review of the aggregate industry in Jamaica is included.

Primary aggregates are made either from crushed rock or naturally occurring sand and gravel. Sources of crushed rock are numerous and may include many different rock types. Their availability varies considerably from country to country and is entirely dependent on the geology. In some developing countries high quality crushed rock for aggregates is not always readily available in some city areas, where demand is greatest, because suitable hard rocks do not occur nearby. The aggregate may have to be transported a considerable distance from its source to the consumer. Rocks, which may appear at first sight unsuitable raw materials for aggregates, are sometimes used and can perform adequately.

Sand and gravel are also essential sources of aggregates. In developing countries, they are exploited often from the active channels of river systems. They are easily extracted, and often require almost no processing other than size selection. They are considered a renewable resource. Their composition varies according to the strata found in the catchment area of the river.

The properties of aggregates from different sources vary considerably, but all must be fit for the purpose to which they are used. The testing of aggregates for quality, and their specification in many countries, such as the UK and USA, are defined by standards. These are often taken by developing countries for use directly or adapted to meet the local requirements.

There are two resources of aggregates in Jamaica. These are sand and gravel from alluvium found in and adjacent to the present rivers, especially the active stream channels, and limestone. Other rocks, which might appear initially to be good resources of aggregates, are either deeply weathered or remote from the major centres of population. In the future these may be considered sources of aggregates for special purposes, such as providing high skid-resistant roadstone. Limestones in Jamaica are located throughout the island, extraction being mainly from the White Limestone Supergroup in the north and west of the island. Some of the limestone is dolomitised. Resources of sand and gravel are located mainly in rivers flowing to the south coast, principally the Rio Minho and Yallahs River. Annual aggregate production is around 4 million tonnes, made up approximately half from limestone and half from river sand and gravel. Over the long term (25 years) there appears to have been some substitution of river sand and gravel aggregate by limestone, especially in the west and north of Jamaica. There is additional production of marl, which is a very soft limestone, used unprocessed for fill purposes. There is also some illegal sand and gravel extraction.

The extraction of sand and gravel in Jamaica is directly from the active stream channel. Extraction from riverbanks, flood plains and older fluvial terrace deposits does not usually occur. The processing varies from a simple screen on an A-shaped frame to remove oversize particles, to processing plants, in which coarse gravel is processed by crushing, washing and screening to make a range of products. Limestone is extracted by ripping, blasting not commonly being used. Limestone is processed by crushing, washing and screening to produce a range of products. Concrete block manufacturing units are often located at the site of limestone production. Marl is extracted and used directly without any processing.

The prices of aggregates in Jamaica, excluding transport costs, are similar throughout the country. Sand is a premium product, because of its relative scarcity, much of the material in the

active stream channels being too coarse. Further sand is made by crushing gravel. It is made also from limestone by crushing, and is known as stone dust. Markets for sand and gravel and limestone aggregates do not overlap, because of the geographic separation of their source regions. There is little competition and almost no substitution.

The total resources of sand and gravel and limestone are effectively infinite in Jamaica. Permission to extract is given by the Ministry of Mining and Energy through licences. These are awarded for 1-2 years only, but renewal appears to be virtually automatic. Quarry Zones are designated but many quarries fall outside these areas.

With few exceptions the mobile and fixed plant used in aggregate production in Jamaica are very old, breakdowns are frequent with consequent loss of production. Considerable overmanning and spare mobile plant capacity is one strategy used to overcome these problems. Finance is available through investment banks for renewal of plant, but the provision of licences for only a short period of time is a disincentive to refinance and re-equip.

Production costs for aggregates in Jamaica are very low and a small-scale sand and gravel unit with simple processing appears to be very profitable. Where the value of a fixed plant has been amortised many years ago, as is the situation at many sand and gravel and limestone extraction sites, production costs appear to enable a significant profit to be made even allowing for a high cost of maintenance. Successful development of an aggregate operation which requires external finance for a new processing plant would need a sustained market over a long period of time. If blasting is required to extract all of a limestone aggregate, accompanied by repayments of capital on new plant, than it is unlikely that a profit could be achieved at present sale prices.

Any positive move away from river sand and gravel production in Jamaica would have severe consequences for the provision of aggregates in a major part of the island including Kingston. Replacement of production of sand and gravel from the active river channels with that from adjacent higher level terraces would increase production costs considerably, because of the presence of an overburden, an increase in the amounts of fines to be removed, and the need to drill the deposits to prove the existence of reserves.

Some general conclusions on the technical and economic issues for aggregate production in developing countries can be made. These include: the need for producers to adopt standards for the quality of their aggregates; the issuing of long term licences and cheap finance to enable aggregate producers to modernise and be efficient; the need to ensure that appropriate legislation is in place to prevent illegal aggregate mining, and the overloading of delivery trucks. Many construction projects in developing countries, especially those using international finance, source the aggregates from outside the existing producers in the country. This situation is likely to change only if the indigenous aggregate producers have an efficient, well-managed operation with reliable plant which produces aggregates to a consistent quality.

1 Introduction

Aggregates are basic raw materials required for all construction activities, and an adequate and sustainable supply is essential for every country. The uses of aggregates are numerous and include road-building, rail ballast, mass concrete for foundations or major structures, concrete blocks, steel reinforced beams, flooring and walls, mortar, plaster and filter media for sewage and other water treatment. Aggregates are invariably the largest volume of minerals produced in every developed country, with numerous large sites of extraction located near to centres of population, where the demand is greatest. A range of aggregate products are made to meet the different uses, each one designed to meet the specifications required by the consumer, commonly defined by national quality parameters (e.g. British Standards in the United Kingdom, ASTM in the United States; see McCarl, 1994; Herrick, 1994; Smith and Collis, 2001). In developing countries, the industry is usually less regulated and poorly organised.

1.1 AGGREGATES IN DEVELOPED COUNTRIES

The aggregate industry is mature in a developed country. Usually, it is dominated by a few large companies with regional or countrywide activities, although there may remain some small producers owning only one or a few sites of extraction at most. Companies often cooperate in trade associations (e.g. Quarry Products Association, and British Aggregates Association in the United Kingdom), adhere to formal or informal codes of practice, and are extremely regulated with respect to the location and development of sites of extraction, environmental, safety and product quality issues (e.g. Herrick, 1994; Langer, 2001, 2002; Arbogast, 2002). In some countries substantial state-funded research has been undertaken to assess the availability, quality and durability of indigenous sources of aggregates (e.g. Industrial Minerals Assessment Unit Reports of the Institute of Geological Sciences / British Geological Survey, see Scott, 1993; Smith and Collis, 2001). A major amount of aggregate is consumed by public (government) financed projects (e.g. McCarl, 1994; Langer, 2002). Demand for aggregates closely follows the overall economic performance of a region or country, and is affected by the world's overall economic climate. In recent years there has been a trend towards fewer but larger sites of aggregate extraction in developed countries, and consolidation of ownership, with aggregate producers merging or being taken over by international mining or construction materials corporations. There is also a trend towards maximising the value of a resource by extended processing to upgrade inferior material and recycling of aggregate products, such as concrete. Governments encourage these practices by applying selective taxation.

1.2 AGGREGATES IN DEVELOPING COUNTRIES

In developing countries, production is often on a small scale, with many small sites of extraction in a single area operated by different companies or informal groups. The granting of permissions to extract is less formal, or even non-existent, with illegal mining commonplace. The supply of aggregates is less consistent, and the quality of products may be extremely variable. Aggregates from established quarries satisfy the demand for domestic or small commercial buildings, road repairs and other small-scale infrastructure developments; but, before major construction projects can be undertaken, whether government, private or financed by overseas aid, a nearby, reliable supply of aggregate with specified properties has to be identified. Often the requirements cannot be met from existing producers. Thus, a new source has to be identified. Plant to process the material to create a suitable product may need to be brought in and its cost included in the overall budget for the construction project. Once the project is completed the extraction site and associated plant are often abandoned without rehabilitation.

1.3 TERMS OF REFERENCE AND STRUCTURE OF REPORT

This report discusses the technical and economic issues relevant to the supply of aggregates in developing countries. It focuses on Jamaica for illustrating current practice, as this is the subject of a wider study on the effects of mining sand and gravel from river systems. The authors have undertaken fieldwork, examining both the sand and gravel, and crushed rock extractive industry in Jamaica, and interviewed many of the aggregate producers. Some comparison is made with other developing countries, using the authors' knowledge acquired during other fieldwork activities. A summary of the sources and composition of crushed rock and sand and gravel in Jamaica is included, as technical and economic parameters have to be related to the available material. Some comparisons are drawn with the aggregate industries in the United Kingdom and the United States as examples of practice in developed countries. Arising from the knowledge gained of the aggregate industry in Jamaica, some general conclusions affecting the development of aggregate production in developing countries are made. Specific conclusions are made regarding the potential for replacement of sand and gravel extraction from river systems in Jamaica with crushed rock aggregates. Place names and major geographical features of Jamaica, referred to in the text, are shown in Figure 1.

Figure 1 Map of Jamaica showing major geographical features

2 Sources and composition of aggregates

Primary aggregates are made either from crushed hard rock or naturally occurring sand and gravel. Sources of hard rock are numerous and commonly include igneous rocks, such as basalt, dolerite and granite, some metamorphic rocks, such as hornfels, gneiss and quartzite, and sedimentary rocks including sandstone, limestone and dolomite. Igneous and metamorphic rocks and many sandstones often are stronger than limestone and dolomite, and are required for arduous applications, such as road surfacing, where strict quality parameters for skid resistance should apply. For general construction purposes, including mass concrete and blocks, limestone and dolomite are extensively used when they are available. They contain softer minerals, are easier to extract, give less wear to the crushing equipment used in their size reduction, and hence are cheaper to produce. Limestone is a very important aggregate; it has many industrial uses and a limestone extractive operation in an industrialised country often supplies stone for cement, chemical and other purposes as well as providing aggregate for construction (Scott and Dunham, 1984; Harben and Kuzvart, 1996).

The availability of hard rock varies from place to place within a country, obviously being dependent on the geological history and the strata at the land's surface. Few countries are totally devoid of rocks suitable for crushing to make aggregates. However, sometimes the resource may be far from a centre of population, especially for cities situated on large coastal plains or deltas (e.g. Miami and New Orleans, USA; Dacca, Bangladesh) and sometimes elsewhere (e.g. an important source of crushed rock to supply the large city of Lahore, Pakistan is situated over 150km away) (Figure 2). In some parts of the world, where the usual sources of crushed rock are absent, another rock may be extracted and crushed for use, because it is the most suitable material available locally, and it serves the purpose. For example, in the remote parts of northern Oklahoma, USA, local roads are built and sometimes surfaced with gypsum or anhydrite (Sharpe and Schroeder, 1999). In southern Trinidad, where the rocks at the surface are a series of fine sands and clays, a naturally burnt clay called porcellanite, arising from the spontaneous combustion of oil reservoir gases, is an important crushed rock aggregate (Mootoo and Suite, 1992; Scott and Jackson, 1994; 1999) (Figure 3). It resembles, and has the same composition, as crushed red bricks. Sand and gravel are also essential sources of aggregates. Gravel is used as an alternative to crushed rock. Sand is a source of fine grained aggregate, supplemented by sand-sized fines made during crushing hard rocks or gravel. Sand and gravel are sediments found mainly in geologically recent deposits, occurring most commonly in the stream channels of active, or historically active, river systems. River stream channels provide a major source of sand and gravel worldwide (Figure 4). They often form a renewable source of sand and gravel, as there is replenishment each time the river floods, bringing down a new load of sediment. However, problems arise from increased erosion downstream of workings where sand and gravel is extracted, and the ecosystem of the river can be altered.

Sand and gravel resources also are found within sediments deposited as a result of glacial action in the Quaternary Period (2 million to 10,000 years ago), especially those deposited by rivers beneath and in front of a glacier. Once the glacier has retreated, deposits of sand and gravel, which accumulated beneath it and in front of its maximum extent, remain and other deposits form in the emerging river systems which become choked with a supply of abundant sediment. Such glacial and fluvioglacial deposits are important sources of sand and gravel in northern Europe and northern North America (Figure 5).

The composition of sand and gravel varies considerably depending on the source rocks which supplied the sediment. Sometimes gravel is quite homogeneous, the major component being a single rock, such as quartzite, which is very resistant to weathering. Flint, for example, which is also made up of quartz (Scott 1993) and is a residue resulting from the erosion of a soft limestone known as chalk, is almost the sole component of gravel in southern and eastern

England. Unless the source of the sand is unusual, quartz grains usually make up the dominant sand component in a sand and gravel deposit, although feldspar, mica and some dense, dark coloured minerals, such as iron and titanium oxides sometimes may be present in significant amounts. Gravel may also be very heterogeneous in composition and contain a wide range of rocks of different compositions. This arises where the river or glacial system penetrates a variety of different rocks and physical erosion of the bedrock is more rapid than chemical weathering processes. The latter causes the more unstable rocks to breakdown, and be largely removed by dissolution and as clay. Sand and gravel resulting from repeated cycles of erosion and re-deposition over geological time are more likely to have a more simple composition, with rocks made largely of quartz and quartz grains dominating in the gravel and sand respectively.

Gravel of heterogeneous composition occurs in many tropical and sub-tropical countries with a highly variable topography, such as Jamaica, where short rivers have a rapidly descending profile from a mountainous area to a flat plain (Figure 6) or the sea. The river may have a highly variable rate of waterflow. The gravel is a mixture of the rock types present in the mountainous area, and individual components may differ considerably in strength and durability. Even rocks which are quite easily weathered, and soluble ones such as gypsum and some limestones can be a component of the gravel. Soil fragments may be present and some components of the gravel may be quite friable. Heterogeneous compositions may also occur in gravels and sands found in major inland continental river systems (e.g. River Indus, Pakistan, Figure 7), where the river flow, and hence sediment transport, is seasonally affected by melting snow from a distant mountainous hinterland. Here the rock types making up the gravel are usually stronger and are likely to include a variety of mainly acid igneous and metamorphic rocks, such as granites, granodiorites and diorites, schists, gneisses, hornfels and vein quartz, with minor basalts, dolerites and gabbros, along with some indurated sandstones and greywackes. The sand component is mainly quartz grains. As would be expected, the gravel found in stream channels of rivers in small volcanic islands, such as those in the Eastern Caribbean, are made up entirely of volcanic rocks, including basalt, andesite, dacite and rhyolite. The sand is made up of smaller volcanic rock fragments and crystals of feldspar, amphibole, mica and other ferromagnesian minerals, but with only minor quartz.

Sand and gravel is sometimes exploited from coast and lake beaches. Extraction from beaches is particularly common in small volcanic (e.g. St Lucia; Osborne and Rajpaulsingh, 1997) and other islands (e.g. Scilly Isles, UK); but, also occurs elsewhere (e.g. Dungeness, UK). Such extraction is increasingly becoming unsustainable on volcanic islands as many of these places have in recent years developed extensive tourist industries, reliant on there being an amenity beach. Removal of beach sand and gravel also increases coastal erosion rates. In recent years, offshore deposits of sand and gravel have been exploited from shallow seas surrounding several countries (e.g. U.K., Netherlands, Hong Kong). Such deposits in northern Europe have an origin due to fluvial or glacial processes, becoming buried as a result of geologically recent sea level rise. Offshore sand and gravel also may be found next to rivers which emerge into a shallow sea after a rapid descent from a mountainous area (e.g. offshore Yallahs delta, Jamaica).

Figure 2 Crushed rock quarrying activities at Sargodha, Punjab, Pakistan, which is an important source of aggregate for Lahore, even though it is 150km distant.

Figure 3 Quarry in burnt clay, known as porcellanite, Trinidad, West Indies.

Figure 4 Extraction of sand and gravel from an active river stream channel, near Abbottabad, Pakistan.

Figure 5 Sand and gravel from glacial deposits, Vancouver Island, Canada.

Figure 6 Aerial view of active river stream channel deposits, South Island, New Zealand.

Figure 7 Gravel in River Indus, Attock Bridge, Punjab, Pakistan.

The proportions of sand and gravel vary considerably between different deposits. The aggregate industry overall requires gravel and sand in the ratio of approximately 3:1. An excess of sand over this ratio means generally that a deposit is not worked to its maximum economic efficiency, since some sand product will accumulate for which there may be no market. Where gravel is in excess, it can be crushed to create more sand. This is a common activity in sand and gravel processing plants, especially where the deposit is made up of a high proportion of material larger than that required for the largest-sized aggregate product (i.e. >40mm). Sand is also manufactured by extended crushing of rocks, such as limestone, sandstone or granite. When used as an aggregate in Portland cement concrete and in some other uses, sand generated by crushing has different properties compared with that made only from naturally occurring sand-sized grains.

Other sources of aggregates, used only where there is a locally available supply, include the waste created from other mining activities, crushed concrete made from the demolition of buildings, and recycled asphalt reclaimed during road construction. They are referred to as secondary or recycled aggregates. They are often considered inferior to primary aggregates, although the policy in some developed countries is towards encouraging the use of secondary and recycled raw materials (Smith and Collis, 2001. p. 251).

3 Technical requirements for aggregates

3.1 PROPERTIES

Aggregates must be fit for the purpose to which they are used. Their properties vary according to composition and origin. For most uses, strength in resistance to impact and crushing forces (known as aggregate impact value (AIV) and aggregate crushing value (ACV) respectively) is an important property, and aggregates are required to be inert chemically. Resistance to abrasion (aggregate abrasion value (AAV)) and attrition (Los Angeles Abrasion), and an ability to resist the creation of a polished surface (polished stone value (PSV)) are important parameter in some uses, such as for roadstone. Chemical requirements include resistance to attack by ions dissolved in groundwater, such as sulphates, and aggregates should not contain any organic matter and soluble salts such as chlorides and sulphates. An ability to withstand freezing and thawing is necessary when the aggregate is used in countries with a temperate or cold climate. Disruptive expansion of concrete can occur with some aggregates as a consequence of reaction with some Portland cements. This may occur when the aggregate contains certain forms of reactive silica including opal, chalcedony or volcanic glass. Aggregates containing releasable alkali metal ions present in some volcanic glasses may also react with Portland cement causing expansion and deterioration of concrete. Reactions caused by the chemical instability of the aggregate create weakness in the concrete and may cause catastrophic failure of structures. A through review of the physical and chemical properties required of an aggregate is given in Smith and Collis (2001).

3.2 PRODUCTS

Aggregates are produced to meet a specific size or size distribution either by screening a naturally unconsolidated material such as sand and gravel or by crushing and screening a hard rock. Larger gravel particles and small boulders are also crushed sometimes to create smaller sizes and more sand. Typical single sized aggregate products, made from gravel or crushed stone, are 40mm, 28mm, 24mm, 20mm, 14mm, 10mm and 6mm. These products are usually known as coarse aggregates. Smaller sizes, made from natural sand, crushed stone or occasionally a mixture of natural sand and crushed gravel, are usually known as fine aggregate (or commonly referred to as ‘sand’) and are specified by a size distribution. Several different products may be made. A graded aggregate product is sometimes made, for example one containing a suitable size distribution of particles which readily compact to give an even, hard surface on which other structures, such as a road, can be placed.

3.3 STANDARDS

The properties required of aggregates are often defined by national standards, and must meet the standards if they are to be accepted for use. The standards state either, or both, the method for testing and the specification. Separate standards also exist for describing the rock types present in the aggregate. Table 1 contains a list of some of the major standards for testing and specification of aggregates in the UK and USA. Some of the titles illustrate some of the uses of aggregates. Some of these standards are embodied in European or internationally accepted standards, and the production of aggregates in some countries is often further assured by adherence to a quality management procedure (e.g. British Standard BS EN ISO 9000; see Table 1).

British or American standards are often taken and used by developing countries in testing and specifying aggregates, the standards being used directly or used as a basis for a national standard (effectively re-badged). Often this is entirely appropriate as it is an unnecessary expense to develop completely new standards when an existing one is relevant. The quality required of the aggregate for the same product is the same irrespective of its final location (e.g. aggregates used in structural beams, mass concrete, or for sewage filtration). Major construction projects are likely to be undertaken by an international consortium of engineers and contractors, who will be familiar with international standards. Funding agencies are likely to insist on adherence to standards, so that the quality of the product can be assured.

Table 1 List of major American and British standards for testing and specifying aggregates.

American Society for Testing Materials (ASTM)	
C33-99. 1999.	Specification for concrete aggregates.
C40-97. 1997.	Testing for organic impurities in fine aggregates for concrete.
C88-90. 1990.	Test for soundness of aggregates by use of sodium sulphate or magnesium sulphate.
C131-96. 1996.	Test for resistance to abrasion of small size coarse aggregate by use of the Los Angeles machine.
C136-84. 1984.	Sieve analysis of fine and coarse aggregates.
C144-89. 1989.	Standard specification for aggregate for masonry mortar.
C227-97. 1997.	Test for potential alkali-reactivity of cement: aggregate combinations (mortar-bar method).
C289-94. 1994.	Test for potential reactivity of aggregates (chemical method).
C294-86. (Re-approved 1991).	Descriptive nomenclature of constituents of natural mineral aggregates.
C295-90. 1990.	Recommended practice for petrographic examination of aggregates for concrete.
C535-96. 1996.	Test for resistance to degradation of larger-size coarse aggregate by abrasion and impact in the Los Angeles machine.
C1260-94. 1994.	Test for potential alkali reactivity of aggregates (mortar-bar method).
C1293-95. 1995.	Test method for concrete aggregates by determination of length change of concrete due to alkali-silica reaction.
D693-98. 1998.	Standard specification for crushed aggregate for macadam pavements.
British Standards Institution	
BS594:1985.	Hot rolled asphalt for roads and other paved areas.
BS812: Parts 1 to 3: 1975.	Methods for sampling and testing of mineral aggregates, sands and fillers.
BS812: Parts 100-124.	Various dates 1994-1999. Testing aggregates.
BS882: 1992.	Specification for aggregates from natural sources for concrete.
BS1198: 1976.	Sands for internal plasters with gypsum plasters.
BS1199: 1986.	Specifications for building sands from natural sources – sands for mortars for plastering and rendering.
BS 1200: 1984.	Specifications for building sands from natural sources – sands for mortars for bricklaying.
BS1377: 1975.	Methods of test for soil for civil engineering purposes.
BS1438: 1971 (amended 1972, 1980).	Specification for media for biological percolating filters.
BS4987: 1988.	Coated macadam for roads and other paved areas.
BS5835: 1980.	Recommendations for testing of aggregates.
BS7493. 1999.	Guide to the interpretation of petrographical examinations for alkali-silica reactivity.
DD249: 1999.	Testing aggregates – method for the assessment of alkali-silica reactivity potentially-accelerated mortar-bar method.
BS EN ISO 9000, Part 1: 1994. Part 3: 1997.	Quality management and quality assurance standards.

There are many situations, however, when a standard test method or specification taken from elsewhere may not be appropriate for use in a developing country. This arises, for example, where building practices and codes are different, such as in earthquake zones compared with tectonically stable regions, and where roads are built with different designs to meet the requirements of a different climate, or level of traffic. The specifications may be over-restrictive for the use of the aggregate, the available material not passing a test, yet it may perform entirely satisfactorily under the conditions of use. In such a situation, historical data confirming the satisfactory performance of an aggregate is more important than adherence to specifications developed elsewhere. Indeed, in most developing countries, a general knowledge of the source of an aggregate of the quality required for a particular use, passed on through personal contact and historical data, is the main criteria used in its selection.

3.4 CONSTRUCTION PRACTICE

The rocks available for use as an aggregate inevitably influence construction practice in a country. For example, the absence of suitable crushed rocks and sand for concrete blocks, such as in the Netherlands and parts of the Indian sub-continent, results in fired clay bricks (or sun-baked clay bricks) being the common material for domestic construction. Other examples of how the availability of rocks suitable as an aggregate influences use have been given above. Such rocks will not meet normal specifications for use as aggregates.

4 Aggregates in Jamaica

4.1 GEOLOGY OF JAMAICA.

Jamaica is the third largest island in the Caribbean with an area of approximately 11,000km^2. Geologically (Figure 8), it is made up of a core of Cretaceous rocks in nine separate inliers, distributed across the country, and each is surrounded mainly by younger limestones of Tertiary – Quaternary (Eocene – Pleistocene) age. These limestones occupy more than one half of the island and have been sub-divided according to their lithostratigraphy (Robinson, 1994). Their surfaces often have a well developed karst, developing into a dramatic scenery in the west central part of the island, known as 'cockpit country'. In many parts of the island the limestone is overlain by bauxite, which constitute Jamaica's main mineral resource.

The Cretaceous rocks are mainly volcanic, with associated volcanic-derived sediments, conglomerates and minor limestones, some schists and minor serpentinite. The latter two occur only in the Blue Mountain inlier in the east of the island, and may be older than Cretaceous. One large, and a few smaller intrusions of granodiorite are also found within the inliers. A belt of thick sedimentary rocks, known as the Wagwater Group, occur to the north and east of Kingston. These are sandstones, shales and conglomerates, with occasional limestone and gypsum, intercalated with further intermediate and acid volcanic rocks. Pleistocene to Recent alluvium, made up of gravel with some sands and clay, occupy large coastal areas in the south of the island, and a few small areas elsewhere. The present-day major rivers drain through the areas of alluvium. A further more detailed description of the geology is given by Lewis and Draper (1990) and Robinson (1994).

4.2 SOURCES OF AGGREGATES IN JAMAICA

There are two main sources of aggregates in Jamaica. These are sand and gravel from alluvium found in and adjacent to the present rivers, especially the active stream channels, and limestone, some of which is dolomitized (Fenton, 1981; Scott and Jackson, 1999). Limestone is available throughout much of the country and resources are effectively infinite. Although sands and gravels are more restricted in their geographical distribution, the ultimate resource can also be considered as infinite.

Other rocks, such as volcanics within the Cretaceous inliers or the granodiorites, which might be expected to be suitable for crushing to make aggregates, exist in large quantities. The location of these strata are often relatively distant from major markets compared with the abundant ubiquitous limestone. Also, these rocks mostly are deeply weathered rendering them weak and friable near the surface. A major expensive excavation for the removal of a thick cover (overburden) of this rock would be needed before a sound, strong aggregate would be encountered. In the Blue Mountain area in the east of Jamaica, the rate of physical erosion is sufficiently rapid in many places that deep chemical weathering is not so prevalent, and unweathered rocks potentially suitable for crushing as aggregates are found near the surface (e.g. basalts, schists, pyroclastics and indurated volcaniclastic sediments). Mostly, these rocks are very remote from the major markets with poor road access. They are much further removed from the urban areas compared with sand and gravel from the major river systems. Production costs would be significantly higher compared with limestone aggregates because of increased wear on the machinery, and extraction would require blasting. Also transport costs would be prohibitively high, making the aggregate products uncompetitive. The volcanic rocks found in the Wagwater Belt to the northeast of Kingston are deeply weathered as are the granodiorites, except in riverbeds in very deep valleys (e.g. Zion Hill; Jackson and Scott, 1994).

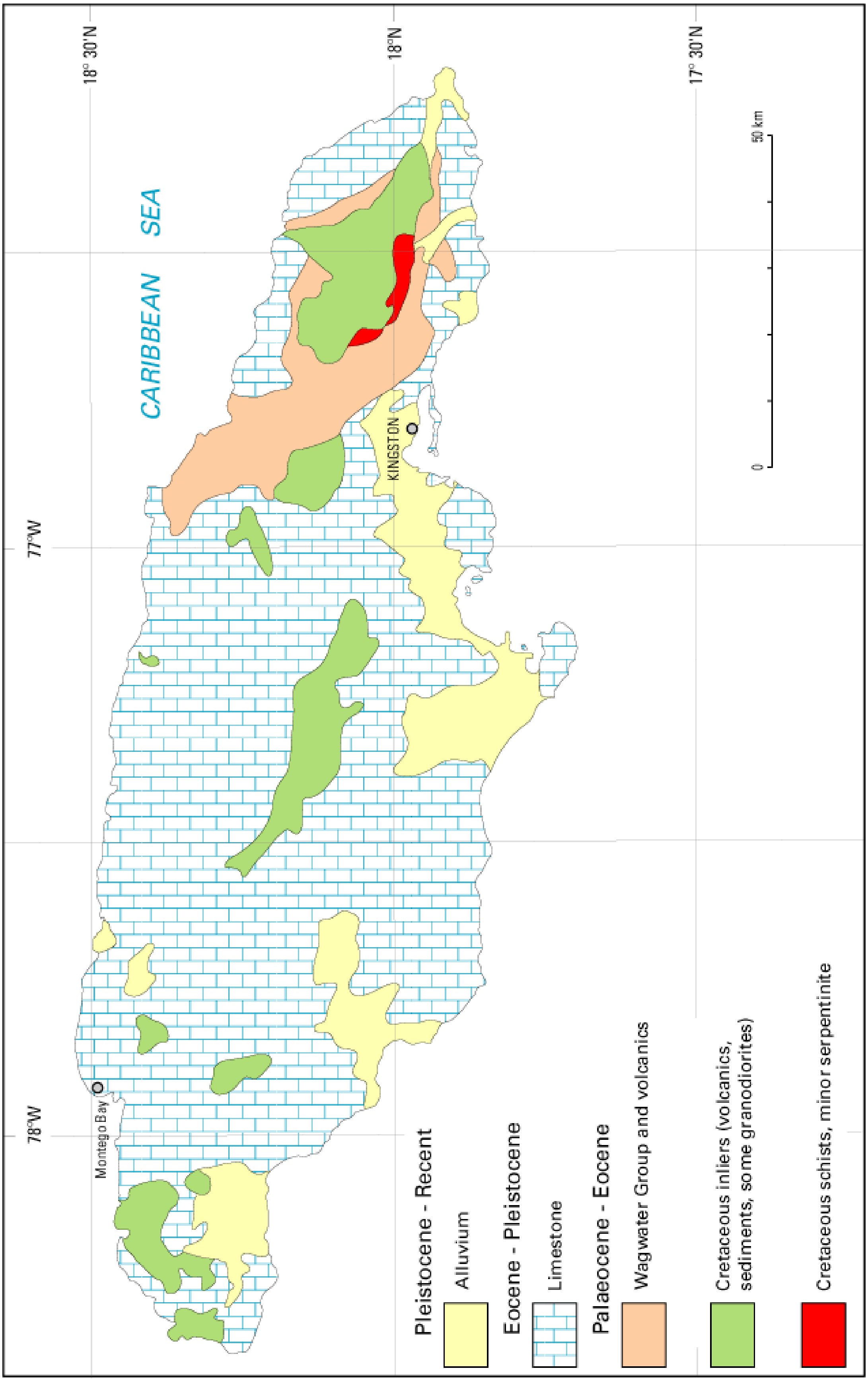
An andesite lava from the Cretaceous Sunderland Inlier, approximately 15km southeast of Montego Bay, has been recently examined as a potential source of aggregate for roadstone (Anon., 2000). It appears to be fresh (i.e. unweathered) and has encouraging properties from the limited test data available (i.e. AIV, 11; ACV, 15; Los Angeles Abrasion, 17; PSV, 57). In addition the Mines and Geology Division have located strata in a further five areas which have potential for use as crushed rock to meet the requirements for a skid resistant aggregate. They are located at Bito and Ramble, St Thomas; Nutfield and Stileman's Cove, St Mary; and Tom Spring, Hanover. All have very large resources and are volcanic rocks of dacite or related composition. Their quality are unknown.

In 1996, the resurfacing of the runway at Norman Manley International Airport, Kingston used 90,000 tonnes of aggregate imported from Canada. Rocks with a suitably high skid resistant property were not available within Jamaica. The importing of aggregate may be justifiable for a one-off use such as this; but, for further applications where a highly skid resistant aggregate is required, such as for new high-speed highways, or for further airport developments, an indigenous source is desirable.

The limestones of Jamaica have been divided into several lithostratigraphical units (Robinson, 1994) (Figure 9), and to a certain extent these follow their use and properties as aggregates. Impure limestones (referred to as the Yellow Limestone in early geological maps), often interbedded with mudstones, occur in the Lower Tertiary. These are not used generally as a resource for aggregates. Limestones of the White Limestone Supergroup form the major resource and are quarried in many places throughout the island (Figures 10, 11 and 12). Although they are often of high or very high purity, their physical properties vary considerably. They range from partly dolomitized and recrystallized varieties of the Troy, Claremont and Somerset Formations (Eocene) which are strong and make good aggregates (Fenton, 1981), to other limestones where case-hardening at the surface increases their strength, but softer limestone occurs below (e.g. Swanswick (Eocene) and Newport (Miocene) Formations). Some of the limestones are often interbedded with clay horizons (e.g. Gibralter, Bonnygate, Walderston and Brown's Town Formations) and are generally soft to rubbly. Limestones formerly known as part of the Montpelier Formation, and now separated into different formations (Robinson 1994) vary from bedded, hard and nodular to soft chalky types. Soft limestone, occurring in a quarry, is referred to as marl in Jamaica, and is sold under this name.

The resources of sand and gravel in Jamaica are found entirely in the Recent alluvium, which occurs mainly, but not exclusively in the south of the island (Figure 8). The alluvium forms wide expanses of low-lying areas, contrasting with the rest of the island, and gently slopes downwards to the sea, for examples in the southern part of Clarendon, east and west of the Rio Minho, and the Black River area, Saint Elizabeth. It also occurs in river valleys between mountains, opening out into plains near the sea, where a delta sometimes forms (e.g. Yallahs and Morant Rivers, Saint Thomas). Major rivers, which have a very variable flow cut through the alluvium. In times of flood these rivers bring down a considerable volume of sediment and frequently change their course as a consequence of sediment build up following storm or hurricane events. Major areas (river names given in brackets) where sand and gravel are important components of the alluvium are to the north and south of May Pen (Rio Minho) (Figure 13 and 14), around Spanish Town (Rio Cobre), Yallahs (Yallahs River) (Figures 15 and 16), Morant Bay (Morant River) (Figure 17), and Kingston (Hope River, which is mostly under urban development). All of these rivers drain. to the south coast. Other rivers, including those at Bath – Golden Grove (Plantain Garden River), draining to the east coast; and Annotto Bay (Wagwater River), Buff Bay (Buff Bay River) and to the west of Port Antonio (Rio Grande), draining to the north coast are minor or potential sources of sand and gravel (Figure 1). Some further details are given in Fenton (1981). Areas of alluvium in the west of the island around Black River and Savanna-la-Mar and Negril are made up of fine sand, clay and peat deposits mainly, and contain no aggregate resources.

Figure 8 Simplified geological map of Jamaica (after Scott and Jackson, 1994).



The short rivers flowing to the north coast further west from Port Maria drain mainly limestone and have little or no potential to generate sand and gravel deposits. Further resources of sand and gravel are known to exist immediately offshore at Yallahs.

The composition of aggregates in the rivers reflects the nature of the strata in the river catchment area. For example, the aggregate from the Yallahs river is made up of many different rock types. It contains volcanic rocks (lavas and pyroclastics), granodiorites, metamorphics including mica and chlorite schists, epidotised schists, indurated volcaniclastics, sandstones, greywackes, conglomerates and limestones. The aggregate is also likely to be quite heterogeneous, the proportions of each rock type varying between batches. Aggregates from the Rio Minho area are more uniform and show less heterogeneity, being dominantly made up of volcanic rock fragments (lavas and pyroclastics) with subordinate limestones and quartz sand.

Figure 9 Lithostratigraphy of Middle Eocene to Quaternary in Jamaica, made up mostly of limestones (after Robinson, 1994). ls, limestone. ss, sandstone. ms, mudstone. cgl, conglomerate. The limestone resources are exploited entirely from the White Limestone Supergroup

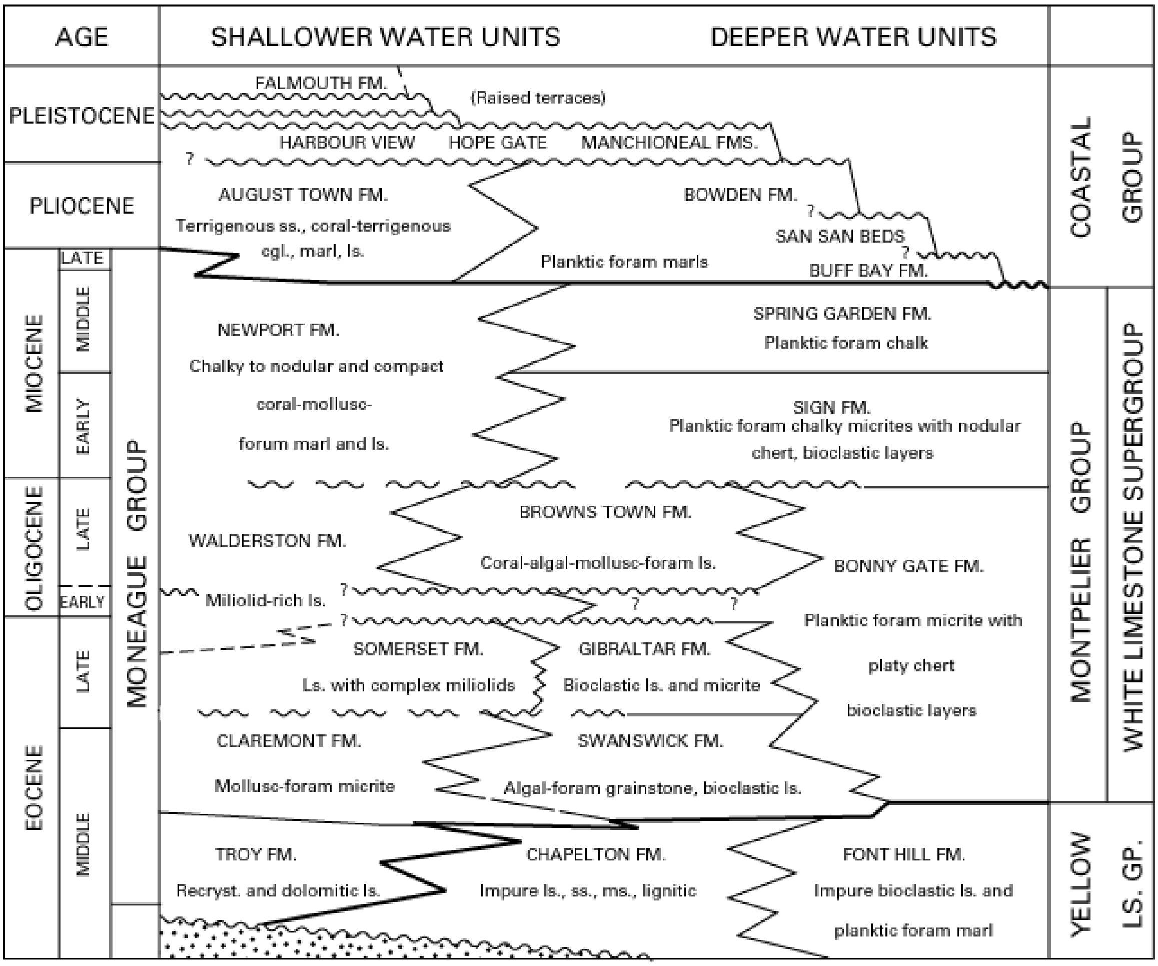


Figure 10 Limestone Quarry near Falmouth, Jamaica owned by Trelawny aggregates. Montpelier Limestone, White Limestone Supergroup

Figure 11 Limestone processing plant, John's Hall Aggregates, near Montego Bay, Jamaica.

Figure 12 Quarry in dolomitised limestone, near Mandeville, Jamaica. Troy Limestone Formation, White Limestone Group. Dunsinane Quarry.

Figure 13 Rio Minho below May Pen. Note evidence of sand and gravel extraction in left of picture.

Figure 14 Processing plant for river sand and gravel, Rio Minho, near Lionel Town, Jamaica. Sha-Gore Company.

Figure 15 Aerial view of Yallahs delta, Jamaica. Note: photograph taken in 1991, before the building of a sand and gravel processing plant on eastern side of the river.

Figure 16 Sand and gravel extraction from Yallahs delta, Jamaica. Note: Blue Mountains in background are the source of the sand and gravel.

Figure 17 Severe disturbance caused to stream bed through sand and gravel extraction, Morant River, Jamaica.

4.3 PRODUCTION STATISTICS

Limestone production in Jamaica in 2000 was 3.4 million tonnes (Anon, 2001), of which it is estimated that 2.0-2.5 million tonnes were used as aggregates, the remainder being for cement, lime and mineral fillers. Similar amounts have been produced in each of the previous few years. In addition, 4.7 million tonnes of marl and fill, which are made from soft, easily compacted limestone were produced in 2000. In excess of 4 million tonnes of marl were produced in each of the previous four years.

Sand and gravel production in Jamaica in 2000 was 2.1 million tonnes, an increase from 1.8 million tonnes in 1996 (Anon., 2001). Fenton (1981) shows sand and gravel production in the period 1974-1980 varying between 1.5-2.7 million tonnes per annum. These data indicate that, even though there has been a year on year increase in total aggregate production of almost 2.5% per annum in recent years, there has been no major expansion of the sand and gravel industry in the last 25 years. Thus, any general increase in construction activity in the country over this period presumably has been satisfied by increased production of limestone aggregates. Fenton (1981) states that limestone is gradually replacing the traditional river aggregates, especially in western Jamaica, and this appears to be a long-term trend. It is thought that there is some under-reporting of limestone production (personal communication, 2002, Mines and Geology Division, Ministry of Mining and Energy, Jamaica), and there is some illegal mining of sand and gravel. Thus, these statistics under-represent the true situation. The amount of illegal sand and gravel mining is unknown; but, as it takes place frequently in several locations, it could contribute as much as 300,000 – 500,000 tonnes per annum.

Apart from importing a significant amount for renewing the runway at Kingston’s Norman Manley Airport a few years ago, imports of aggregate are negligible (2,527 tonnes in 2000). Potentially, there is a very small export market to adjacent small islands devoid of aggregates, such as the Cayman Islands.

4.4 LOCATION OF ACTIVE QUARRIES

The locations of active aggregate quarries, identified as sand and gravel, limestone or marl are shown in Figure 18. As expected, there is a greater amount of production near to the centres of population than in the sparsely populated parts of the country, but active aggregate quarries exist throughout the island. The major producers of sand and gravel are in the coastal plains of the Yallahs and Morant River systems and in the lower parts of the Rio Minho River, both above and below May Pen. The greatest volume is produced from the Yallahs River because the industry is well organised and has some relatively modern plant. In the Rio Minho area there are several licensed quarries extracting sand and gravel, but apart from one, most are relatively small operations in terms of amounts of production. There is some production of sand and gravel from the Wagwater river, Saint Mary; to the east of Ocho Rios, and minor production elsewhere (e.g. Rio Grande, near Port Antonio; Rio Pedro, Saint Catherine). Very small amounts may be produced in the west of the island. Quarries producing sand dominate over those which produce both sand and gravel.

Limestone (including marl) aggregates are produced in many locations, but dominate in the north and west of Jamaica and in the area around Mandeville (Figure 18). In general it appears that the quarries have developed because of their historical existence, rather than because they provide a suitable high quality stone for present-day construction activities. Most quarries have existed for a long time (in excess of 20 years, and some probably much longer). New developments have taken place, such as the quarry at Salt River, in the Brazilletto Mountains, south-south-east of May Pen which opened in 2000. However, although it has, and does produce aggregate for construction, the long term plan for this quarry is a source of high quality pure limestone for filler applications, lime and possibly cement production. It has ownership outside Jamaica. Dolomite from the Troy Formation, near Mandeville produces a good quality strong aggregate.

Ignoring the illegal and the very small intermittent producers of sand and gravel, production from different sites ranges from around 70,000-300,000 tonnes per annum. The range of production of limestone is from around 25,000-230,000 tonnes per annum from different quarries. Most producers operate well below capacity (50-75%), at least partly due to down time caused by breakdowns, although a varying market will also affect production rates.

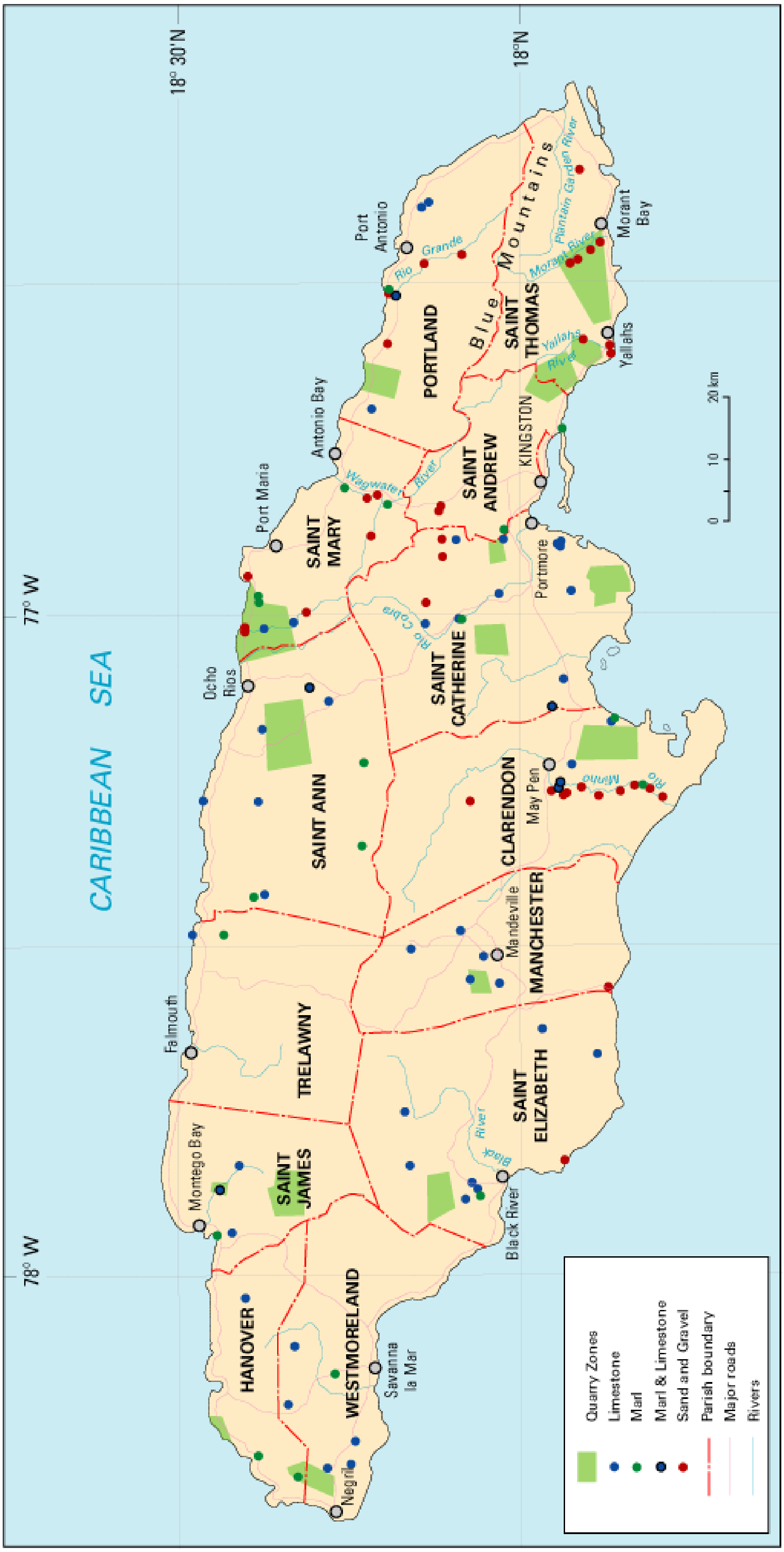
4.5 EXTRACTION AND PROCESSING OF SAND AND GRAVEL

The major and preferred place for extraction of sand and gravel aggregate in Jamaica is from the active stream channel of the various rivers. At most times of the year the water flow is very low, and thus the river bed forms a ready-made access route to the deposit, as well as an easy place for removing the sand and gravel using a front-end bucket loader. There is no overburden to be removed, the material is clean, requiring minimal or no washing to remove any fines. Visual selection is made of suitably sized material available at the surface. Large boulders and areas rich in fine sand, silt and clay are avoided. Some extraction takes place from flood plain terraces, adjacent to the active stream channel, and again the river bed provides an easy access route to the adjacent working face. Although higher level terrace deposits are a common source of good quality sand and gravel in many countries, and the gravel to sand ratio is often higher than in the active stream channels, there is virtually no extraction from these sources in Jamaica. Although extraction of aggregates from the active stream channels has to cease during times of flood, the sand and gravel producers extol the benefits to them of their resource being renewed periodically.

A simple form of processing of river sand and gravel used extensively in developing countries is a small A-frame with a single mesh screen. This system is common in Jamaica (Figure 19), the mesh being ½ inch, 1 inch or some intermediate size depending on the product required (Note: Imperial units are used throughout the aggregate industry in Jamaica). There is no washing of the aggregate product. The oversized material is rejected. This form of processing is extremely cheap, is easily set up and moved, requiring no fixed plant. It is used by the smaller licensed producers and the illegal sector.

There are currently eight sites in Jamaica where there is semi-permanent or fixed plant for the production of sand and gravel from active stream channels. Four sites are in the Rio Minho area (Clarendon), and two in the Yallahs delta (St Thomas) (Figure 20). These plants take all sizes of material apart from very large boulders and use crushing and screening with some washing to produce a range of products. The plant is generally old, some being purchased second hand. The only evidence of very recent new plant is a new Burmac impactor purchased and installed at the Sha-Gore aggregate quarry, Lionel Town (Rio Minho area), although the processing plant at Jamaica Pre-mix at Yallahs is less than 12 years old.

Figure 18 Location of active quarries and quarry zones for aggregate production in Jamaica. Taken from quarries map prepared by R. Smalling and S. Miller, Industrial Minerals Unit, Mines and Geology Division, Ministry of Mining and Energy, Jamaica.



4.6 EXTRACTION AND PROCESSING OF LIMESTONE

Limestone quarries are almost always located on hillsides, with extraction taking place into the hillside adjacent to a road. As the bare limestone face is mostly quite white, the quarries are easily visible from a distance, presenting a severe visual environmental impact. There is virtually no overburden to be removed in any of the limestone quarries.

Drilling and blasting are used sometimes as the first stage in the extraction of limestone, especially the harder, more indurated, dolomitised stone of the Troy Formation (e.g. Dunsinane Quarry, Mandeville). However, at many locations the limestone is rubbly and mostly can be ripped (e.g. using a D9 bulldozer as at John's Hall Aggregates, near Montego Bay), blasting only being used when massive stone is encountered. Blasting is often undertaken by a contractor, who has no specific instructions to produce an even breakage. Consequently, the blast produces both oversize blocks, which are too large to go through the primary crusher, and a considerable amount of fines. Marl is easily ripped, and does not require any blasting. As with limestone, there is virtually no overburden to be removed.

Although in some quarries the limestone is extracted in benches, this is not always the case. High quarry faces result. These are unsafe and potentially unstable. They would not be allowed in many developed countries.

Limestone aggregate products are made by crushing and screening with fixed plant in most locations; the new quarry at Salt River is an exception with mobile plant. Marl is produced with no processing, the as-dug material being sold directly to the consumer. There are 17 active licensed limestone quarries with crushing plants in Jamaica in 2002. They produce a range of products of different sizes, sometimes along with marl, which is also produced as a sole product from some smaller limestone quarries. Crushing sometimes produces considerable fines (up to 25% at John's Hall Aggregates, Montego Bay) for which there is no market. The quarry and processing plant are generally old (often more than 30 years), sometimes having been purchased second hand. Breakdowns are common and are regarded as a routine and acceptable hazard in the industry. At all the quarries visited, the management did not appear to maximise the efficiency of the extraction and crushing operation to produce a minimum amount of waste, or to optimise the quality of the products. There appears to be a significant level of over-manning, probably so that immediate attention can be given to dealing with breakdowns of plant.

4.7 AGGREGATE PRODUCTS AND PRICES

The product range of aggregates is similar for sand and gravel and limestone, also with little or no variation between producers or in different parts of the country. Mostly single sizes are produced, not all by every producer, as follows:

1½, 1¼, 1, ¾, $^{5}/_{8}$, ½, $^{3}/_{8}$, $<{}^{3}/_{8}$ inch.

Products are specified in Imperial sizes throughout by the industry, even though the JS124:2000 Jamaican Standard Specification for aggregates for concrete uses the equivalent metric values. It is important to note that some sizes (1¼, 1, and $^{5}/_{8}$ inch) are not included within JS124, whereas the specification includes three graded aggregates which generally do not appear to be produced by the industry. The $<{}^{3}/_{8}$ inch product is generally regarded as sand, and is the product used for block making. The other larger sizes are known as stone. Four grades of fine aggregates, named Grading zone 1 to Grading zone 4 of increasing fineness, are specified in JS124:2000. The industry does not appear to make these separate products.

The ex-works prices of aggregates varies between producers, although the cost to the consumer increases depending on the distance from the quarry. Some, but probably not all of the variation may relate to differing quality. Examples of prices are given in Table 2. Measurements are usually in cubic yards, which approximately equates to one metric tonne. Not all quarries have weighbridges. Thus the measurement of a cubic yard is often made by the size of the bucket of the loading shovel. Illegal producers are said to sell sand at 150$J per cubic yard. Sand is a premium product, which is unusual compared with many other countries, where single sized aggregates are usually higher priced. This differential reflects the lack of naturally occurring particles of sand size in many river gravels. Marl, which is used for fill purposes mostly, has a low price. Concrete blocks vary little in price in different parts of the island.

Table 2 Examples of ex-works prices of aggregates in Jamaica in 2002 (in Jamaican dollars per cubic yard).

		Product size					
Location of quarry	**Type of product**	**Sand**	**Single sized stone**	**Marl**	**Block mix**	**Concrete blocks, 6 inch +**	**Unspecified**
Yallahs	Sand & gravel	300	135				
Rio Minho	Sand & gravel	270-280					
Rio Minho	Sand & gravel	350	280				
Near Montego Bay	Limestone	330*	330	140		23.62	300
Near Mandeville	Limestone	300*	280-300		280	22	
Salt River	Limestone		250				
Trelawny	Limestone					23.50	
Near St Ann's	Limestone					23	
Estimated, Mining and Quarrying Association	Limestone			200			
Estimated, Ministry of Mines and Energy	Limestone Sand & gravel	230-250 350# 280□	250-350				
Estimated, Caribbean Cement Co	Limestone						250
	Sand & gravel						350

* Specified as stone dust
+ Retail price per block (excluding tax) from block works adjacent to limestone quarry. Wholesale prices to local hardware stores are less (around 19-22$J)
\# Washed
□ Screened
Note: One cubic yard approximately equals one tonne.
1$US ≡ approx. 40$J, £1 ≡ approx. 60$J in October 2002.

Figure 19 A frame-screen used for simple processing of sand and gravel. Yallahs delta, Jamaica.

Figure 20 Fixed plant, processing sand and gravel, Yallahs Delta, Jamaica.

4.8 MARKETS FOR AGGREGATES

The market for aggregates is dominated by sand and gravel in the Kingston area, and the eastern and central southern parts of Jamaica. Limestone is mostly used along the north coast, Montego Bay and west of the island. This reflects the availability of the resources, historical preference by the consumer and high haulage costs, which prevent a more even distribution of the market for the two types of material.

Haulage costs are around 0.12$J per tonne per kilometre or 7,000–10,000$J for 30km (e.g. Yallahs to Kingston) for 25 tonnes of aggregate (Note: 1$US ≡ approx. 40$J, £1 ≡ approx. 60$J in October 2002). This equates to an additional cost of 1120-1600$J per tonne from Yallahs to Ocho Rios, and significantly more for delivery further west along the north coast. The haulage distance and thus the cost from the Rio Minho area at May Pen to the north coast will be less than that from Yallahs, but nevertheless the sand and gravel aggregates produced on the south coast would generally cost well in excess of 1,000$J per tonne delivered to north coast sites of construction. The transport of aggregates is done mainly by hauliers, rather than the quarry companies. Overloading of trucks is commonplace (Figure 21), creating a significant hazard for other road users, and damaging road surfaces.

Aggregates are sold either direct to the consumer from the site of extraction, through retail hardware stores (equivalent to both builders' merchants and DIY stores in UK), or internally within a vertically integrated company producing concrete blocks or readymix products. There are some sales to transport companies (usually one person who owns a lorry), which supply the aggregate to the consumer at a delivered price. Illegal as well as licensed producers supply the retail stores, although the main market for illegally produced aggregates is for domestic and small commercial construction activities.

Limestone and sand and gravel aggregates are used to make concrete blocks, which is a major material for domestic and small commercial construction. Blocks are hollow, reinforcing steel is passed through them during construction, and they are often filled with mass concrete. A cage construction system with reinforcing is necessary for structures to withstand earthquakes. Clay bricks are not used and there are no brick-making plants in Jamaica. Although there are several block-making plants adjacent to limestone quarries, either owned by the limestone producer or another company, this does not appear to be the case at the sand and gravel sites of extraction. This reflects the situation that the vast majority of blocks are made using limestone aggregates, which is the preferred material.

Concrete batching (readymix) plants (7 in Jamaica) and bituminous coating plants (4) are not located at the sites of sand and gravel or limestone extraction. Around 70-80% of the readymix concrete market in Jamaica is under the control of one company which supplies its own river sand and gravel to its batching plants in the Kingston area and east of the island. As there is a major amount of on-site mixing of concrete, even that required for major projects, this company may not dominate the mass concrete market, except perhaps in the Kingston area. Gravel aggregate is used for the wearing course on roads throughout the island. Limestone is not suitable because of its very poor skid resistance, although it is used on some roads in Jamaica.

Although several of the aggregate producers interviewed by the authors did not foresee an increase in the market for aggregates in the near future, the recent statistics (1996 - 2001) for the number of housing starts, completions, mortgages, cement production and sales show a significant upward trend in the construction sector (approx. 80% increase in housing starts over the period 1996 – 2001) (Anon., 2001; Economic Update and Outlook, January, 2002). General observations during several periods of fieldwork over the past few years by the first author also would confirm this upward trend, at least in the Kingston area, with significant middle class suburban housing developments on Long Mountain (e.g. Beverly Hills) and other areas surrounding the city (e.g. Stony Hill).

A major market for aggregates will arise as a consequence of the Jamaican government's two major public-private infrastructure development projects (Carr, 2002) These are the Highway 2000 project (US$850 million), which will create a new road from Kingston to Montego Bay, with a spur to Ocho Rios, and the expansion of Sangster International Airport at Montego Bay (US$200 million). The north coast road between Ocho Rios and Montego Bay is currently being upgraded as well (Northern Coastal Highway Improvement Project). Major housing developments are also planned, such as Clarendon New Town (Knipe, 2002). Although sub-base and roadbase aggregate for the new Old Harbour by-pass road came from an existing quarry at Salt River, the aggregate for the north coast road improvements is being sourced from new borrow pits created by the contractor using imported plant, the existing limestone producers being ignored.

Several aggregate producers commented on the importance of political patronage in the awarding of government contracts. Although this may result in certain producers being favoured over others, there is no evidence that this has any significant effect on the general market situation described above.

4.9 AGGREGATE RESOURCES AND RESERVES.

The total resources of sand and gravel in Jamaica have not been quantified, but are effectively infinite given the current rate of extraction if one includes the river terraces within the overall resources. Aggregates in the active stream channels are replenished during times of flood, and especially following a hurricane. The resources of limestone in Jamaica are infinite, accessibility and proximity to market being much more important in defining the economic resource.

The long term availability of reserves of sand and gravel or limestone does not appear to be a concern of the producers. Many have large volumes of resources under their ownership or lease. These are unproven mostly, but are doubtless there. Along the north coast, limestone quarrying into a hillside is seen as beneficial, and even encouraged by landowners who give leases for mineral extraction. It creates a level area of ground adjacent to a road which can be used subsequently for agriculture or high cost housing with views out to sea.

4.10 PERMITTING AND ENVIRONMENTAL PROTECTION.

Permission for the extraction of aggregates is given by the Ministry of Mines and Energy through the issuing of a licence (Quarries Control Act, 1984, with amendments 1994) by the Commissioner of Mines. Although there is no maximum or minimum time specified in the Quarries Control Act, licences are awarded usually for one or two years only. Application fees are currently set at 5,000$J per submission and royalty payments of 3.5% on quarry sales are levied on commencement of quarrying. Renewal appears to be virtually automatic, but nevertheless, under these circumstances there is no long term assurance allowing extraction, such as might be needed to support a financing agreement.

Quarry Zones have been designated (Figure 18), and the Quarries Control Act specifies that licences for extraction outside these zones are allowed only in special circumstances. Most active quarries, however, are located outside the Quarry Zones (Figure 18) and presumably preceded the zonal designation.

The quarrying of aggregates without a licence is an offence under the Quarries Control Act, and a fine of up to 40,000$J, up to 12 months imprisonment or both can be imposed for a first offence. The act specifies that licensees shall provide a bond with the Commissioner for rehabilitation of the land on which the quarry is located. The amount is unspecified and exemption may be granted. One example is 4,500$US per acre.

Licences may be refused where the operation would be against the public interest. Examples for refusing a licence mostly relate to the protection of the environment. Further protection for the environment is given in the Natural Resources Conservation Authority Act (1991). The Natural Environment and Planning Agency (NEPA) can demand an environmental impact statement for any quarrying activity under the terms of this act, although this would only apply to new quarrying developments. Some unlicensed sand and gravel operators have been prosecuted successfully by NEPA under the Quarries Control Act, rather than because of environmental infringements, the strength of the Quarries Control Act being greater than environmental legislation currently.

Other government acts related to planning and development, and agencies, such as the National Water Authority, have no influence or control on quarrying activities.

4.11 ECONOMICS OF QUARRYING AGGREGATES IN JAMAICA.

Small scale extraction of sand and marl requires little capital outlay, other than mobile plant and a frame and mesh for processing. Mobile plant is available for hire in Jamaica, and renting by the hour or day is a common way of enabling the extractive operation to take place.

With few exceptions the fixed plant for processing in the larger scale limestone operations is very old (more than 20 years), and the capital costs are likely to have been amortised. The processing plants for sand and gravel in the Rio Minho area are likewise quite old. There are two sand and gravel operations with fixed plant in the Yallahs area. One has relatively new plant (<12 years). Both plants are built on the floodplain terrace, which could be inundated should there be a hurricane event. There appears to be a reluctance, certainly by limestone operators, to invest in new plant and any that is purchased is usually second-hand from the USA or UK.

The requirements for maintenance of old equipment and lost production due to breakdown of processing and quarry plant are high and the costs of these appear to be accepted as a direct expense without efforts being made to reduce them. Power charges also form a considerable element of cost of production, at 0.13$J/Kw/hr this can cost 750,000$J per month at a large operation. Transport of material from the quarry to the consumer is usually by a haulage contractor, saving capital outlay by the aggregate producer.

The National Investment Bank of Jamaica (NIBJ) provides equity financing to invest in development projects, which are designed to improve and broaden the country's economic base. Targeted areas for expansion include non-metallic mining and quarrying projects, and these are currently (January 2002) under-represented. Banking activities can provide venture capital funding to new projects as well as equity financing to projects which are expanding or need restructuring. Investment guidelines of the NIBJ are:

A minority stake is taken in a project (normally 20% of total equity, up to 40% on good but high risk capital intensive schemes).

The project requires external funding of more than 5 million J$.

Investment is made only within the country.

The project fits the NIJB portfolio.

Mineral projects are less than 5% of the existing portfolio of the NIJB. Several approaches have been made to NIJB for funds to support quarries bidding for Highway 2000 contracts to supply aggregates. If successful, some contingency funds will be released. Approval of funds can be granted within two months of verification, which will involve an independent check of the technical feasibility by an external mining consultant.

Data provided by producers and the Mining and Quarrying Association of Jamaica, augmented by estimates for capital costs of equipment from international sources have enabled an estimate of the cost of production of aggregates to be undertaken for four different scenarios (Table 3). Given the retail prices of products (Table 2), these data would indicate that the aggregate industry in Jamaica is very profitable (i.e. Cases 1 and 2, Table 3). This is especially true for small scale operations using minimal plant, a situation which is also likely to encourage the illegal miner, who will find a ready market by undercutting the sale price of licensed producers and still make a large profit. Existing producers, who have no capital repayments to be made on mobile or processing plant also have production costs of around 60-75% of the ex. works sales price, even though a large amount is allowed in the calculations for maintenance of aged plant. However, in order to achieve this level of profit at these costs, a sustained market demand for the products has to exist. Any market downturn or sustained period of plant breakdown would have a considerable impact on the economics of an aggregate operation which relies on crushing and screening to make its products.

Table 3 Economic appraisal of sand and gravel, marl and limestone extractive operations in Jamaica.

Case 1. Small scale artisanal extraction. Small scale sand or marl extraction (~250 tonnes per day), using mobile plant and a single fixed frame for screening, assuming 50% efficiency. No crushing. No overburden removal required.

Mobile plant (hired), (1 loader, 1 P/T bulldozer)	130 $J per tonne
Royalty and Quarry Tax	35
Labour (1 skilled, 2 labourers)	10
Total cost	**175 $J per tonne**

Case 2. Large scale extraction, no blasting. Sand and gravel or limestone extraction and processing, including crushing and screening. No drilling and blasting. Production approximately 1,000 tonnes per day. Assume around 70% efficiency. No capital repayments for plant purchase required. No overburden removal required.

Mobile plant (purchased), 3 loaders, one bulldozer)	50
Crushing plant	35
Royalty and Quarry Tax	35
Labour	25
Power	25
Maintenance	20
Total cost	**190 $J per tonne**

(note: maintenance costs for sand and gravel production will be marginally greater than that for limestone because of the increased wear on plant caused by greater hardness of the constituent rocks)

Case 3. Large scale extraction, with blasting. Limestone extraction and processing as for Case 2. Production approximately1000 tonnes per day including blasting for source of stone.

Case 2	190
Drilling and blasting	55
Total cost	**245 $J per tonne**

Case 4. Large scale extraction, capital investment required, no blasting. Sand and gravel or limestone extraction and processing, including crushing and screening as for Case 2. No drilling or blasting. Production approximately1,000 tonnes per day. Assume 70% efficiency. Capital cost of new mobile and crushing and screening plant (1.5m$US) to be funded by a loan over 10 years (constant 16% interest). No overburden removal required.

Case 2 (with labour, maintenance & power savings: reduced by 20$J per tonne)	170
Capital repayments	53
Total cost	**223 $J per tonne**

(Note: 1$US ≡ approx. 40$J, £1 ≡ approx. 60$J in October 2002)

Drilling and blasting adds significantly to production costs (Case 3, Table 3), and is avoided if at all possible by existing producers. This significant additional cost also accounts for producers leaving blocks in the quarry, which are too large to be crushed without blasting. Capital repayments of around 25% of production costs are required for establishing an operation using new plant (Case 4, Table 3). Additional requirements, which would add to the costs of production in a developed country, such as exploration to prove the reserve, creating access, site preparation, commissioning of plant, and tailings disposal, and the costs of an environmental impact assessment, compliance with environmental and safety legislation, and restoration bonds have not been taken into account. These would add considerably more to costs, such that it is likely to be unprofitable, even if a sustained market could be established for 1,000 tonnes product per day. Compared with aggregate production in a developed country, the cost of labour forms a small component of the total amount in Cases 2-4. The addition of a further labourer increases the production costs by less than 1$J per tonne.

4.12 AGGREGATE QUALITY AND QUALITY ASSURANCE.

As the only commercially available aggregates in Jamaica are sand and gravel from rivers and limestone, the consumer has a very limited choice in the type of products. In some parts of the country, especially the north coast and western part of the island, choice is further restricted by the absence of locally available sand and gravel, and the high cost of transport if it is brought in from elsewhere. Aggregates from both sources are used in block manufacture, in ready-mix and hand mixed mass concrete and for most other applications. Both sand and crushed limestone are used as aggregates in mortar. Road surfacing aggregates are made from crushed river gravel, limestone being unsuitable for this purpose because of its very poor skid resistance, especially in wet conditions.

Facilities for testing the quality of aggregates are generally lacking at the sites of extraction, and it appears that little monitoring is done even on checking the size specifications of aggregate products. Physical properties, such as strength are generally unknown, and not monitored by the producer. Even general data on the properties of aggregates from the different sources are mostly lacking, and none is found in academic or trade literature. Data sheets produced by the companies are lacking.

Facilities for testing, such as some of those methods listed in Table 1, exist at the National Works Agency in Kingston. The agency's role is to provide technical expertise for infrastructure projects. These facilities appear not to be used by the aggregate producers, who effectively pass on the responsibility for ensuring quality to the consumer. However, there is a broad empirical understanding of aggregate quality in the construction industry. For example, it is known that river sand and gravel require more cement in the mix to give the same strength in a block compared with crushed limestone and the block is heavier. Marl which is said to be 'gummy' (i.e. has bonding properties without the use of cement) is considered good as an unbound aggregate. River gravel is known to be a reasonably skid resistant aggregate for use on the wearing course (top surface) of roads, but properties vary as its composition is highly variable.

The Jamaican Bureau of Standards has three current standards for testing and specifying aggregate quality. These are listed in Table 4. They are based largely on ASTM or British Standards, using identical test procedures. Specifications are very loose, for example, nominal single sized aggregates can have quite a broad size distribution according to JS124, and the maximum values for compliance in respect of aggregate strength, abrasion resistance and soundness allow for extremely low quality material to be used. Contracts of construction works do not always specify the quality required of the aggregate raw materials and thus there are no effective means of ensuring that standards are met.

Table 4 Standards relevant to aggregates in Jamaica.

JS35:1998	Jamaican Standard Specification for Standard hollow concrete blocks.
JS86:1984	Jamaican Standard Specification for Prepared stone and gravel ballast.
JS124:2000	Jamaican Standard Specification for Aggregates for concrete.

There is a registration procedure for aggregate producers. A *Registered Producer* has had a sample of aggregate tested and has the capability to make a product to the required quality at the time of the test. The nature of the tests performed is unknown. Further regular testing is not a requirement for maintaining registration. Many aggregate producers are registered, but question the benefits over non-registered producers. A further quality standard for producers is to become *Certified,* which gives a guarantee of consistency of product. A few concrete block manufacturers are certified, but as yet not the aggregate suppliers, who have been criticised for poor quality of product (Jamaica Gleaner, 2002). A few block manufacturers are working towards achieving ISO9000 quality management systems accreditation, but others including aggregate producers see no benefit in the certification procedures, even though the bureau of Standards has intentions of bringing everyone into compliance (Jamaica Gleaner, 2002).

5 Technical and economic issues

The sources and supply of aggregates in a country are dictated by its geology, with either various types of crushed rock or sand and gravel being used according to availability and location. In many regions, such as in North America and Europe, an abundant supply of different strong rocks are available for crushing, along with sand and high quality gravel from active or ancient river systems. However, in many developing countries, especially small nations with a limited variety of geology and a deep tropical weathering mantle, aggregates may be less readily available, and quality may be variable or poor. In some large developing countries, urban centres are located on geologically recent lowland areas dominated by fine grained sediments, such as a delta. Here, a long distance between the source of an aggregate in a hinterland and the major consuming area adds significantly to cost.

In Jamaica, an extreme situation for aggregate supply exists. The only conveniently available hard rock at the land's surface is limestone. This is used extensively as a source of aggregate for most applications. The other source is from the active stream channel of rivers. The two sources are separated geographically within the island. Their respective markets hardly overlap and thus there is very little competition or substitution. The consumer in Montego Bay, for example, has little option but to use a limestone aggregate, whereas in Kingston, sand and gravel aggregates dominate. Other sources of rock suitable for aggregates exist in Jamaica, especially volcanic rocks within the Cretaceous Inliers mostly in the inland central parts of the island, and volcanic and metamorphic rocks in the Blue Mountain region to the east. Crushed rock aggregates from these sources are likely to be of an acceptable quality for most uses, but their cost of production relative to existing supplies would be much higher. Weathering is sometimes intense and before extraction could take place, significant removal of overburden would be needed to reach the resource. Their occurrence in mountainous areas makes road access much more difficult, and transport costs would be high compared to existing supplies.

Any growth in aggregate demand in Jamaica over the past 25 years is likely to have been taken up mainly by an increase in limestone production. This may be explained by the major growth in construction for the tourist industry being along the north coast, for which limestone is conveniently situated, rather than a general trend away from the production of sand and gravel from the stream channels of active rivers. Any positive move away from river sand and gravel production, so that the associated environmental impact can be reduced, without the provision of major local additional supplies of limestone or other crushed rock aggregates would have a severe consequence for the construction industry in a major part of the island. A region encompassing Kingston, the whole of the area east of Kingston (St Andrew, St Thomas and Portland), and as far west from Kingston almost to Mandeville, including Spanish Town, Portmore and May Pen (St Catherine and Clarendon) would be affected. Based on the relative amounts of cement sales in the different parts of the country (private communication Caribbean Cement Company Ltd, 2002), this region takes around 50% of aggregate production in the country. Additional costs for the transport of limestone aggregates and products such as blocks from the west and north of Jamaica would be significant, accompanied by the considerable additional amount of road traffic, and its associated environmental impact. Resources of limestone exist in the Kingston area, such as the Newport Formation on Long Mountain used for cement manufacture. There is some relatively small limestone production to the east of Kingston, which could be expanded to take up a small amount of the market currently occupied by sand and gravel products, but further expansion of limestone extraction would result on encroachment into the urban area which is rapidly expanding in this direction, around Long Mountain.

Replacement of production of sand and gravel from the active river channels with that from adjacent higher level terraces would reduce much of the environmental degradation associated with present practice. These terraces might be vulnerable to extreme storm events, but in general they will be unaffected by normal annual variation in stream flow. They are almost entirely used as agricultural land, and have a high value for this purpose. The benefits of sand and gravel extraction over that of agriculture in a country where high quality agricultural land is not especially abundant would need to be assessed. In some developed countries (e.g. UK), there has been considerable extraction of sand and gravel from terrace deposits adjacent to rivers. Following the extraction of sand and gravel, the land is returned to agricultural use. This could take place in Jamaica (c.f. restored former areas of bauxite extraction). Alternatively, the land could be used to create another amenity (e.g. lagoon storing water for irregation, etc) or wildlife habitat (e.g. nature reserve) when extraction is below the permanent water table.

An overburden of silt and clay of considerable thickness may be present above the sand and gravel in a higher level terrace, and there may be significant amounts of infiltrated fines within the resource. These fines would require containment or disposal as waste. Drilling would need to be used to evaluate resources to support the investment, before any quarrying could commence. One benefit of extraction from the active stream channels is that the resource is visible at the surface, requiring little or no exploration to prove it.

There are several issues arising from this study that are relevant to improving technical and economic aspects of the aggregate industry in Jamaica. These are the age of the fixed and mobile plant, the licensing of the extractive operations, efficiency of raw material extraction, adherence to specifications, the assurance of quality of products, and delivery to the consumer. Some are inter-related, but they are discussed individually below. Similar issues also are likely to be relevant to the aggregate industry in other developing countries. Addressing them will enable the industry to provide improved products to the construction industry for it to meet the demands for the country's future development, and at the same time sustain its long term profitability. Specific issues relating to the environmental and social impact of aggregate production have not been addressed.

5.1 AGE OF FIXED AND MOBILE PLANT.

The major part of the aggregate production in Jamaica uses very old mobile and fixed plant. There are frequent breakdowns with the associated loss of production and disruption of supply to the consumer. Efficiency is also reduced in old processing plant by the creation of unnecessary fines and other waste. The aggregate producers anticipate that there will be breakdowns, and have developed strategies to cope with them, mostly involving having significant excess manpower and spare capacity of mobile plant. It appears that this issue is being partly addressed as there is one new limestone extractive operation (Salt River), for which there was a large overseas investment recently, albeit justified on the basis of the chemical quality of the limestone, and not aggregate markets. There is a relatively new processing plant for a sand and gravel operation at Yallahs, and a minor amount of recent investment in new plant elsewhere. However, most producers do not appear to have any plans for capital replacement of plant. Funds are available for investment, but the data above show that repayment costs make a significant addition to the cost of production, and for a private producer this will be accompanied by some loss of equity. The problem of ageing and inefficient plant may also influence those responsible for new highway developments, such that they decide to source aggregates by developing their own temporary quarries with plant brought in specifically for the project rather than use existing producers.

5.2 LICENSING OF AGGREGATE EXTRACTION.

The award of short-term licences (1-2 years in Jamaica) does not give the owners of aggregate companies any long term security in production, such as would be needed to acquire financial aid for developments or to encourage long term planning for their operation. Such planning should include the developments of their quarry, progressive restoration, accommodation of waste piles and fine tailings, water storage and circulation, as well as product and market development, and financing. Clearly many aggregate producers in Jamaica have existed for many years at the same site, and presumably the licence has been automatically renewed each year. Thus, it seems unnecessary for them not to be given a licence for a longer term, as long as the other safeguards to the environment, restoration, etc., are retained. It is usual in the UK for permissions to extract (Planning Permission) to be granted for periods of 10-20 years for aggregate production, and investments are made to be amortised over this time.

5.3 EFFICIENCY OF EXTRACTION OF STONE.

The properties of the raw material, combined with the methods chosen for extraction and the design of the processing plant control the relative amounts of the different types of aggregates produced. A mass balance between products and relative market demand, accompanied by the production of minimum amounts of waste, gives maximum efficiency in utilisation of the raw material.

Significant amounts of fines are produced by several of the limestone producers in Jamaica for which there is no market. These accumulate as waste. This partly relates to the soft nature of the raw material, but also to poor design of the processing plant. Impact crushers are most suited to produce single sized limestone products with an equidimensional, rather than elongate shape, and a minimum amount of fines.

Only a very small amount of fine waste occurs from sand and gravel extraction and processing as there is virtually no silt and clay in the raw material. Only minor amounts of fines are produced during crushing. A major containment and disposal problem of fines does not exist; but fine waste has been observed being pumped into the sea (Figure 22). As sand is a premium product always in demand in Jamaica, increased amounts could be made as manufactured sand using a gyratory disc crusher, following secondary or tertiary cone crushing within a sand and gravel processing plant.

The design of blasting is critical in creating efficient and even breakage of stone, saving on crushing costs. The use of trained in-house staff to undertake this activity in limestone quarries, rather than external contractors, who have no interest in the subsequent use of the broken material, would improve efficiency, reduce wastage, and the need for secondary blasting.

5.4 QUALITY ASSURANCE OF PRODUCTS.

The consumer of an aggregate, or product made from an aggregate such as a concrete building block, should have confidence in its quality and fitness for purpose. This can be achieved in a qualitative way by the aggregate producer gaining an established ‘good’ reputation for providing an aggregate suitable for a particular application. This situation probably exists in Jamaica, although the location of aggregate production relative to the consumer, and price also play important parts in the selection process. These factors also provide encouragement to the illegal sand and gravel mining sector. Regular physical measurements of quality by the producer, supplemented by external validation and accreditation, are more objective. Tests by the consumer or an independent third party, as usually happens with major construction projects, further provides an assurance of suitability of an aggregate for its intended purpose.

Although the Bureau of Standards in Jamaica have developed a few standards for the quality of aggregates and concrete blocks, these are not adhered to by the industry. For example, JS35:1998 (reference in Table 4) for concrete blocks divides them into Class A and B on the basis of strength. Even though Class A blocks are not required to have a particularly high strength (minimum of 7MPa), producers mostly do not specify the category(ies) of their blocks, at least openly, and do not have test facilities to ensure compliance. In general, the aggregate producers have little or no knowledge of the quality of their products, and do nothing to ensure or monitor

Figure 21 Truck loaded with river sand aggregate, Yallahs delta, Jamaica.

Figure 22 Pale brown plume of fine waste from disposal into the sea, Yallahs delta, Jamaica. Note contrast with blue sea offshore.

consistency. It is likely that the quality of the same named aggregate product from two adjacent limestone quarries will be different, and it is possible that neither may meet the requirements of the Jamaican Standard. No external monitoring of aggregate quality from different quarries is made within Jamaica and the message *caveat emptor* should be paramount in the mind of the consumer. Contracts of works do not usually specify the required quality of the aggregates (personal communication, Wycliffe Graham, University of Technology, Jamaica, 2002). Thus, there is little incentive for the producer to ensure that a suitable quality of product is supplied.

The capital cost of setting up a laboratory with comprehensive facilities to measure the quality of aggregates is large (up to 150,000$US for equipment alone). It also requires skilled technicians to operate it, and an income to sustain the activity. This is not needed by each producer, nor is a comprehensive laboratory found at every extractive site in a developed country; but a single independent facility in a country such as Jamaica might be expected. A producer should have comprehensive tests made to establish the properties of the products, and monitor parameters such as grading continually. Re-testing should be done when changes to the source of the raw material occur (e.g. extraction from a different part of a river; extraction of a different horizon in a limestone quarry) and when changes are made to the processing route.

Producers are likely to be reluctant to have aggregate properties measured and to monitor the quality because of the financial cost, and in case it shows their products to be inferior to that of others. On the other hand it would give consumers a guide on where to source their aggregates, and a benefit to some producers could be gained. An opportunity to supply aggregate of a consistent and known quality to the Highway 2000 project might provide some encouragement in this respect.

For infrastructure development, for developing a properly planned extractive industry, and for enabling informed political debate on the construction industry and activities in a country, it is essential for the overall quality of aggregates and their variation to be known. For this purpose an inventory of the properties of aggregates is required. Tests should include the particle size distribution of products, and relevant physical properties for each product, such as strength, abrasion resistance, water absorption and sulphate soundness. Strength tests for blocks produced at sites of aggregate production also could be included. This work should be undertaken by a government agency, such as the Ministry of Mines and Energy, and the results made public ally available. Government would be informed and able to make judgements, and an informed public would be able to make a more objective choice in sourcing aggregates. Producers would be encouraged to ensure further the quality of their products. If testing of the quality of aggregates were well established in the country, the opportunities for illegal (unlicensed) producers to sell their aggregates to reputable customers, such as hardware stores or to large contracts, would be reduced.

5.5 DELIVERY TO THE CONSUMER.

The consumer receives aggregates either directly from the quarry or through an intermediary, such as a merchant (hardware store in Jamaica). In a country such as the UK, with numerous sites of aggregate production, most customers requiring a minimum of a few tonnes of aggregate will purchase it directly from the quarry, delivery being made by the aggregate company’s own vehicles, or by a haulage company contracted to the producer. Only small amounts of aggregates for small domestic construction activities are supplied through intermediaries. The presence of an intermediary, either a hardware store or a haulage company, appears to be common practice in Jamaica. Thus the consumer has no contract with the aggregate producer, and little redress regarding the quality of material. Other than aggregate producers who also have ready-mix concrete operations, those in Jamaica generally do not have their own or contracted delivery vehicles. This situation, exacerbated by any double handling costs, is likely to inflate the price to the consumer above that directly attributed to transport costs.

In Jamaica only some of the larger aggregate producers have weighbridges. Without this facility, measurement is made through knowing the capacity of the loading shovel. Errors may be large. The consumer may be receiving less tonnage than is paid for, or the producer is losing value in the resource by supplying an excess of material. The latter is most likely as a customer will be reluctant knowingly to receive less aggregate than has been paid for. Even where there is a weighbridge, considerable overloading of lorries often occurs. This creates damage to roads, as well as being a considerable danger to pedestrians and other road users if brake or other catastrophic failure occurs through exceeding the design capacity of the vehicle. Enforceable regulations for measurement and safety would be beneficial to the aggregate producer and in the public interest.

5.6 EDUCATION

Improving efficiency, cost savings and product quality in the aggregate industry in Jamaica could be addressed in the short term through developing educational programmes on different aspects of the business for owners and key personnel, and in the long term by the industry employing graduates in mine and quarry engineering The former could be achieved through the Mining and Quarrying Association of Jamaica (MQAJ). The latter would require Jamaicans to be educated in a university outside the Caribbean. The University of the West Indies (UWI) does not provide degree courses in this area, although geology graduates from UWI could gain some relevant training through MSc programmes in mining engineering and/or industrial rocks and minerals. The MQAJ could also address these and other issues discussed above through achieving one of its primary objectives, which is *'modernisation of the industry with regard to price competitiveness, adherence to international standards and specifications, safety and environmental protection'*, as stated in their publicity leaflet (Mining and Quarrying Association of Jamaica, 2002). It might consider developing a scholarship programme through subscription by the industry to pay for students to gain a relevant qualification, such as a degree in mining and quarrying.

6 Specific conclusions on the supply of aggregates in Jamaica.

1. Sand and gravel from the stream channels of some of the river systems, particularly the Rio Minho and Yallahs River are important sources of aggregate (approximately 50% of consumption). Production is almost entirely from the active river channel, with minor extraction from the adjacent floodplain.

2. Coarse and fine aggregates from limestone make up the remainder of production (approximately 50%). It is concentrated in the west and north of Jamaica, with the White Limestone Supergroup being the main resource. The quality of limestone varies considerably from hard dolomitised stone to soft rubbly material and very soft marl. The latter is considered a separate material, principally used as a good quality, compacting fill, although some may be used in block manufacture.

3. The markets for sand and gravel aggregates and those from limestone do not overlap and opportunities for substitution are minimal, because of the geographical distribution of their sources.

4. Unlike many countries, sand (fine aggregate) is a premium product in Jamaica and commands a higher price compared with coarse single sized gravel or limestone products.

5. The sand and gravel in stream channels is clean requiring little or no washing. Small scale production of sand uses simple processing with a single frame to remove oversized particles. Crushing is used to create additional sand in the larger production sites, where washing and screening is also used to make a variety of single sized products.

6. Limestone extraction mostly is by ripping. Blasting is usually avoided. Processing is by crushing and screening to make single sized products and a graded sand. The latter is commonly used in concrete block-making.

7. Sand and gravel and limestone are effectively unlimited resources in Jamaica. There are alternative materials available, but the cost of their extraction and general remoteness would make their extraction uneconomic for general purpose aggregate production.

8. Production costs for a small scale sand and gravel unit, with simple processing are estimated around 50-60% of the average ex-works sales price. For a larger production unit where the mobile and fixed plant value has already been amortised and a complete range of aggregate products is made from either a limestone or sand and gravel source, the costs are around 60-75% of sales price. As long as there is a sustained market for aggregates, production in these situations is probably very profitable. For a limestone extractive operation involving financing of new plant and blasting to source the stone, the cost increases to around 85-100% of sales price (achieved by adding blasting costs to Case 4, Table 3). For an equivalent sand and gravel operation it is approximately 70-80% of sales price. A continuing sustained market would be needed to support a business where financial repayments are required.

9. Reduction in the rate of production of sand and gravel from the active river channels in the Rio Minho and Yallahs River would have a severe effect on the supply and economics of aggregates in the Kingston, St Andrew, Clarendon and St Catherine parishes, which could not be made up from additional limestone sources.

10. Extraction of sand and gravel from higher level terraces in the Rio Minho and Yallahs River systems would reduce the available agricultural land temporarily but could be restored. It would be less economic because of overburden to be removed and the presence of additional fines in the mineral resource. Exploration to prove the resources would also be needed.

7 General conclusions and recommendations on technical and economic issues for aggregate production in developing countries.

1. In a developing country the supply and availability of aggregates is dictated by the geology, but may be restricted by the lack of suitable materials near to the consumer, and /or near the surface due to deep tropical weathering. Sand and gravel from the stream channels of active river systems is an important source of aggregates in many developing countries. They compete with aggregates produced from crushed rocks when they are available.

2. Aggregates must be fit for the purpose to which they are used. Hence, they need to be produced to acceptable quality standards. A large number of standards are published by developed countries, such as the UK and USA, and many, but not all of these are suitable for adoption in developing countries, or as a basis for setting standards for indigenous aggregate quality. Although some standards exist in some developing countries, there is little attention paid to them in the production of aggregates, and aggregate products, such as concrete blocks. The Jamaican standards, for example, are not especially restrictive and could easily be met by most of the aggregate producers. Adherence to standards gives a degree of confidence to the consumer in the quality and consistency of products. The development and implementation of a building code that only allows aggregates which meet specifications to be used, would also encourage the aggregate industry to adhere to quality standards. Education within the construction industry so that aggregates are perceived as a manufactured product and not just a 'cheap pile of dirt' would also help. A requirement for regular testing of aggregates and specification of quality in contracts for works, would force the industry into compliance. Most of the laboratory tests are simple, and require little investment in equipment, although some skills are required in carrying them out. Aggregate companies should be encouraged to set up their own small laboratories to carry out the simple tests on a routine basis, more difficult ones (e.g. AIV, ACV, AAV, PSV) which are required less frequently, being carried out by an independent laboratory.

3. The mobile and processing plant used in aggregate production in developing countries is usually very old and there are frequent breakdowns. Spare parts may not be readily available, and are expensive. Major parts have to be imported with accompanying delay, and often require special customs clearance. Investment in new plant is generally lacking.

Overmanning is endemic, but it enables repairs to plant to be undertaken quickly. Spare mobile plant capacity is common allowing for breakdowns to be accommodated without too much loss of production.

4. The provision of licences for aggregate extraction only for short periods is a disincentive to the producers to re-finance and re-equip their activities, and to take a long term view of their property. Long term licences and available finance at preferential rates of interest are important if aggregate producers are to modernise and be efficient.

5. Unlicensed (illegal) extraction is common, and penalties provided in mining or environmental legislation preventing this activity may not be effective. The legislation should be strengthened. If the recommendations in 2 above are implemented, and accepted by the construction industry, the market for products from the illegal producers would disappear.

6. The aggregates for major externally- or aid-funded construction projects in developing countries usually is sourced from outside the existing producers, as the latter are unlikely to be able to provide a reliable product due to breakdowns, and/or a lack of ability to produce a consistent product of known quality. It is recommended that contracts for such projects should specify that aggregates are to be sourced from existing producers as far as possible, but without compromising on the quality of the product or the testing required for compliance. This would further encourage the aggregate industry to provide a quality assured product.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

ANONYMOUS, 2000. Sunderland Quarry Zone Report. Mines and Geology Division, Ministry of Mining and Energy, Jamaica, 77p.

ANONYMOUS, 2001. Mining and Quarrying. Economic and social survey, Jamaica 2000. Planning Institute of Jamaica, Kingston, Chapter 9, 5p.

ARBOGAST, B. 2002. An overview of reclamation law dealing with mineral resource development in the USA. Pp. 283-294 in SCOTT, P.W. and BRISTOW, C.M. (Eds) Industrial Minerals and Extractive Industry Geology. The Geological Society, London, 376p.

CARR, A. 2002. Lift-off for $1bn schemes to get Jamaica moving. Focus on Jamaica supplement, The Times, August 6, 2002, London p.11.

FENTON, A. (Ed.) 1981. Mineral Resources of Jamaica (2nd Edition). Bulletin 8 Geological Survey Division, Ministry of Mining and Energy, Jamaica, 104p.

HARBEN, P.W. and KUZVART, M. 1996. Industrial minerals: a global geology. Industrial Minerals Information Ltd., Metal Bulletin plc, London, 462p.

HERRICK, D.H. 1994. Stone, crushed. Pp. 975-986 in CARR, D.D. (Ed.) Industrial Minerals and Rocks. Society for Mining, metallurgy and Exploration Inc, Colorado, 1196p.

JACKSON, T.A. and SCOTT, P.W. 1994. The mineral and rock chemistry of the Above Rocks pluton, Jamaica: New information on emplacement and petrogenesis. Caribbean Journal of Science, 30, 1-11.

JAMAICA GLEANER, 2002. Block makers resist certification. Jamaica Gleaner, Saturday 8th June, 2002 (www.jamaica-gleaner.com/gleaner/20020608/real/real1.html)

KNIPE, M. 2002. Workers hold key to cheaper homes. Focus on Jamaica supplement, The Times, August 6, 2002, London, p.11.

LANGER, W.H. 2001. Environmental impact of mining natural aggregate. Pp. 127-138 in BON, R., RIORDAN, R.F., TRIPP, B.T. and KRUKOWSKI, S.T. (Eds) Proceedings of the 35th Forum on the geology of industrial minerals – The Intermountain West Forum 1999, Miscellaneous Publication 01-2, Utah Geological Survey, 286p.

LANGER, W.H. 2002. An overview of aggregate resources in the United States. Pp. 9-16 in SCOTT, P.W. and BRISTOW, C.M. (Eds) Industrial Minerals and Extractive Industry Geology. The Geological Society, London, 376p.

LEWIS, J.F. and DRAPER, G. 1990. Geology and tectonic evolution of the northern Caribbean margin. Pp. 77-140 in DENGO, D. and CASE, J.E. (Eds) The Caribbean region. The Geology of North America, Volume H, Geological Society of America, 528p.

McCarl, H.N. 1994. Aggregates: markets and uses. Pp. 287-293 in CARR, D.D. (Ed.) Industrial Minerals and Rocks. Society for Mining, metallurgy and Exploration Inc, Colorado, 1196p.

Mining and Quarrying Association of Jamaica. 2002. What is the MQAJ? 1p.

MOOTOO, D.A. and SUITE, W.H.E. 1992. An investigation into the engineering properties of porcellanite aggregate from south-western Trinidad. Journal of the Geological Society of Jamaica, 24, 1-12.

Natural Resources Conservation Authority Act 1991. Natural Resources Conservation Authority Act, Government of Jamaica, 36pp.

OSBORNE, R.W.A. and RAJPAULSINGH, W.T. 1997. Pumice sands as an alternative to beach sand as fine aggregate for the construction industry in St Lucia. Pp. 25-34 in LYEW-AYEE, A. (Ed.) Proceedings of the Caribbean Industrial Minerals Workshop May 17-18, 1994 and The Second Caribbean Industrial Minerals Workshop, October 30-31, 1995. Journal of the Geological Society of Jamaica, Special Issue No.13, 163p.

QUARRIES CONTROL ACT, 1984, with amendments, 1994. The Quarries Control Act, Government of Jamaica. 31pp.

ROBINSON, E. 1994. Jamaica. Pp. 111-127 in DONOVAN, S.K. and JACKSON, T.A. (Eds) Caribbean Geology, an introduction. University of the West Indies Publishers' Association, Kingston, Jamaica, 289p.

SCOTT, P.W. 1993. Distribution of flint and chert in Quaternary and Recent gravel aggregates in the United Kingdom. Transactions of the Institution of Mining and Metallurgy, 102, Section B, 1-4.

SCOTT, P.W. and DUNHAM, A.C.1984. Problems in the evaluation of limestone for diverse markets. Proceedings of the 6th Industrial Minerals International Congress, Metal Bulletin, p. PWS1-21.

SCOTT, P.W. and JACKSON, T.A. 1994. Industrial rocks and minerals in the Caribbean: geology, exploitation and attitudes. Pp. 95-106 in S.J. MATHERS and A.J.G. NOTHOLT (Eds) Industrial Minerals in Developing Countries. AGID Report Series, Geoscience in Industrial Development No. 18. British Geological Survey, 272p.

SCOTT, P.W. and JACKSON, T.A. 1999. Industrial minerals in the Caribbean.. Pp. 319-328 in JOHNSON, K.S. (Ed.) Proceedings of the 34th Forum on the Geology of Industrial Minerals, Oklahoma Geological Survey, Circular 102, 364p.

SHARPE, R.D. and SCHROEDER, W.A. 1999. Oklahoma's gypsum resources - an overview of geology and manufacturing of value-added products. Pp. 57-68 in JOHNSON, K.S. (Ed.) Proceedings of the 34th Forum on the Geology of Industrial Minerals, Oklahoma Geological Survey, Circular 102, 364p.

SMITH, M.R. and COLLIS, L. (Eds) 2001. Aggregates. Sand, gravel and crushed rock aggregates for construction purposes (3rd Edition). Geological Society, London, Engineering Geology Special Publication, 17, 339p

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