

SAND AND GRAVEL FROM SHALLOW SEAS^{1,2}

E. OELE³

ABSTRACT

Oele, E. (1978). Sand and gravel from shallow seas. *Geol. Mijnbouw*, 57, p. 45-54.

Various factors which influence the economic feasibility of offshore mining are discussed. The mined sands and gravels are used for constructional purposes. Therefore, some specifications of the grain-size distribution of the exploitable product are mentioned.

A gravel exploration by the Netherlands Geological Survey in an area off the Norfolk coast is mentioned. Some special samplers, used for this purpose, are described.

Sand and gravel on the shelves have been transported and supplied by rivers, glaciers, wind and locally by longshore currents. Marine erosion may contribute as well. The North Sea and English Channel are good examples of an aggregate-bearing shelf, since shells, sands and gravels are all present.

The availability is at least as important as the transporting agents. Controlling include a.o. climate, tectonic instability and distance from the source area. Even in the Pleistocene the weathering processes in the tropical zones resulted in only small amounts of sand and gravel reaching the present-day shelf areas. In the subtropical zone the humidity and tectonic instability are a prerequisite for their presence, whereas in the temperate zones various mechanisms have led to mineable deposits.

From a combination of prospective areas and densely populated regions it follows that only very restricted parts of the shelf are of interest as far as mining is concerned.

INTRODUCTION

Importance of aggregates

It is already several years since LÜTTIG (1973) drew attention to the fact that the importance of sand and gravel production was underestimated. Not only the consumers, but also the proper authorities had shown insufficient interest in the matter, despite the fact that sand and gravel extraction covers more than 60% of the non-metallic raw materials production in the German Federal Republic. In the U.K. too the yearly aggregate production of 110.10⁶ tons makes it a close second to coal mining (ROWE, 1976).

It is quite clear that the aggregate production deserves more attention, even from the geologists. In the near future serious

problems will arise in trying to meet the demand (OELE, 1971; LÜTTIG, 1973; U.S. NAT. AC. SCI., 1975).

Recently CRUICKSHANK & HESS (1975) have also drawn attention to various aspects of marine aggregate mining.

Importance of offshore mining

As well as the highly important production and a possible future shortage two more reasons favour an increasing interest in offshore production. First there is the increase in regulations, arising from attempts at environmental protection. In this connection it is significant, that in one of the German states application for sand and gravel extraction licenses must be made 17-fold.

The second reason deals with the use of the products. The enlargement and improvement of ports, on the border of land and sea, stimulates offshore winning. For instance for the new harbour entrance of Rotterdam Europort 6.10⁶ tons of gravel were imported from the British shelf. The gravel was used as foundation for the breakwaters (ANDREAE, 1975). Nevertheless high amounts of gravel from onland sources were required to make the concrete blocks, which were put on top of the gravel foundations.

Other examples are artificial offshore islands, the con-

¹ Paper presented as invited lecture, 25th International Geological Congress, Symposium 108.1 – Economic geology of the sea floor.

² Manuscript received and accepted: 1977-11-30.

³ Netherlands Geological Survey, P.O. Box 157, HAARLEM, The Netherlands.

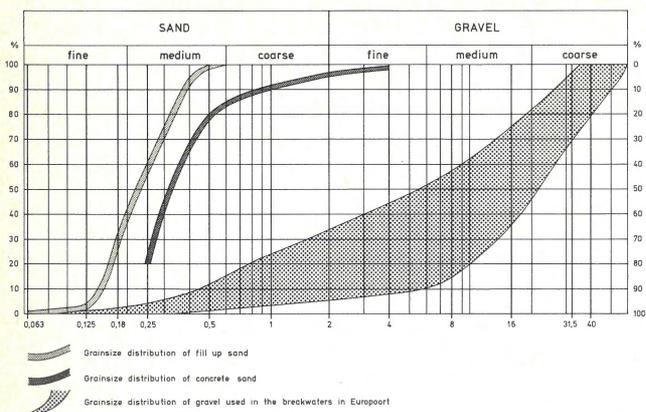


Fig. 1
Grain-size distributions as required for some industrial products.

struction of which is under consideration in various countries.

Restricting or limiting aspects of marine mining

Marine exploitation of aggregates has some obvious advantages. In this paper, however, some less obvious limiting factors will be reviewed briefly.

In relation to land operations the mining costs at sea are raised because of the necessary application of expensive positioning systems, the higher investment required for seagoing vessels and the unproductive days due to bad weather. The waterdepth of about 30 metres appears to be the economic limit, dredging beyond that depth requiring heavier, more costly equipment.

The environment of the dredging area might suffer in various ways. Firstly the fine particles, which are screened out, may cover and pollute the sand and gravel beds still present. Discharge of the undersized particles below sealevel together with a stream of air-bubbles is a Japanese solution to the problem. In this manner the particles are kept in suspension for a longer distance. The consequences to coastal protection and the fisheries seem more serious.

In view of coastal defence, in many countries dredging is not allowed within a certain distance of the coast. In The Netherlands a distance of 20 km is the limit. As far as the fisheries are concerned, the operations can interfere with the living or growing conditions of certain fish. A SCOR working group convened recently to discuss the subject and formulated some recommendations, which were submitted to the Board of SCOR. One protection measure could be that a certain amount of sand and gravel must be left on top of the bedrock. In France a layer of one metre must be left behind.

If the aggregate is not used in an offshore construction, the material must be transhipped at additional cost. For this purpose a special harbour was adapted in Rotterdam. Finally, the chloride content, which in some cases must be washed out in desalination plants, may require additional handlings and investments.

Quality and application of marine aggregates

It will be clear that the quality and composition of marine aggregates are as varied as their onland counterparts. Also the applications are variable and therefore the requirements are too. Fig. 1 shows 3 grain-size distributions: (1) for the material used in the breakwaters in Europoort; (2) for sand to make concrete; and (3) for sand, which was used to heighten construction sites. The last type of sand is very common along the Dutch coast in the southern North Sea; the other types are found along the British east coast only.

The feasibility of an offshore mining operation depends mainly on local circumstances. The low quality sands off the Dutch coast can only compete with other sands of other areas in price to only 20 km inland. LÜTTIG (1973) mentioned the delivery of aggregates from England in northern Germany at competitive prices. Northern Germany is poor in aggregates, they have to be transported along canals from inland sites. For Western Holland the situation is different despite the shorter shipping route from England, since in this case good inland waterways are available for the transport of material from inland sites.

As far as the quality is concerned attention is drawn to the article by WILLIAMS & DUANE (1975), who suggest the use of waste materials in the coastal zone to save high quality material for a more proper application. In constructions like breakwaters a special gradation is usually required, which cannot be met with by waste material. Application could be found therefore in using waste material as filling material for instance to build offshore islands. In such a case the transport and loading costs will probably be much higher than those resulting from exploiting the seabed by trailing suction dredgers, which dump the material directly at the site.

INVESTIGATION FOR SAND AND GRAVEL

General

The decision to use the British offshore gravel for the foundation of the breakwaters was based upon samples from the area. During the production it appeared that the product delivered did not meet with the grades required. Apparently the material in the licensed area was more variable than anticipated. A site investigation was carried out by the Netherlands Geological Survey together with the Ministry of Public Works, North Sea Department, which provided a vessel and rendered technical support. The geological results, laid down in a report of the survey (NETH. GEOL. SURV., 1974), have been published, together with additional technical information by VAN OOSTRUM (1973).

Geophysical investigation

First a geophysical survey was carried out in the area. The

application of a subbottom profiler – which scans the subbottom discontinuities and thus provides the basic information for a geological concept – is quite obvious. In this respect there is no difference from the information wanted for cassiterite exploration or required for construction purposes, the geophysical methods helping to unravel the composition of the geological and sedimentological system.

In dealing with gravels the application of the known profilers is really hampered by the coarse components, which have a scattering effect on the energy waves, thus prohibiting their penetration. Nevertheless the results of the Sonia system, applied here, were good enough to get a good indication of the presence and distribution of gravelly layers.

Sampling equipment

Representative sampling of loose sediments is difficult, and

becomes more so the coarser the material involved. Straight flush coring devices give only approximate information, which in this case was far from sufficient. It was decided to use a vibrocorer with a 300 mm barrel. Its penetration was restricted to less than 1 metre only.

Bearing in mind, however, that a trailing suction dredger takes away a thin surficial layer only over a wide area, a sampling programme to several decimetres below the sea-bed was informative. If it had been possible to get really representative samples to such a depth at a high speed renewed sampling could easily be done after the first dredging phase and a good insight into the material to be collected would be assured. However, the sampling equipment on the market did not meet the requirements. The Van Veen grab and Reineck box sampler did not work satisfactorily. The gravel may stick between the snaps of the sampler, due to which sand is washed out.

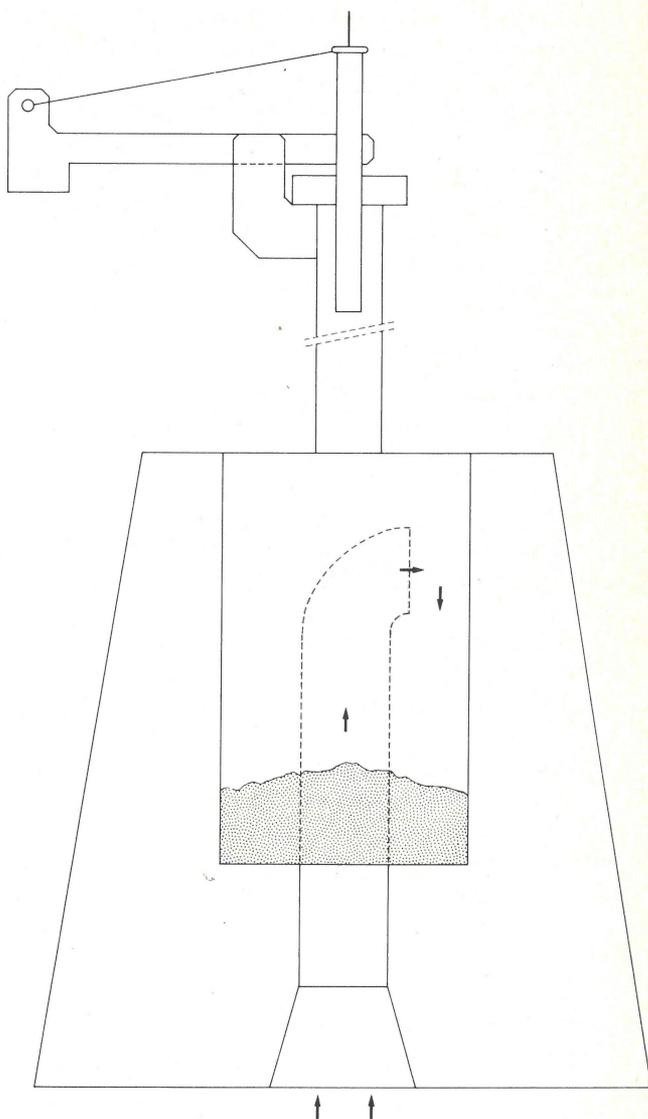
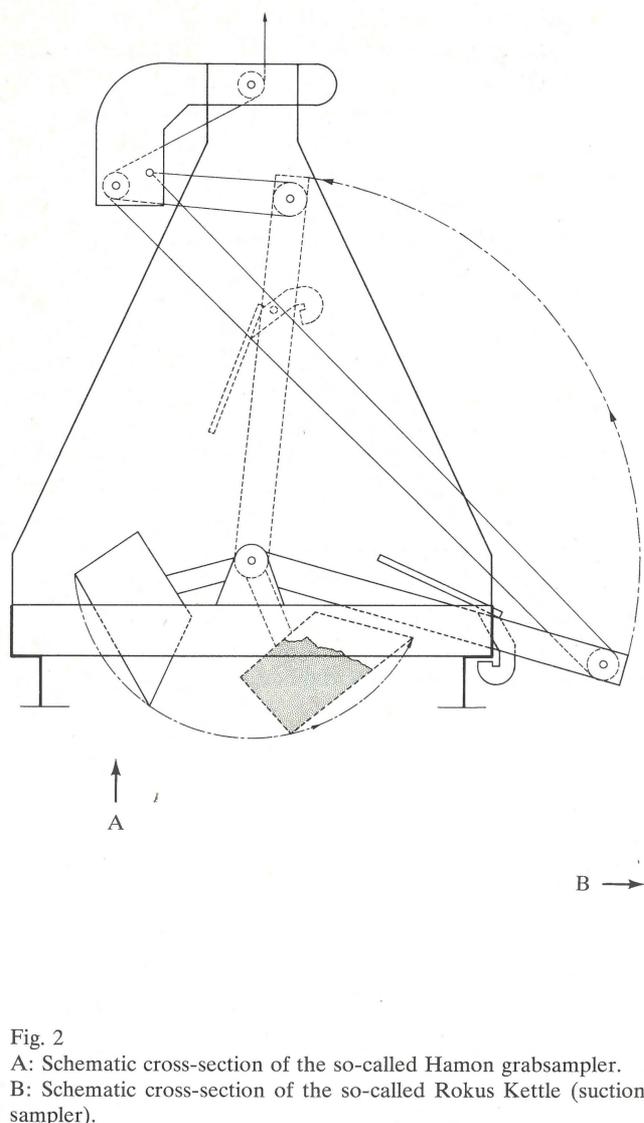


Fig. 2
A: Schematic cross-section of the so-called Hamon grab sampler.
B: Schematic cross-section of the so-called Rokus Kettle (suction sampler).

Based on the Reineck box sampler a new device was constructed, the so-called Hamon-grab. Fig. 2A gives a schematic impression of its working principle. After the sample is shoveled the box containing the material is pressed against a plate, which prevents any loss of material.

Another new device constructed for this purpose is the so-called 'Rokus kettle'. On Fig. 2B a cross section is represented. The working principle is as follows: the kettle filled with air is lowered into the sea, a valve preventing its escape. As a result of water entering the kettle through the pipe in the bottom the air is compressed to a pressure that corresponds to the water depth. Once on the sea-bed the valve opens automatically, the sudden escape of air creating an impressive suction. The bottompipe with a diameter of 20 cm penetrates 50 cm into the sea-bed, all the material being sucked into the kettle. Pebbles of over 30 cm diameter have been sampled. The swan's neck form of the pipe makes subsequent loss of material impossible.

The advantage of the hamon grab is the possibility of sampling without anchoring the ship, the advantage of the kettle is a deeper penetration, a better performance in coarse sediments and a greater quantity of the sample.

On the basis of the samples, collected with the equipment described above, a map has been constructed (Fig. 3). The sampling points with an equal percentage have been contoured. This isoconcentration chart was later used as a guide for the trailing lines of the dredging vessel. The product appeared to have been improved. A prerequisite is of course the presence of a high precision positioning system.

TRANSPORTING AGENTS AND CONCENTRATION OF MARINE AGGREGATES

General

It is a generally accepted view that the continental shelves of the world are floored with relict sediments. They mainly date from the Quaternary and they seem to be related especially to the last post-glacial sealevel rise (EMERY, 1968). In some places older sediments might be found e.g. off S.E. Australia, where coarse Tertiary deposits found on shore, might extend offshore. The repeated low sealevel stands and the distribution of the glaciers themselves have greatly influenced sedimentation in the areas of the present shelves. The effect of the transporting agents in building mineable aggregates will be discussed on the basis of the geological knowledge of the NW-European shelf. In this respect this shelf is interesting, because mineable aggregates of various depositional types occur (c.f. VEENSTRA, 1974).

Fluviatile aggregates

On the continent the main rivers debouching on the present-day shelf are the Elbe, Weser in Northwestern Germany,

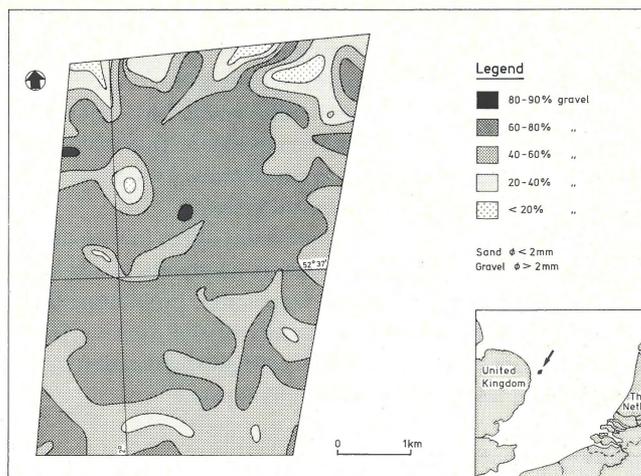


Fig. 3
Isoconcentration map of gravel mining area off Norfolk (U.K.).

Rhine and Meuse in The Netherlands, Seine and Gironde in France. The geological history of NW-Germany, and The Netherlands is such that during the Quaternary the area can be considered as the delta plain of the rivers mentioned.

The rivers have supplied coarse material, including gravel, as a result of the low sealevel stands but even more because of tectonic uplift in the source areas. However, deposition of the coarser components in appreciable amounts took place far from the present day coast line.

Fluviatile gravel deposits in The Netherlands are restricted to the Limburg area, i.e. 200 km inland from the coast. Along the Dutch/German coast fluviatile sands have been deposited, but the material is suitable for infill purposes only (c.f. Fig. 4).

Apparently the Seine was capable of transporting coarse sand and gravel further downstream than the present place of debouchure, Le Havre. This, however, results from the short distance to the source area of the sand and gravel. For the oil terminal Le Havre/Antifer the required gravel has been dredged offshore (ANDREAE, 1975). Also the Gironde brought gravel deposits to the area of the present mouth and perhaps beyond (ALLEN ET AL., 1970), but it is doubted that offshore gravel deposits are of sufficient quantity to be mineable. The whole area between the Gironde estuary and the Spanish frontier in the south seems to bear fluviatile gravel and coarse sands (cf. ALLEN ET AL., 1971).

On the British side the Thames will have contributed material in Pleistocene times, likewise part of the aggregates off the British eastcoast is thought to represent fluviatile deposits (NETH. GEOL. SURV., 1974).

The conclusion is that on the NW European shelf fluviatile sands and gravel deposits are restricted to sites, which even today are at short distances from the source area.

(Fluvio)glacial aggregates

Glacial activities have led to mineable aggregate deposits in

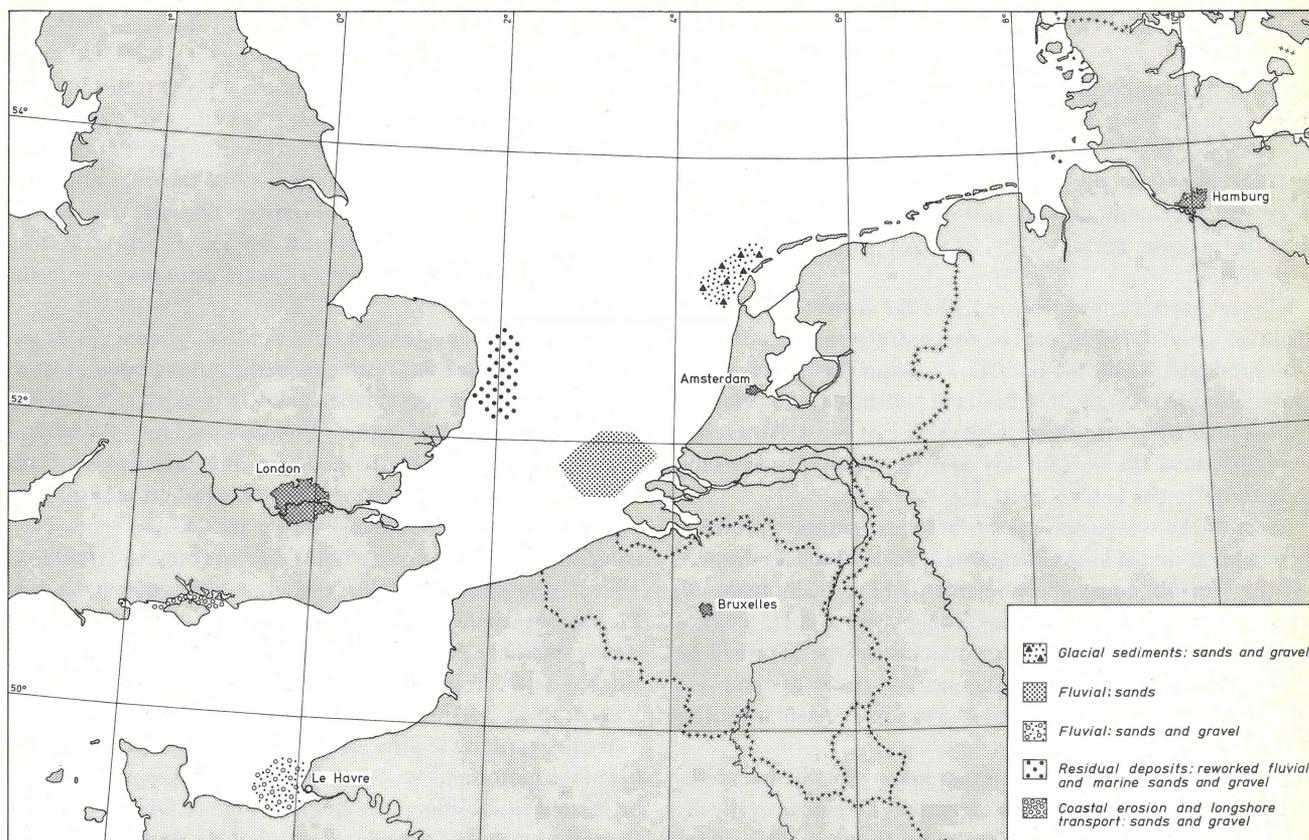


Fig. 4
Relation between mined aggregates and geological concentration mechanisms in W-Europe.

various ways. Material deposited by the glaciers consists of boulder clay, the boulder content being strongly variable as it depends on the type of bedrock in the source area, morphology etc.

Concentration of these coarse components, like lag deposits might lead to economic deposits. Occurrence of such coarse lag deposits is reported by HOLTEDAHL & BJERKLI (1975) on the edge of the Norwegian Channel and by SEIBOLD ET AL. (1971) from the Baltic Sea. Some gravel of this type was dredged in Holland in a Holocene tidal gully, which had eroded the boulder clay. It is noted, however, that in general boulder clay is not susceptible to abrasion or erosion. Just for that reason it was applied in the construction of the first dam, closing an important lagoon in The Netherlands, the Zuiderzee dike. Only small quantities of aggregate will have originated in this way.

More interesting are the fluvioglacial deposits, which range from clay to coarse sands and gravels. Although they are quarried in various places, in The Netherlands the distribution of fluvioglacial coarse sands and gravel is restricted. From the mainly clayey composition of the glacial and fluvioglacial sediments the conclusion has been drawn that in the adjoining North Sea the presence of aggregates would be doubtful.

Despite extensive surveys economic quantities of coarse fluvioglacial material have not been found. The recent finds of gravel of (fluvio)glacial origin on the German shelf are further proof that slightly different conditions in source area have an important effect on the grain size of the resulting sediment.

Also along the British coast, roughly north of the Thames and in the Irish sea fluvioglacially or glacially supplied coarse material is present (e.g. OWENS, 1977).

A final contribution of the glacial activities, that can be important, is the formation of ice pushed ridges. Due to ice-pushing otherwise deeply buried layers are outcropping in The Netherlands and, as a result, can be exploited. Although in the North Sea the phenomenon of ice pushing has been observed, no typically coarse sediments have been involved. The older sediments are mainly fluvial, having settled close to the edge of the deltaic plain.

Apparently, as far as glacial concentrations are concerned, only fluvioglacial ones seem to lead to economically interesting deposits. The typical subglacial tunnel valley deposits are of special interest, their occurrence is difficult to predict.

Coarse graded, glacial related, sediments do not occur far beyond the line, which marks the ultimate limit of glaciations.

Coastal processes

These can be important contributors to offshore aggregate formation. A good example is the situation in the Solent between the Isle of Wight and the British mainland. DYER (1972) writes that, due to coastal erosion, high quantities of material are brought into the Solent. Longshore currents support the process, various paths of transport having been established.

Coastal barriers now drowned, like the Brown Bank in the North Sea (OELE, 1971), may be concentrations of good mineable products. Again the baseline situation is important. The material supplied to the middle of the North Sea in the Pleistocene is finer than that along the British east coast. As a result the banks near the present day coast consist of coarser sand than those in the central part.

Most of the mineable deposits are concentration products or combinations of above mentioned mechanisms. In the area off the Norfolk coast glacial elements have been analysed, glacial contributions have therefore played a role, albeit a minor one. The valley infilling material in the area will be related to fluvial action, whereas the cover of sand and gravel represents a marine transgression deposit with elements of coastal erosion.

The above review has shown that many types of sediments occur on the North Sea shelf in particular. This is caused by the variation of the conditions from place to place. The subsequent transgression has not flattened out the original differences, although KRUIT (1963) once suggested a gradual fining of the material due to such a process. Stochastic models like those proposed by SWIFT ET AL. (1971) also allowing for an erosion with subsequent unidirectional transport and sedimentation, therefore seem to be based on a somewhat oversimplified depositional model.

THE OCCURRENCE OF SAND AND GRAVEL ON THE SHELVES

Following the review on the formation of productive sand and gravel deposits it might be of interest to discuss the presence or probable presence of such deposits on the shelves. Because of the generally recognized importance of the climate the present climatic zoning may serve as a starting point for a subdivision.

Tropical zone

In the last decade many papers have been published with regard to the West African shelf sediments. The paper by EMERY ET AL. (1975) gives a good review of the earlier publications, although the paper itself hardly deals with recent and relict sediments. An older review can be found in the printed collection of lectures, presented at a meeting on the East Atlantic continental margin (DELANY, 1971).

There is a general agreement, that the recent sediments are

carbonate-rich sands or silts and clays (ALLEN, 1964; MC MASTER & LACHANCE, 1969; MARTIN, 1971; HOSPERS, 1971; CALVERT & PRICE, 1971). Coarse material is not transported to the shelves themselves. Some longshore transport takes place as noted by BROGNON (1971), which results in the formation of offshore bars of a sandy composition like the ones along the Angolan coast. TUCKER (1973) even describes the transport of relatively coarse quartz sands in an opposite direction i.e. from the shelf into the present Sierra Leone estuaries, where the sand builds the bars.

The present day situation does not lead to deposits of aggregates, which are interesting from the mining point of view. However, coarser and cleaner material was supplied in the Late Pleistocene and early Holocene. ALLEN (1964) and MARTIN (1971) describe the presence of coarse sands, of this age, which could be inferred from radiocarbon datings. Borings in the Niger delta have shown that coarse sands even constitute an important part of the delta complex (OOMKENS, 1975). An area east of the Niger delta supplied coarse sands in Pleistocene times according to HOUBOLT (1973). Also the above mentioned sands off the Sierra Leone coast are considered to be relict on the basis of strong arguments (MC MASTER ET AL., 1971; TUCKER, 1973).

With regard to the area under discussion the tectonic stability of the hinterland is evident. The supply in the past seems to be related to subsiding movements of the sedimentary basins (Senegal basin, Niger basin). In case of the coarse sediments off Guinea and Sierra Leone the short distance to the source area must have contributed highly to the type of sediment deposited. Apparently the supply of aggregates in the past was governed by local conditions on top of the dramatic sealevel movements.

A short review of the scarcer and less coherent information on the tropical shelf sediments in other parts of the world may give a better overall picture.

Very little information is available on the African east coast. MEYER (1974), describing the composition of heavy-mineral bearing sands in front of the Zambezi delta, mentions the presence of medium sands, but their source and age are not part of his study.

Further eastward in the Bay of Bengal terrigenous sediments, mainly consisting of fine sand, are found in a small area near the Ganges delta (SIDDIQUE, 1967). Although in the Pleistocene gravels and coarse sands have been transported by the rivers, a tectonic uplift of the delta plain during the Pleistocene, which is reported by NIYOGI (1973), could exclude the presence of important quantities of aggregates on the shelf. In the adjoining Andaman Sea the present author carried out an offshore investigation for cassiterite along the Thai coast. It appears that bedrock is covered by a layer of fine sand only, a lateritic soil sometimes being intercalated.

East of the Malay Peninsular no coarse sands and gravels are encountered. Here also recent investigations for tin (OELE & YOUNG, 1975) revealed the presence of a basin, which continued to subside in the Late Quaternary, but again only fine

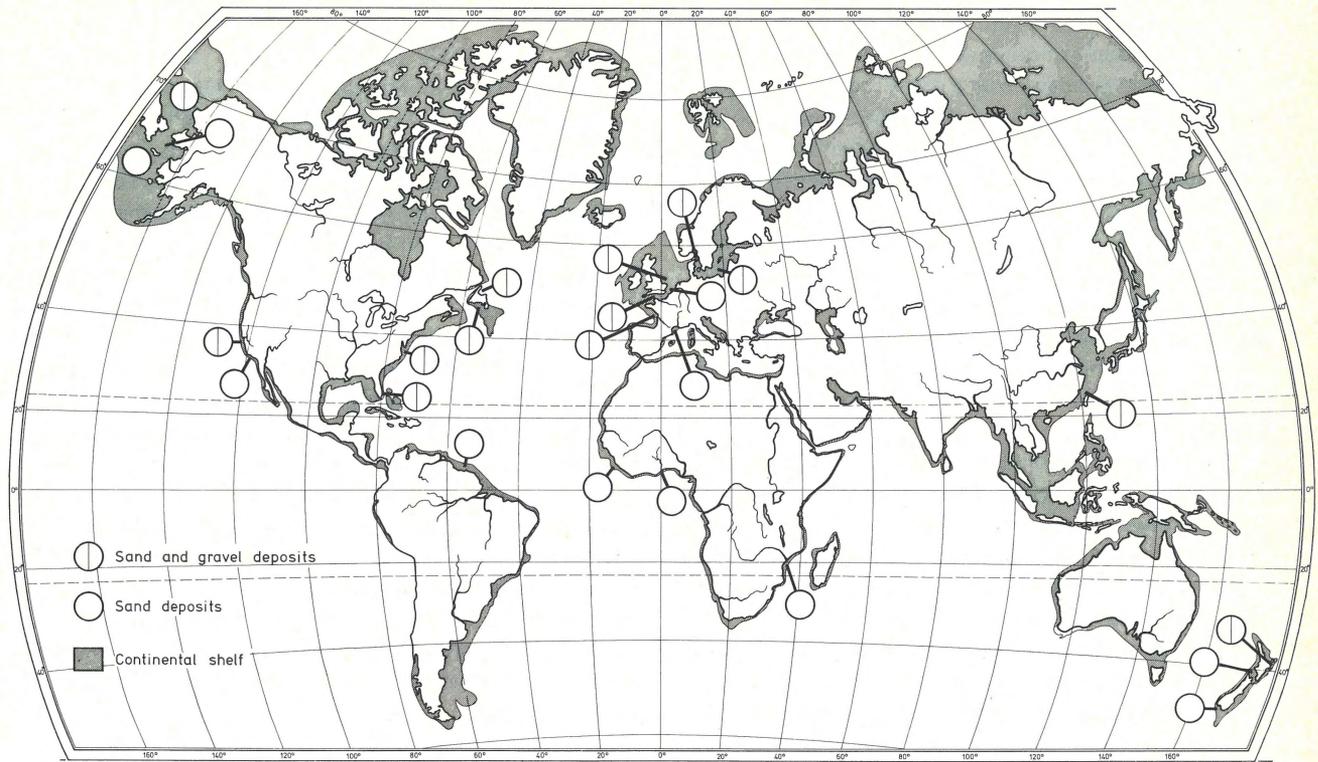


Fig. 5
Distribution of gravel and coarse sands for industrial application on the continental shelves of the world.

material is and was supplied to the area of the present shelf by the Pahang river.

The work of VAN ANDEL (1965), ALEVA ET AL. (1973) and NIINO & EMERY (1961) reveals that the Indonesian Sunda shelf, the Sahul shelf and Indochinian offshore zones bear fine sediments only.

The erosional channels that cross the Sunda shelf have a basal infill, which can be coarse. The depth of occurrence and kind of overburden make the sands and gravels hardly attractive as an aggregate mining object.

The effects of the Pleistocene sea-level changes on the sedimentation on the Sahul shelf are not known, whereas EMERY (1968) indicates that relict sediments along the China coast border the shelf edge, not being exposed to a great extent along the coast.

Finally the literature confirms the predominance of fine sands, mainly biogenic on the tropical shelf zone around America (NOTA, 1971; GIBBS, 1973). Although according to NOTA (1958) the Pleistocene rivers were capable of contributing coarser sands to the Guiana shelf, the observations of VAN DER HAMMEN (1972) make it clear that again local conditions were favourable enough. VAN DER HAMMEN has shown that the tropical rain forest in the Amazon area alternated with open grassland savannahs as a reaction to the climatic changes in the Pleistocene. This implies that even in the Pleistocene no material other than fine clastic particles could reach the con-

tinental shelf.

In this connection it is noted that, with regard to the climatic distribution during the last glaciation, the map presented by CLIMAP (1976) does not give indications for an other possible climatic, i.e. humid or arid, influence on the coarse sediment production in the zone under discussion.

From the foregoing it can be concluded (cf. Fig. 5):
(1) present-day sediments in the tropical zone are mainly fine, mostly carbonate-rich;
(2) coarse sands have been brought into the present shelf area in the Late Pleistocene and early Holocene at some localities. This process, however, was controlled by local conditions (e.g. coarse sedimentation in the Senegal and Niger basin, whereas the in a similar way subsiding Pahang basin (Malaysia) received fine sediments only; the assumed absence of gravel and coarse sands of the Pleistocene underlying the present day sediments off the Indian delta in the Bay of Bengal);
(3) no obvious further climatic influence (arid or humid) could be traced as a second source.

Subtropical zone

Contrary to the tropical zone a subdivision of the subtropical zone in arid and humid areas appears to be useful.

As far as the arid areas are concerned SEIBOLD ET AL. (1973, p. 80) concluded that the Persian Gulf is 'a sedimentation

model for a marginal sea within the arid climatic zone'. Apparently small amounts of sands are found in those seas, even close to the mountain ridges, which deliver some terrigenous material in the form of influxes. The sands present contain high amounts of carbonates. The environment is favourable for lithification of the deposits soon after sedimentation, a process here taking place under water.

Also on the N.W. African shelf the presence of carbonate-rich sands with some gravel is reported by TOOMS ET AL. (1971) and MC MASTER & LACHANCE (1969). The latter also describe lithified sediments, the lithification having taken place in the Pleistocene, apparently under subaerial conditions. Such rocks have also been observed on the Israelian shelf (HALL & BACKLER, 1975).

Special conditions rule in the Great Australian bight, where the drainage pattern is directed landward. As a result the shelf south of Australia is not fed by rivers with sediment. Coastal abrasion is responsible for some terrigenous material along the coast. The calcareous sediments dominate however (CONOLLY ET AL., 1970).

Also in the more humid areas the present rivers appear to contribute only small amounts of coarse sand and gravel. The situation in the Pleistocene seems less clear. No coarse material of that period has been reported from important rivers like the Mississippi and Rhône. The presence of coarse sand along the Florida coast described by HYNE & GRANT GOODELL, 1967 seems to be related to longshore transport in a westward direction. The material has been supplied by rivers in the east.

Other occurrences in the humid zone coincide with tectonic unstable areas: around Taiwan (BOGG, 1975) and the Seto Inland Sea in Japan (GEOL. SURV. JAPAN, 1975), where it is actually mined. Bogg is the only one, to mention the occurrence of gravel.

The conclusion can be drawn that: (1) as far as the subtropical zone is concerned sand and gravels are almost absent near present day arid zones, with a possible exception in the sedimentation along the Texas coast, north of the Rio Grande (VAN ANDEL, 1960); and (2) that in the humid zones sands and occasionally gravel can be present in mineable amounts especially in unstable areas. The vegetational cover as revealed in CLIMAP 1976 supports the view that in some of the areas discussed no supply of coarse material could have taken place in the past, for instance in the Mississippi drainage area.

The temperate zone

As mentioned before, the Northwest European shelf area is a good example of an aggregate-bearing shelf. With reference to the concentrating mechanisms discussed there, the situation on the other shelves in this climatic zone is reviewed briefly.

Besides the North Sea and British Channel other European sea areas that are aggregate bearing are the Irish sea and the Baltic Sea. A situation which is geologically comparable to the European one is found along the U.S./Canadian East coast. Many authors have already described the occurrence of sand

and gravel in the area between Boston and the Lawrence Bay (SCHLEE & PRATT, 1970; LORING & NOTA, 1973; KING, 1969; US NAT. AC. SCI., 1975). The deposits, which are mined at certain localities, are the result of fluvial, fluvioglacial and marine concentration. Also along the West coast of the U.S. the presence of mineable sand is recorded. The presence of sand and gravel along the Canadian coast in a more northerly direction can be assumed from the geological history. The supposition may find support in the description of the Alaskan shelf sediments by DIETZ ET AL. (1964).

Little information is available with regard to the South American shelf sediments. AUER (1974) mentions the presence of coarse Pleistocene deposits in the mouth of the Rio Negro, which may indicate the presence of sand and gravel in near-shore area.

As far as the West Pacific coastal zone is concerned it appears, that the shelf around New Zealand is aggregate bearing (CARTER, 1975). Because of the coastal development and recent tectonic uplifts (STEVENS, 1973) the sediments are probably relict and partly of glacial origin.

Economic gravel and sand deposits will be found in this climatic zone, where the conditions are as concluded in the previous section.

CONCLUDING REMARKS

Sand and gravel for industrial purposes are mined only in a few offshore areas: the Northwest European shelf – especially the North Sea and British Channel –, the U.S. East Coast and the Seto Inland Sea (Japan) are the most important at the moment. The exploitation reflects the high demand from adjoining densely populated areas. The question arises of whether any other sites are prospective with regard to aggregate exploitation.

In general the shelves in the tropical zone are non-aggregate-bearing, only some coarse sand is present locally. In the subtropical zone the seas in the arid areas also lack exploitable industrial sand and gravel, whereas in more humid and unstable areas such material can be present. The latter areas together with the sea-floors in the temperate climate zone are the most attractive for sand and gravel prospection.

Gravel is found, where the source area is not far away, unless the material has been supplied by glaciers. Coarse sands are more widely distributed, but outside the once glaciated zones strongly related to present day river mouths. Even the distribution of coarse sand is more limited than generally assumed.

Apart from the areas, where aggregate exploitation is taking place it seems that only a few sites could be attractive to economic mining. For example the Taiwan shelf. For most of the densely populated areas even marine aggregate-mining will be no real possibility. This relative scarcity of the commodity, however, obliges the geologists to apply their knowledge as far as possible to assist in meeting the demand.

REFERENCES

- Aleva, G. J. J., E. H. Bon, J. J. Nossin & W. J. Sluiter 1973 A contribution to the geology of a part of the Indonesian tinbelt: the sea areas between Singkep and Banka Islands and around the Karimata Islands – *Geol. Soc. Malaysia Bull.* 6: 257-271.
- Alan, G. P., A. Klingebiel & A. de Resseguier 1970 Evolution et signification dynamique de quelques indices granulométriques des sédiments de l'embouchure de la Gironde – *Cahiers oceanogr.* 22: 801-813.
- Allen, G. P., P. Castaing & A. Klingebiel 1971 Preliminary investigation of the surficial sediments in the Cap-Breton Canyon (Southwest France) and the surrounding continental shelf – *Mar. Geol.* 10: M27-M32.
- Allen, J. R. L. 1964 The Nigerian continental margin: bottom sediments, submarine morphology and geological evolution – *Mar. Geol.* 1: p. 289-332.
- Andreae, J. F. R. 1975 Aggregate mining – *De Ingenieur* 87: 649-654.
- Auer, V. 1974 The isorhythmicity subsequent to the Fuegro-Patagonian and Fennoscandian ocean level transgressions and regressions of the latest glaciation – *Ann. Acad. Sci. Fennicae ser. A III Geol.-Geogr.* 115: pp. 88.
- Boggs, S. 1975 Seabed resources of the Taiwan continental shelf – *Acta Ocean. Taiwanica* 5: 1-18.
- Brognon, G. 1971 The geology of the Angola coast and continental margin – In: F. M. Delany (ed.): *The geology of the East Atlantic continental margin* – Great Britain Inst. Geol. Sci. Rept. 70/16: 143-152.
- Calvert, S. E. & N. B. Price 1971 Recent sediments on the South West African shelf – In: F. M. Delany (ed.): *The geology of the East Atlantic continental margin* – Great Britain Inst. Geol. Sci. Rept. 70/16: 171-186.
- Carter, L. 1975 Sedimentation on the continental terrace around New Zealand: a review – *Mar. Geol.* 19: 209-237.
- CLIMAP 1976 The surface of the ice-age earth – *Science* 191: 1131-1137.
- Conolly, J. R., A. Flavelle & R. Dietz 1970 Continental margin of the Great Australian Bight – *Mar. Geol.* 8: 31-58.
- Cruikshank, M. J. & H. D. Hess 1975 Marine sand and gravel mining – *Oceanus* 19: 32-44.
- Delany, F. M. (ed.) 1971 *The geology of the East Atlantic continental margin* – Great Britain Inst. Geol. Sci. Rept. 70/16.
- Dietz, R., A. J. Carsola, E. C. Buffington & C. J. Shipek 1964 Sediments and topography of the Alaskan shelves – In: R. L. Miller (ed.): *Papers in Marine Geology, Shepard Commemorative Volume* – Macmillan Cy (New York).
- Dyer, K. R. 1972 Recent sedimentation in the Solent area – *Mém. B. R. G. M.* 79: 271-280.
- Emery, K. O. 1968 Relict sediments on continental shelves of world – *Am. Ass. Petr. Geol. Bull.* 52: 445-464.
- Emery, K. O., E. Uchupi, J. Phillips, C. Bowin & J. Mascle 1975 Continental margin off Western Africa: Angola to Sierra Leone – *Am. Ass. Petr. Geol. Bull.* 59: 2209-2265.
- Geol. Surv. Japan 1975 Exploitation of offshore sand and gravel in Japan – *Comm. Coord. Joint Prosp. Min. Res. Asean Offsh. Areas (CCOP), Proc. 12th session:* 288-293.
- Gibbs, R. J. 1973 The bottom sediments of the Amazon shelf and tropical Atlantic Ocean – *Mar. Geol.* 19: M39-M45.
- Hall, J. K. & N. Bakler 1975 Detailed bathymetric and shallow seismic surveys at five locations along the Mediterranean coast of Israel – *UN-UNDP/Geol. Surv. Isr. Offsh. Dredging Proj., Field Rept.* 1: 21 pp.
- Holtedahl, H. & K. Bjerkli 1975 Pleistocene and recent sediments on the Norwegian continental shelf (62°N-71°N) and the Norwegian Channel area – *Norges Geol. Unders.* 316: 241-252.
- Hospers, J. 1971 The geology of the Niger delta area – In: F. M. Delany (ed.): *The geology of the East Atlantic Continental Margin* – Great Britain Inst. Geol. Sci. Rept. 70/16: 143-152.
- Houbolt, J. J. H. C. 1973 The deep sea canyons in the Gulf of Guinea near Fernando Poo – *Verh. Kon. Ned. Geol. Mijnb. Gen.* 30: 7-18.
- Hyne, N. J. & H. Grant Goodell 1967 Origin of the sediments and submarine geomorphology of the inner continental shelf of Choctawhatchee Bay, Florida – *Mar. Geol.* 5: 299-313.
- King, L. H. 1969 Submarine endmoraines and associated deposits on the Scotian shelf – *Geol. Soc. Am. Bull.* 80: 83-96.
- Kruit, C. 1963 Is the Rhine delta a delta? – *Verh. Kon. Ned. Geol. Mijnb. Gen.* 21: 254-266.
- Loring, D. H. & D. J. G. Nota 1973 Morphology and sediments of the Gulf of St. Lawrence – *Bull. Fish. Res. Board Can.* 182:147 pp.
- Lüttig, G. 1973 Exploration for and exploitation of sand, gravel and related non-metallic deposits on the European shelf – Paper presented at the Interocean 1973 in Düsseldorf.
- Martin, L. 1971 The continental margin from Cape Palmas to Lagos: bottom sediments and submarine morphology – In: F. M. Delany (ed.): *The geology of the East Atlantic continental margin* – Great Britain Inst. Geol. Sci. Rept. 70/16: 79-95.
- Mc. Master, R. L. & T. P. Lachance 1969 Northwestern African continental shelf sediments – *Mar. Geol.* 7: 57-67.
- Mc Master, R. L., T. P. Lachance, A. Ashraf & J. de Boer 1971 Geomorphology, structure, and sediments of the continental shelf and upper slope off Portuguese Guinea, Guinea and Sierra Leone – In: F. M. Delany (ed.): *The geology of the East Atlantic continental margin* – Great Britain Inst. Geol. Sci. Rept. 70/16: 105-124.
- Meyer, K. 1974 Laboruntersuchungen mariner Schwermineralsande aus Moçambique – *Erzmetall.* 27: 31-37.
- Netherlands Geological Survey 1974 Geologisch onderzoek in de grindconceessie Norfolk – *Rapport* 1136.
- Niino, H. F. & K. O. Emery 1961 Sediments of shallow portions of East China Sea and South China sea – *Geol. Soc. Am. Bull.* 72: 731-762.
- Niyogi, D. 1973 Quaternary geology of the Bay Coastal Plain of Eastern India – *Ninth Congr. Int. Un. Quat. Res. Abstr.:* 270.
- Nota, D. J. G. 1958 Sediments of the Western Guiana Shelf – *Med. Landbouwhoges. Wageningen* 58: 98 pp.
- 1971 Morphology and sediments off the Marowijne river Eastern Surinam shelf – In: *Scientific investigations on the shelf of Surinam H.N.L.M.S. Luymes* – *Hydrogr. Newsl. Spec. Publ.* 6: 31-35.
- Oele, E. 1971 The Quaternary geology of the Southern area of the Dutch part of the North Sea – *Geol. Mijnbouw* 50: 461-474.
- 1973 The gravel and sand supply in The Netherlands – *Verh. Kon. Nederl. Geol. Mijnb. Gen.* 29: 81-84.
- Oele, E. & S. K. Young 1975 Reconnaissance offshore survey for cassiterite and other detrital heavy minerals off the East coast of peninsular Malaysia. Paper presented at the 12th session of the Comm. Joint Prosp. Min. Res. Asean Offsh. Areas (CCOP).
- Oomkens, E. 1974 Lithofacies relations in the Late Quaternary Niger delta complex – *Sedimentology* 21: 195-222.
- Oostrum, W. H. A. 1973 Grind uit zee – *Land en Water:* 10-21.
- Owens R. 1977 Preliminary report on the superficial sediments of the North Sea between 56° and 59°N, 2°W and 2°E. Great Britain – *Inst. Geol. Sci. Rept.* 77/13.
- Rowe, R. P. 1976 Dredging for marine aggregates in the U.K. – *Internat. Dredg. Ports Constr. Ser.* II/3: 15-19.
- Schlee, J. & R. M. Pratt 1970 Atlantic continental shelf and slope of the United States. Gravels of the Northeastern part – *Geol. Surv. Prof. Paper* 529-H: 40 pp.
- Seibold, E., L. Diester, D. Fütterer, H. Lange & F. Werner 1973 Holocene sediments and sedimentary processes in the Iranian part of the Persian Gulf – In: B. H. Purser (ed.): *The Persian Gulf* – Springer Verlag: 57-80.
- Seibold, E., N. Exon, M. Hartmann, F.-C. Kögler, H. Krumm, G. F.

- Lutze, R. S. Newton & F. Werner 1971 Marine geology of Kiel Bay. Sedimentology of parts of Central Europe – Int. Sed. Congr. 1971. Guidebook VIII: 209-235.
- Siddique, H. N. 1967 Recent sediments of the Bay of Bengal – Mar. Geol. 5: 249-291.
- Stevens, G. R. 1973 Late Holocene marine features adjacent to Port Nicholson, Wellington New Zealand – New Zealand J. Geol. Geophys. 16: 455-484.
- Swift, D. J. P., D. J. Stanley & J. R. Curray 1971 Relict sediments on continental shelves: a reconsideration – J. Geol. 79: 322-346.
- Tooms, J. S., C. P. Summerhayes & R. L. Mc. Master 1971 Marine geological studies on the North-West African margin: Rabat-Dakar – In: F. M. Delany (ed.): The geology of the East Atlantic continental margin – Great Britain Inst. Geol. Sci. Rept. 70/16: 9-26.
- Tucker, M. E. 1973 The sedimentary environments of tropical African estuaries Freetown Peninsula, Sierra Leone – Geol. Mijnbouw 52: 203-216.
- U.S. National Academy of Sciences 1975 Mining in the outer continental shelf and in the deep ocean – Washington D.C.: 119 pp.
- Van Andel, T. 1960 Sources and dispersion of Holocene sediments, Northern Gulf of Mexico – In: Am. Ass. Petr. Geol., publ. Recent Sediments, Northwest Gulf of Mexico 1951-1958: 34-55.
- 1965 Morphology and sediments of the Sahul shelf, North-western Australia – Trans. New York Acad. Sci. Ser. II, 28: 81-89.
- Van der Hammen, T. 1972 Changes in vegetation climate in the Amazon Basin and surrounding areas during the Pleistocene – Geol. Mijnbouw 51: 641-644.
- Veenstra, H. J. 1974 Gravels from the North Sea – Bull. Int. Ass. Eng. Geol. 10: 31-34.
- Williams, S. J. & D. B. Duane 1975 Construction in the coastal zone: a potential use of waste materials – Mar. Geol. 18: 1-15.