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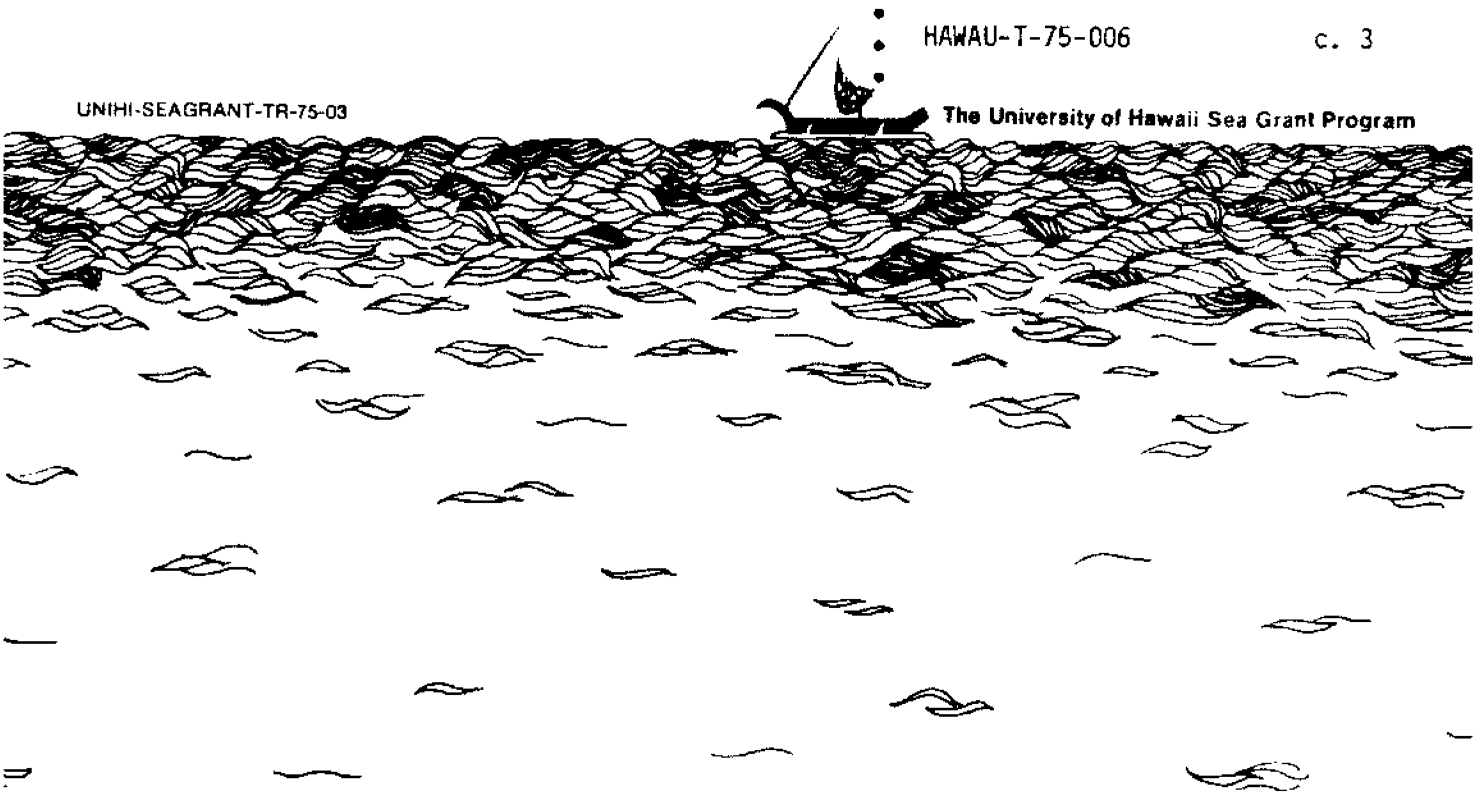

Offshore and Other Sand Resources for Oahu, Hawaii

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OFFSHORE AND OTHER SAND RESOURCES FOR OAHU, HAWAII

by

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ABSTRACT

Sand is a vital raw material for the construction industry. Greatest usage in Hawaii occurs on Oahu from sources at Papohaku Beach, Molokai and crushed dune-sand limestone at Waimanalo. In view of the law ending exploitation of beaches, alternate sources for the future are discussed and their sizes tabulated. Factors of economics, quality, and pollution will decide which of the following sources will be used: (1) old beach ridges and dunes, now inland and commonly needing crushing on Oahu, Kauai, and Maui; (2) basalt lava to be quarried; (3) quartz sand to be imported from a continental source; and (4) sand bodies off-shore but beyond the beach systems to be dredged from around and near Oahu.

Location, thickness, and extent of offshore sand bodies near Sand Island, Mokuleia, Waimea, Kahana, and Penguin Bank are mapped and described. It is recommended that the quality of these deposits be determined by sampling from pilot dredge runs or long cores.

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INTRODUCTION

The aim of this report is to provide for industry and planners an assessment of the sand resources for the island of Oahu. It includes not only known reserves--workable deposits already discovered and inventoried --but also the general magnitude of all resources that are geologically available if one is able to use them economically in this or future generations. In this way an attempt is made to parallel on a local scale the style of response by the U.S. Geological Survey to the Mining and Mineral Policy Act of 1970 (Brobst and Pratt, 1973).

In an attempt to augment the state's known reserves, some nearshore sand bodies discovered by geophysical methods are described and a recommendation that their quality be evaluated is made. Because the construction industry in the Honolulu area is the largest user of sand in the state, the focus of the report is on Oahu. Moreover, Oahu potentially will be the largest user of additional sand for restoration of eroding beaches. Nevertheless, the remarks made apply to the other Hawaiian islands as well.

This is the final report of the Sand Inventory project which was conducted by Hawaii Institute of Geophysics staff and funded by the Sea Grant College Program and the Hawaii Institute of Geophysics of the University of Hawaii.

SAND AND ITS PRINCIPAL SOURCES

Sand is used mainly by the construction industry in concrete, bituminous mixes, fill, mortar, and plaster. Together, sand and gravel constitute the commodity possessing the lowest average unit value of all mineral commodities ($1.11 per ton or about $1.40 per cubic yard or about $1.85 per cubic meter; U.S. average in 1968). The most important commercial sources of the world's sand and gravel are river channels and glaciated terrain (Yeend, 1973). These sources are virtually nonexistent in Hawaii. An ideal commercial deposit should contain about 60 percent gravel and 40 percent sand in order to provide the general proportion of sizes for usage in aggregate and other materials (Goldman, 1961). There are no such combinations in Hawaii. Coarse material used is crushed lava or is excavated from cinder cones. Some individual small smooth stones are taken from stream beds and beaches for ornamental walkways and other specialized uses. Historically, Hawaii's beaches have been excavated to provide sand. The unit value of sand in Hawaii is very high compared with the continental United States, ranging from $5 to $12 per cubic yard over the past 20 years.

The rapid growth of Hawaii's economy during the statehood period increased the exploitation of raw materials needed for construction. The 1970 State Legislature, recognizing the danger to beaches by increased mining, passed Act 136 banning all beach mining in the state effective 1 July 1975.

Hawaiian beach sand comes chiefly from the whole and broken calcium carbonate skeletons of marine animals and plants such as foraminifers, mollusks, algae, corals, and echinoids; some comes from eroded basalt lava and, in special instances, olivine or basalt glass. Individual beaches fluctuate in size as the sand moves onshore and offshore or up and down the beach under seasonal and long-term changes in waves and currents. Sources of sand may change and so may avenues of loss such as transport by currents into deep water or by wind into dunes. Very long-term changes result from fluctuations in sea level. Sources of Hawaiian beach sand, the budget of gains and losses in the individual beach system, and the loss of beach sand are discussed in Moberly et al. (1965), Chamberlain (1968), and Moberly (1968), respectively.

There are several alternatives to mining beach sand. One possibility is to mine sources of sand that are found on land and are not part of the present-day beach system. Old beach deposits and consolidated dunes formed under geologic conditions that existed hundred to hundreds of thousands of years ago are being mined to some extent on Oahu, Kauai, and Maui at the present time. The major drawbacks to this solution are the limited extent of the resources near the main markets and the cost of transporting the material from areas having large supplies. The largest unconsolidated deposit of this type in the state fronts the Mana coastal plain on Kauai. On Oahu, old lithified dunes are being quarried and crushed at Waimanalo and Laie and old beach ridges are excavated at Mokuleia and Kawailoa.

Another potential source of sand is basalt, which can be crushed and sieved to manufacture sand. The quarries mining basalt at present are not designed to produce sand-sized material. However, the management of one of the large local quarries is building a new crushing plant that will produce sand-sized material.

Another option would be to bring in sand from the U.S. mainland or from Australia where large supplies of sand are available. At present, the cost of transporting continental sand to Hawaii makes this an unlikely solution.

A fourth possibility is to mine deposits of sand found in the shallow waters surrounding the Hawaiian Islands. Reconnaissance surveys of the past several years have shown a large amount of sand in the shallow waters around the islands (Moberly and Campbell, 1969; Campbell et al., 1970; Campbell et al., 1971). The positive results obtained from the reconnaissance work indicate the possibility of exploiting the offshore sand deposits and, toward this end, detailed surveys of several areas were carried out to determine the pattern of the areal extent and thickness of the deposits. The seismic reflection method of geophysical prospecting used is an improvement of the method described by Campbell et al. (1971). The EG and G Uniboom Transducer sound source resulted in records with a resolution of 1 meter or less.

Listed in Table 1 are estimates of the best available measurements and mapping of the size of Oahu's sand resources. Because basic legal

TABLE 1. SUMMARY OF OAHU SAND RESOURCES

SOURCE	VOLUME (Millions of cubic yards**)		QUALITY		IMPACT*
	Total source	Likely to be useful	For component of concrete	For beach restoration	
COASTAL ZONE, OAHU					
Onshore					
Alluvium, colluvium, and glacial drift	0.8	0	poor to fair	very poor	slight to severe
Raised reefs (to be crushed)	400	4 (?)	very poor	very poor	slight to medium
Lithified dunes (to be crushed)	14	4	very good	good	slight to severe
Inactive dunes and old beach ridges	15	2.7	fair to good	fair to very good	very slight to severe
Beaches above MLLW	10.3	0	fair to excellent	good to excellent	very severe
Offshore					
Beaches and other nearshore to 9 m (30') depth	24	0	fair to excellent	good to excellent	slight to severe but generally unknown
9 m to 18 m (30' to 60') depth	8 (?)	4 (?)	unknown	unknown	slight
18 m to 91 m (60' to 300') depth	520	52 (?)	unknown	unknown	very slight
Dredged reef (to be crushed)	4,100	20 (?)	poor	poor	very severe
INLAND OF THE COASTAL ZONE, OAHU					
Alluvium, colluvium, and glacial drift	700	0.1	poor	very poor	very slight to severe
Basalt (to be crushed)	800,000	320+	good	poor	slight to severe
IMPORTATION TO OAHU					
From Neighbor Islands (principal sources)					
Papohaku, Molokai	3.2	0	excellent	very good	slight, if careful
Mana, Kauai	14.5	10	fair to good	fair to very good	slight
Central Maui (to be crushed)	640	200+	very good	good	medium to severe
Penguin Bank	350+	35 (?)	unknown	unknown	very slight
From Outside the State					
America	large	none	excellent	poor to fair	none to Hawaii
Australia	very large	some	excellent	poor to fair	none to Hawaii
New Zealand, Southeast Asia, etc.	very large	some	excellent	poor to fair	none to Hawaii

*Probability of unfavorable impact on the natural environment due to exploitation of the sand
**1 cubic yard = 0.76 m^3 or about 1.3 tons

and transportation differences are so important, geologic types of deposits are described in the following sections according to their location in the coastal zone of Oahu, inland of the coastal zone of Oahu, and in areas away from Oahu. To avoid repetition, raised reefs and lithified dunes are discussed only in the coastal zone section although some are well inland. Basalt is discussed only in the inland sections although some basalt quarries could be developed within the coastal zone.

RESOURCES OF THE OAHU COASTAL ZONE

Onshore Resources

The usual sources of sand from unconsolidated non-marine deposits are meagre in Hawaii, including the Oahu coastal zone. These are alluvium (stream-bed, flood-plain, and other deposits from running water), colluvium (slump, mudflow, and other deposits from gravity movements down slopes), and drift or diluvium (till and stratified deposits from glaciers). Of these, there are no glacial deposits and almost no useful colluvial deposits in the coastal zone. Some of the colluvium on the talus slopes of Kaena Point might provide a few thousand cubic meters of sand and gravel but the high cost of excavation, sorting, washing, and transportation would preclude profitable mining of such a small amount. Colluvium along the windward coast is too deeply weathered to be considered. About 25 km^2 of coastal areas are underlain by alluvium (Foote et al., 1972; Stearns, 1939), but most have too much silt and clay for any sort of economical extraction of sand. Alluvial resources include small deltas building into Kaneohe Bay, where the fines are carried on out and thus separated, and deposits at the mouths of streams between Makua and Kahe on the leeward coast where there is little chemical weathering and soil formation. Sandbars occasionally form in Halemono and Anahulu estuaries near Haleiwa. Alluvial deposits total about 0.5 km^2 but are very thin and discontinuous. The Kaneohe Bay deltas, where measured, are less than 1.5-m thick where they spread over the fringing reefs. The estimated volume of 6×10^5 m^3 (0.8 million cu yd) which is listed in Table 1 takes into account the muddy lenses in these deposits. Probably none of this will ever be used for anything other than local fill because of its poor quality. Most of the areas are already covered with homes.

About 130 km^2 of Oahu are underlain by reef limestones that were deposited when glacial ice was not on Antarctica and Greenland and the volume of ocean water thereby was greater than at present. The most extensive area is the Ewa Plain (Stearns, 1939), where the limestone is 10's to 100's of meters thick. The only physical limitation to quarrying would be the depth to the water table at about sea level because the cost of pumping the pits dry would increase immensely below that. Two cement plants and several barrow pits use reef limestone. Presumably the limestone could be quarried and crushed to sand size to serve as an inexhaustible reserve, but there is a difference in crushing limestone to feed a portland cement kiln and crushing it to manufacture sand. In the first instance all of the crushed material is used. In the second, the finest sizes cannot be used and must be elutriated with air or water. The raised reefs vary markedly in texture and fossil composition from punky, soft corals to dense shell fragments; it would be almost impossible to quarry selectively in the hard limestone. The resultant sand would have many grains that would collapse under slight stress and thus be very poor for either construction purposes or beach restoration. About 7 x 10^8 m^3 of limestone is above sea level; allowing generously for waste, perhaps 3 x 10^8 m^3 (400 million cu yd) of poor quality sand could be produced. Most of the area is in sugar plantations and military installations; some is in homes and the Campbell Industrial Park.

In contrast to the raised reefs, limestones that are lithified former sand dunes are an important known reserve on Oahu. These rocks, termed eolianites, were formed by the partial natural cementation of dunes of lime sand that blew inland from beaches in the geologic past. The rock is homogenous and when crushed either breaks to the former sand-sized grains or, if it breaks across the old grains, at least they are hard, resistant grains. Eolianite is being quarried and crushed at Waimanalo and Laie; a deposit in Kailua has been completely extracted. Other deposits are scattered from Kahuku to Kahala (Figure 1). About 10.5 x 10^6 m^3 (14 million cu yd) is readily available. Much of the eolianite is covered by houses at Kahala, Waimanalo, and Laie, or is in such thin patches to preclude building an expensive plant, or is inaccessible as on the side of Kahana Valley. But this resource is of great importance to Oahu. Thus, even though part of the deposits are adjacent to urban areas, the value of the reserves must be weighed against the noise and dust created to extract it and present operations should be continued until the available deposits are mined completely.

Dunes and beach ridges that are vegetated and inland of the present-day beach system are another sand resource. On Oahu these inactive dunes and old beach ridges total about 11 x 10^6 m^3 (15 million cu yd). They are most extensive at Kailua and Waimanalo on the windward coast, Maili and Makaha to Makua on the leeward coast, and along the north shore (Figure 2) where deposits are being exploited at Mokuleia and Kawailoa. Formerly there were operations at Kahuku, Maili, and Keewaula ("Yokohama Bay"). Most of the remainder is not accessible for economic extraction because it is covered by homes and beach parks at Kailua and Lanikai, Bellows Field and Waimanalo, Portlock, Kahala, military housing on either side of the Pearl Harbor entrance, homesteads at Maili, and houses near the shoreline at many localities from Camp Erdman northeast to Kahuku Point. Probably less than 2 x 10^6 m^3 (2.7 million cu yd) is available for future use. When washed free of the dirt that has been blown over and washed down into these deposits, the old beach ridges provide good sand for beach restoration or to mix with cement. The remaining deposits should be exploited carefully so as to leave a strip along the seaward edge to act as a natural barrier to exceptionally high waves.

Active dunes constitute a small amount of Oahu's sand resources (less than 1 x 10^5 m^3 or less than 0.1 million cu yd). Except in a few instances, such as at Makapuu where some sand blows well inland across the highway, dunes help protect the coast from storm waves and tsunamis.

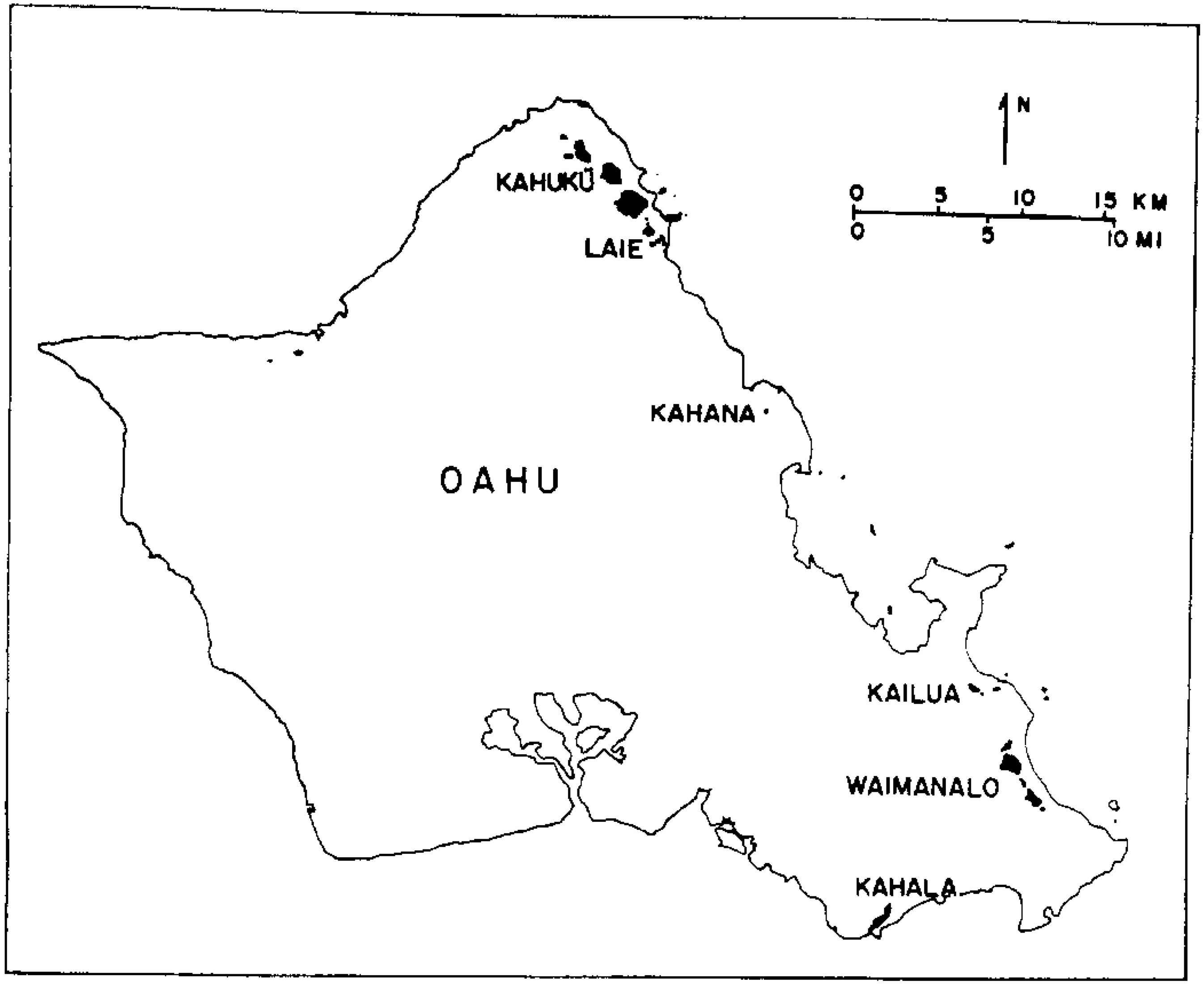

Figure 1. Sites of eolianite deposits on Oahu, Hawaii.

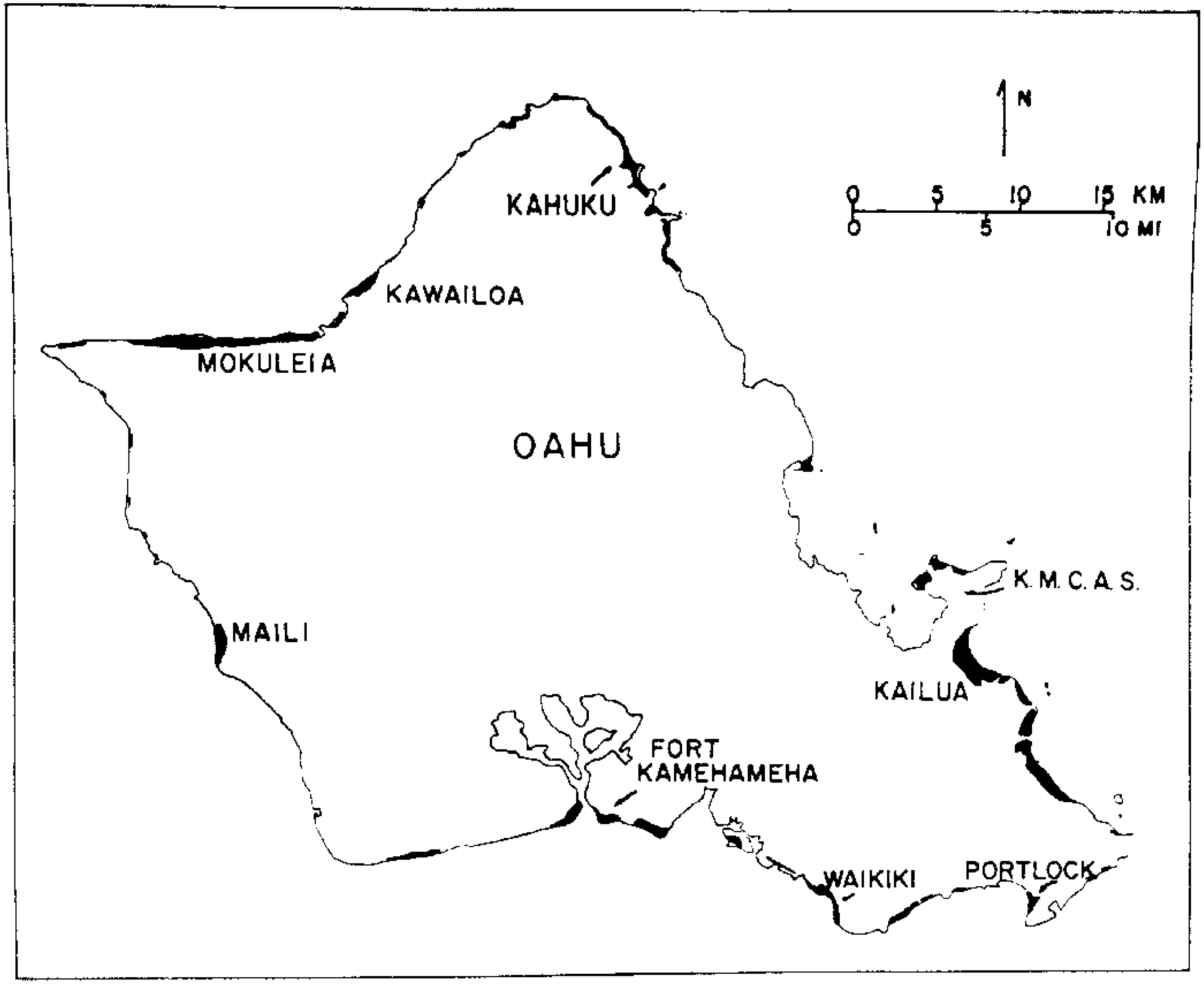

Figure 2. Sites of inactive dunes and old beach ridges on Oahu, Hawaii.

Many are attractive features at beach parks. Therefore, active dunes should not be exploited.

Oahu beaches above mean lower low water contain about 7.7 x 10^6 m^3 (10.3 million cu yd) of excellent-quality sand. Illustrations of 28 principal beaches and tabulated volumes of those beaches as well as the smaller beaches located between them are in Moberly and Chamberlain (1964) and need not be repeated here. Waimanalo and Maili are the largest Oahu beaches, followed by Kahana and Sunset. Sand was formerly exploited at several localities including Waimea, Kahuku, Nanakuli, and Maili. Now none can be taken legally and so this resource of excellent quality is listed as zero for availability. Someday if monitoring shows that Waimea and Sunset have regained their former widths, the question of whether a crop of the coarse sand of those beaches can be transshipped to nourish eroding beaches that have a high density of users should be re-evaluated.

Offshore Resources

Sand is present in the offshore part of Hawaiian beaches and also farther seaward down the island slopes. The part between mean lower low water and about a 9-m (30 ft) depth of water is tabulated separately from the part lying deeper than about 9 m because legal restrictions are now imposed against using sand down to about 9 m in depth. Although it may be helpful for regulatory agencies where laymen enforce the rules to have some arbitrary figure such as about 9 m, there is great variation in nature and the actual depth for regulation at a particular location should be based on the data of that location. The figure was selected as a conservative one, based mainly on studies in California in the 1930's as a depth below which sand apparently moves only seaward and does not return to the beach system during any season of the year. However, in Hawaii substantial sand movement at about 9-m depths has been measured on western Kauai and observations of winter-time breakers at several additional places on northern Oahu and Kauai strongly indicate that sand does move at such depth.

On the other hand, in some places sand at shallower depths is completely removed from any beach system. In Kaneohe Bay an example is the sand spilling down into the deep water of the lagoon near Ahu o Laka Island (Moberly and Campbell, 1969). If any of that sand should spill deeper than about 2 m (6 ft), it will never return to the surface and would be a good source of sand for establishing beaches at parks along the muddy or gravelly shores of Kaneohe Bay. At Kahana Bay all the evidence from physical oceanography, sedimentology, and micropaleontology (Coulbourn, 1971) indicates that the coarse calcareous sand spilling from the reef edge (near 21°34'N, 157°52'W) down to the bottom of the bay at about 7-m (22 ft) depth does not enter into the beach system but moves farther down into deeper water. This sand is not needed at Kahana Beach itself, which has a long history of accretion, but it ought to be considered as a source of nourishment for such chronically eroding beaches as Kaaawa and Punaluu.

Mapping the areal extent of nearshore sand reservoirs is fairly easy (Figure 3), but determination of volumes is very difficult because of the limited number of holes jetted through the sand and the extreme variability of the size of the sand channels and sand pockets. The earlier estimate of about 10 million cu yd listed by Moberly and Chamberlain (1964) is certainly too low, based on more recent work in various parts of Kaneohe Bay and a current evaluation of the history of sea level changes in the most recent geologic past. A revised estimate is about 1.8×10^7 m^3 (24 million cu yd), but the figure might be increased or decreased substantially as new information is obtained. With present legal restrictions none of these reserves is available for use.

Very little is known about the belt between depths of about 9 m (30 ft) and 18 m (60 ft). The waters are too deep for observation from the air except under the most ideal conditions when some outlines of sandy and non-sandy bottom can be seen. The original surveying gear gave records of poor resolution where the bottom was shallow and, for safety of navigation, the earlier geophysical traverses generally avoided such shallow water. Much of the area is close enough to shore to fall under the more stringent regulations and probably dredge operators would prefer not to work so close to shore on open coasts. Finally, the water is too deep for extensive reconnaissance by diving. For these reasons there was very little exploration at these depths and thus, the estimate listed in Table 1 is less substantiated than any other figure in the table. Based on the shoreward ends of some seismic lines and scattered observations by divers, apparently there is less sand in this belt than in those shallower or deeper, but locally as in the sand-bottomed channels there are substantial deposits. The deposit in Halekulani channel is generally medium to fine sand (Casciano and Palmer, 1970). Only a few other samples have been taken around Oahu. The estimate of 6×10^6 m^3 (8 million cu yd) probably is a conservative lower limit; perhaps the deposits are much larger. Additional study is desirable, but additional work is of second priority compared with sampling the deeper deposits that is recommended at the end of this report. Regulations, safety considerations, and spotty distribution of smaller deposits would allow only part of these to be exploited under present conditions. A guess of 3×10^6 m^3 (4 million cu yd) is highly subjective.

Most of the survey efforts have been concentrated in the zone between about 18 and 90 m (60 and 300 ft) in depth. Sand covers narrow submarine terraces or beaches and fills channels that cross the terraces. Figure 4, showing the extent of the sand, is a compilation of maps of five individual sectors of the leeward coasts reported earlier by Campbell et al. (1970), of reconnaissance lines off northern and windward Oahu, and of some detailed studies that make up the second part of this present report.

More than 3.9×10^8 m^3 (520 million cu yd) of this huge resource is present around Oahu. The estimate is very good for the leeward coasts where, in fact, it has been calculated for various depths and sectors (Campbell et al., 1971). It is good to fair for the north and windward coasts and there it is a conservative estimate. Probably the

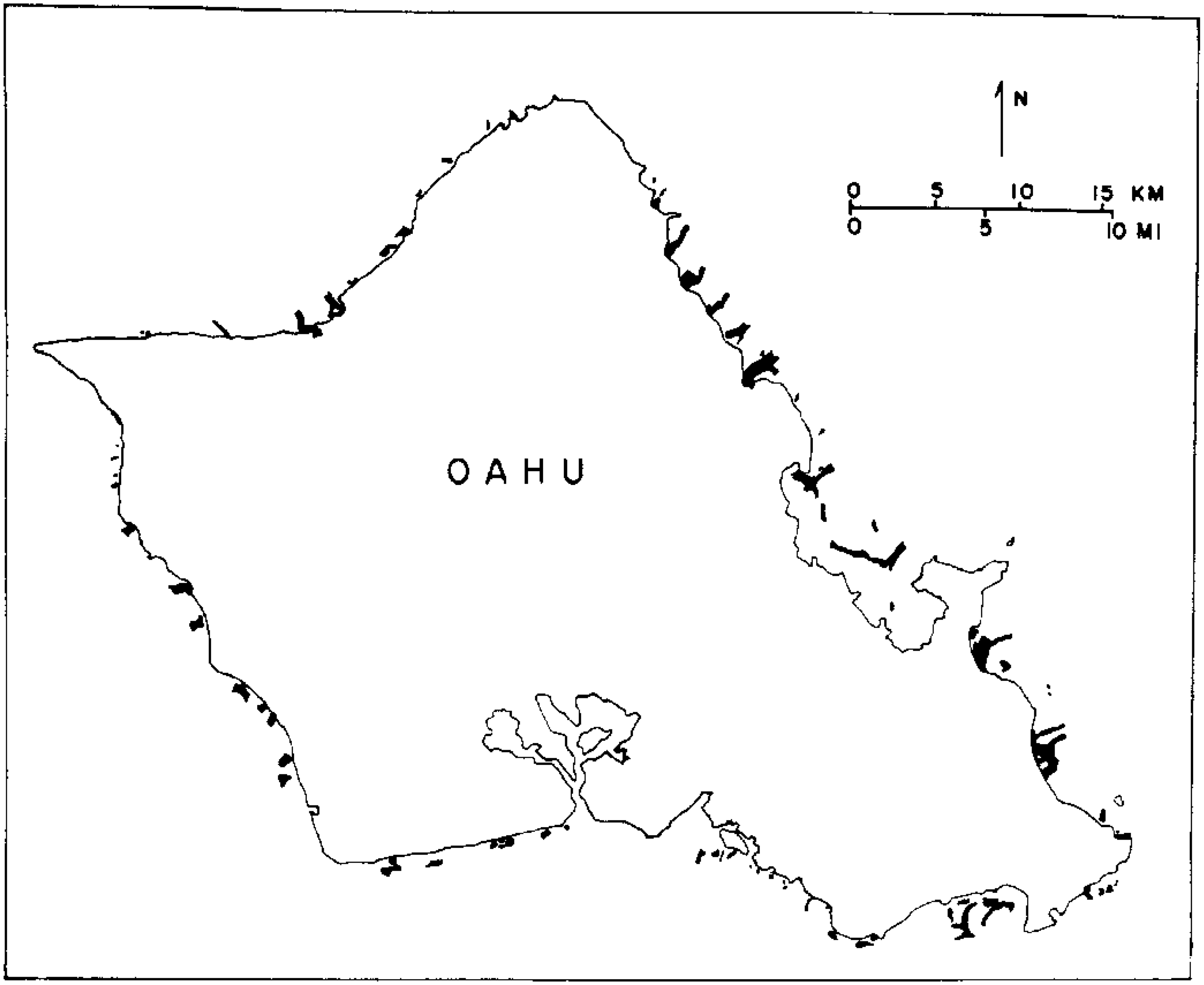

Figure 3. Sand bodies (dark areas) surveyed between shoreline and 18-m (60-ft) depth of water around Oahu, Hawaii.

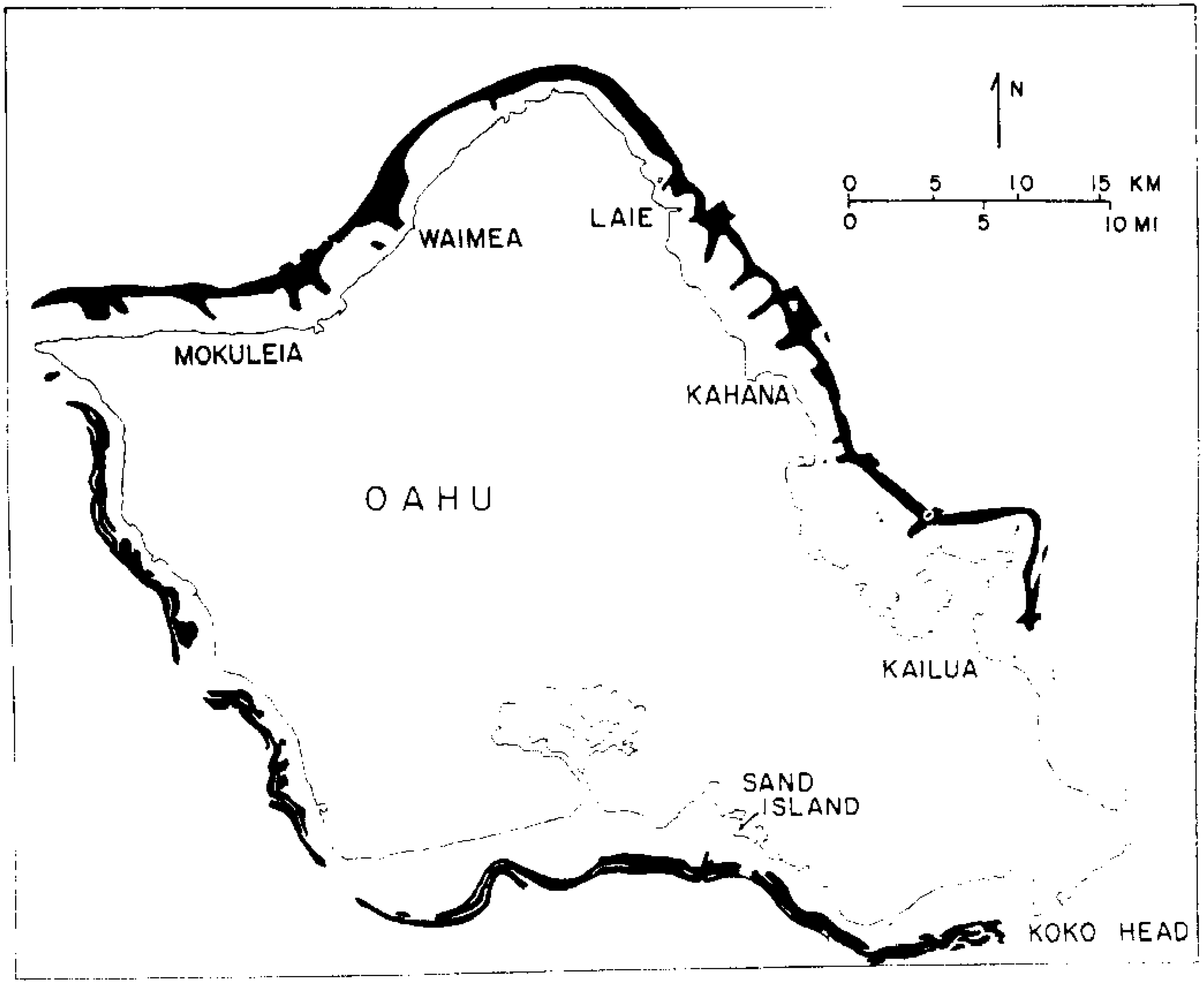

Figure 4. Sand bodies surveyed between 18-m (60-ft) and 90-m (300-ft) depth of water around Oahu, Hawaii. The southeast section between Kailua and Koko Head was not surveyed. The north section between Waimea and Laie was surveyed very roughly.

total amount is not less than 3.5×10^8 m^3 nor more than 5.0×10^8 m^3. Most surface samples are of fine to medium sand and most are too deep for economical dredging with present techniques. About 50 million cu yd might be used, but that figure needs re-evaluation after the quality of the sand is determined. Further discussion of these deposits is in the section on "detailed survey areas." This report's recommendation for sampling concerns these deposits.

A final possible offshore source for sand is the great mass of reefs around Oahu. Locally they extend more than 300 m in depth. Their enormous volume is at least 7.5×10^9 m^3 down to the 100-m depth. Like the reefs onshore they would have to be crushed and sieved or elutriated to provide a consistent supply of sand, although some natural pockets of sand might be uncovered anywhere within the reef masses. Environmental problems would be so severe as to allow this source to be a reserve only under rare conditions, such as a by-product during required dredging operations. Quality for cement would be as poor as for crushed subaerial reefs. Experience using a selected size-fraction of dredge spoil to restore the Ft. DeRussy beach shows the poor quality of this resource for beach nourishment.

Some of the very hard ledges of reef limestone, which were cemented when reefs were exposed to air while sea level was lower, would make good sand (or gravel or dimension stone) if selectively removed from the rest of the reef mass and crushed. These hard layers are listed as the 20 million cu yd of usable reef, based on their infrequent encounter in drilling or driving piles through reefs ashore. The great expense of dredging off the overburden and selectively removing the ledges and the accompanying damage to the reef environment effectively rules out this source.

OAHU RESOURCES INLAND OF THE COASTAL ZONE

Relatively large areas of Oahu at the foot of the Nuuanu Pali and on the eastern and western slopes of the Waianae Range are underlain by ancient alluvium and colluvium from the erosion of those heights. Virtually all of the older deposits are deeply weathered; a knife blade can be sunk to the hilt into the remains of pebbles and the former sandy lenses are now iron-stained clay. Small amounts of alluvium in modern streams could yield some sand to selective excavation and screening processes. There are no glacial deposits on Oahu.

The basalt bedrock of the island constitutes the largest onshore resource of sand. It would be artificial sand crushed from the basalt lava. The basalt is firmer than reef limestone and within large structures, such as within a thick core of an aa flow or in a flow ponded by topography, the texture is more predictable than reef rock. Quarries already exist on Oahu (Figure 5) and many of the facilities such as sheds, roadways, utilities, and concrete batch plants are already present. Most of the technology is identical with existing methods at the quarries. The ultimate limit--the volume of the island above sea level--will of

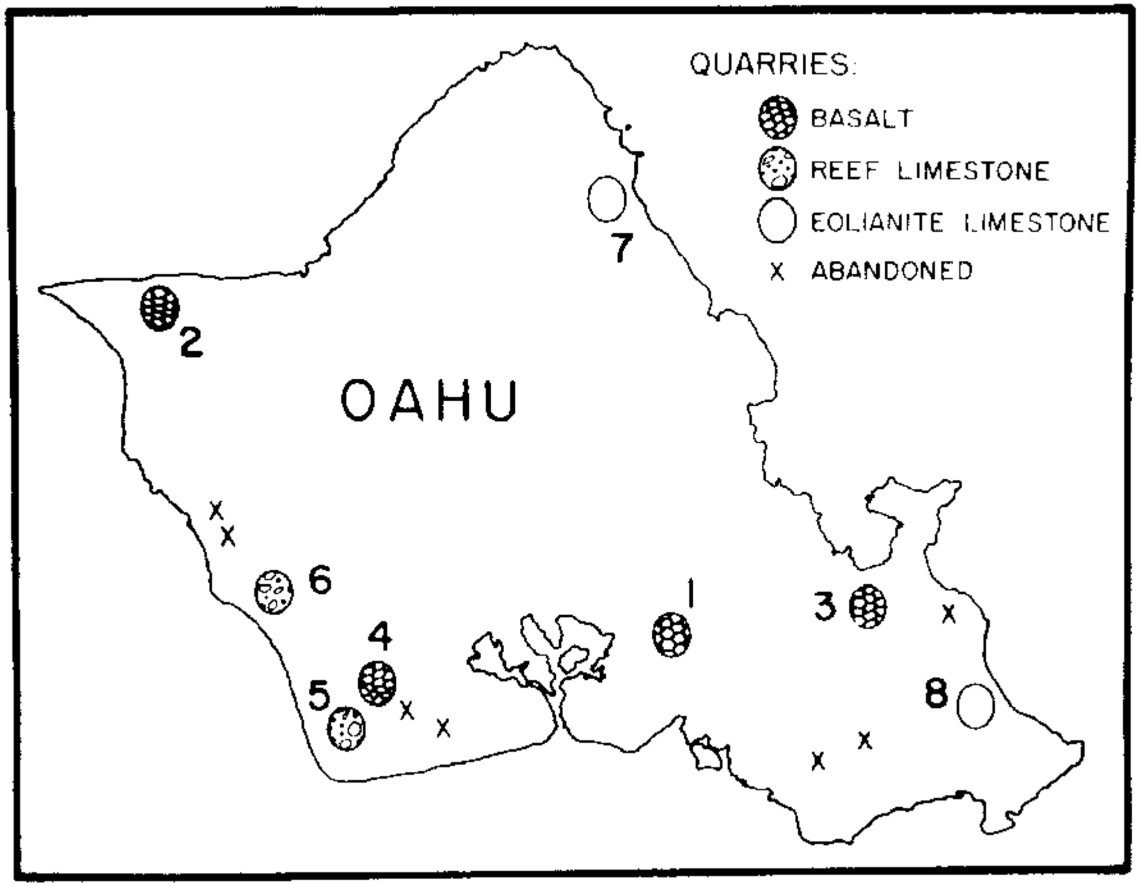

Figure 5. Quarries on Oahu, Hawaii: basalt is quarried chiefly for aggregate from (1) Halawa, (2) Kaena, (3) Kapaa, and (4) Palailai; reef limestone for cement from (5) Campbell and (6) Nanakuli; eolianite limestone for crushing to sand and other purposes from (7) Laie and (8) Waimanalo. Larger abandoned quarries are also shown.

course never be approached. The reserve of 320 million cu yd listed in Table 1 only considers 40 percent of the future output of the Halawa, Kaena, Kapaa, and Palailai basalt quarries assuming each of them would yield at least 1.5×10^8 m^3 of rock. That would level the mountain at Kapaa and extend the cuts of the other three for 2 km up their mountain slopes.

Oahu's need could be satisfied for hundreds of years or until quarry activity became restricted by future environmental considerations. Hillside scars, the cost and noise of machinery and explosives, and the dust from air elutriation or the mud from washing are the main adverse considerations for using basalt as a raw material for sand for construction purposes. The initial visual contrast of dark-gray sand added to cream-colored beaches and the angularity of the grains would make basalt sand a poor choice for such use on Oahu. After a season or two of surf action the basalt sand should become mixed into the rest, giving a medium-gray color overall, and the grains would be abraded. The appearance might be similar to some of the north Kauai beaches.

IMPORTATION OF SAND RESOURCES TO OAHU

Importation from Neighbor Islands

For the past several years most of the sand used on Oahu has been imported from Molokai. Although a substantial amount of sand has been mined from Kapukawahine Beach, the principal supply has come from Papohaku Beach. It is trucked about 10 km to Hale o Lono Harbor and barged about 60 km to Honolulu.

No beach sand in Hawaii should be exploited if non-beach supplies of generally comparable quality and cost are available, but nevertheless the Papohaku operation was well located from the point of view of conservation. At Papohaku Beach the sand forms from the calcareous skeletons of shallow-water organisms. Part of that sand is driven inshore under periodic and seasonal wave conditions to form the beach (Figure 6). The prevailing currents and winds cause the beach sand to drift from the northeast to the southwest along the beach. At the southwest end sand is lost naturally into deep water at a rate that balances the rate of supply over a few years. The extraction plant was placed at the southwest end of the beach to intercept sand that might normally be lost from the beach system. The total onshore and offshore beach system contained about 2.5×10^6 m^3 (3.2 million cu yd) of sand with perhaps 5 to 10 percent of that volume added and subtracted naturally each year. Because Papohaku is a large beach, minor fluctuations in the sand budget are easily absorbed. It has very low public usage. The sand is of excellent quality for use in concrete and would be excellent for beach restoration. Finally, from the standpoint of economics and the cost of sand to consumers, Papohaku is the non-Oahu beach closest to Honolulu, the center of sand utilization in the state. If the Papohaku operations had included a means of monitoring the balance between sand drift to the

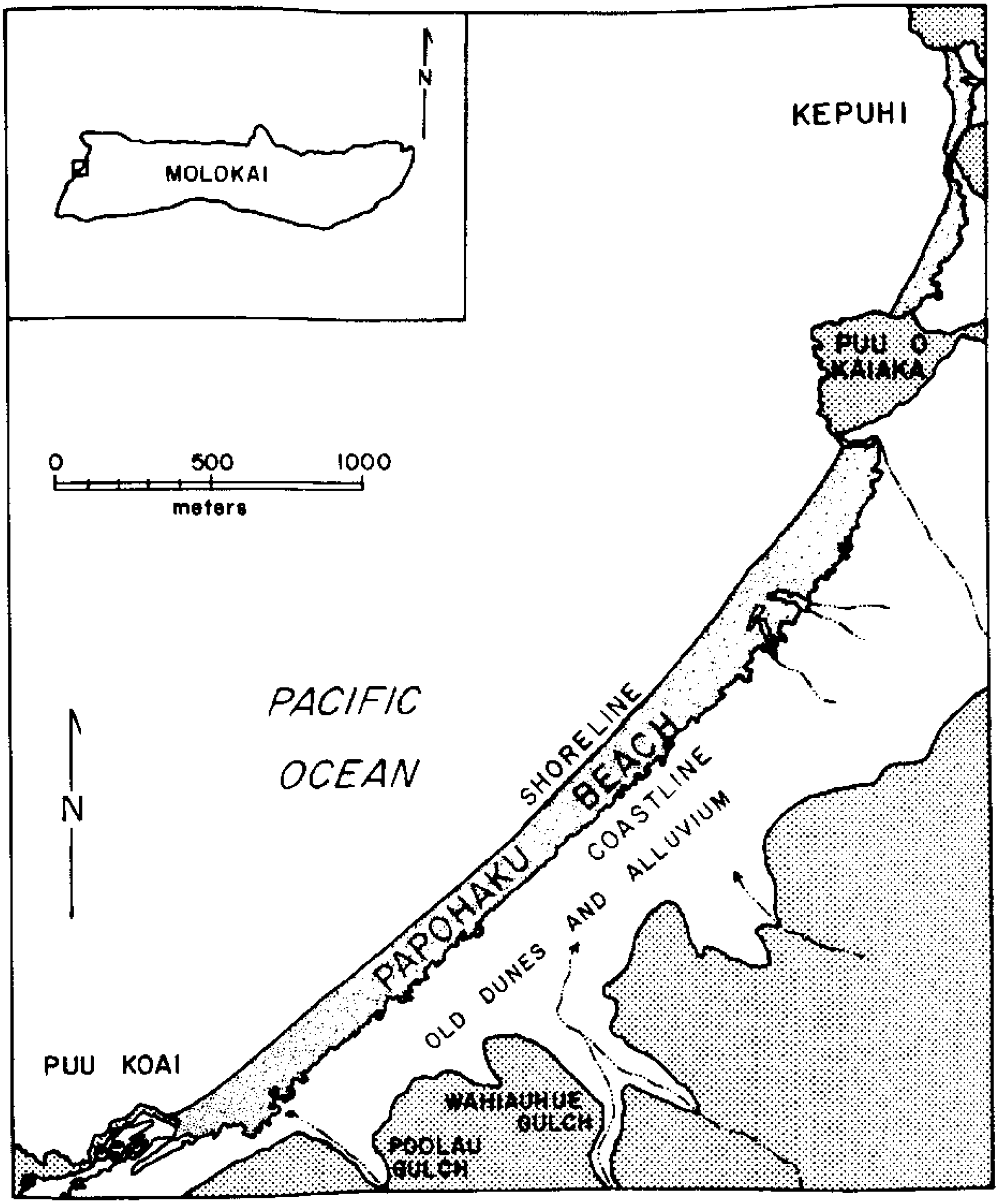

Figure 6. Map of Papohaku Beach, western Molokai, Hawaii. Sand exploitation is from southwest end.

plant and the extraction by the plant, such as by periodic measurements of beach profiles up-drift from the plant to insure that the sand was "harvested" or "cropped" rather than "mined," it would be very difficult to find fault with the operation. It would have been possible to take only as much sand as would otherwise have been lost by natural transport to deep water, which would have been a wise use of that resource. Unfortunately, there is no year-by-year record, although apparently the beach has been "mined" in recent years (Figure 7).

By state law the Papohaku Beach sand operation will be terminated in 1975. At present there is other litigation involving the operation. If there is no change in the law, Papohaku Beach will no longer be a source of sand for Oahu.

Other sources of beach sand in the state of Hawaii are covered by the same state law forbidding their exploitation. Of sand outside the active beach system, the largest potential source is the series of former beach ridges left on land known as the Mana Plain of southwest Kauai which is being built by aggredation at Kokole Point (Figure 8). Not all should be exploited. Some of the inland sand has been mixed with bagasse to make a soil and some near the coast should be left for wave protection. An extensive area of the Maui isthmus is underlain by lithified sand dunes, which might be crushed to manufacture sand (Figure 9). Part is covered by the Kahului-Wailuku urban area, part is a sugar plantation, and part is in grazing land of less value.

Sand from Mana Plain or the Maui isthmus, like that blowing inland in dunes at Kawaaloa on Molokai, Polihale on Kauai, and Polihua on Lanai, may supply some local neighbor island needs, but at present the transshipment costs almost certainly rule out barging it to Oahu. If future technological developments in the recovery, cleaning, or transportation of sand make the utilization of any of these neighbor island sources attractive, the Mana Plain would probably be the most important source.

Importation from the Continents

Occasionally it has been suggested that sand be imported from the mainland. Bulk ocean cargo can be handled in Honolulu Harbor. For example, sugar is shipped out and feed shipped in. Some bulk minerals are imported to mix with local limestone in the manufacture of portland cement. Elsewhere, large ocean-going ore carriers move rock and minerals at very low costs per ton. Of possible continental sources, probably the west coast of North America can be excluded. The U.S. has existing plants and harbors, but the building of so many flood-control check dams across mountain streams has cut off the supply of sand in the rivers and beaches. As a result, there is little sand now available near the harbors. Existing sand and gravel operations have become surrounded by cities and towns (Yeend, 1973). Mexico has fewer facilities. Central and South America are farther than Australia.

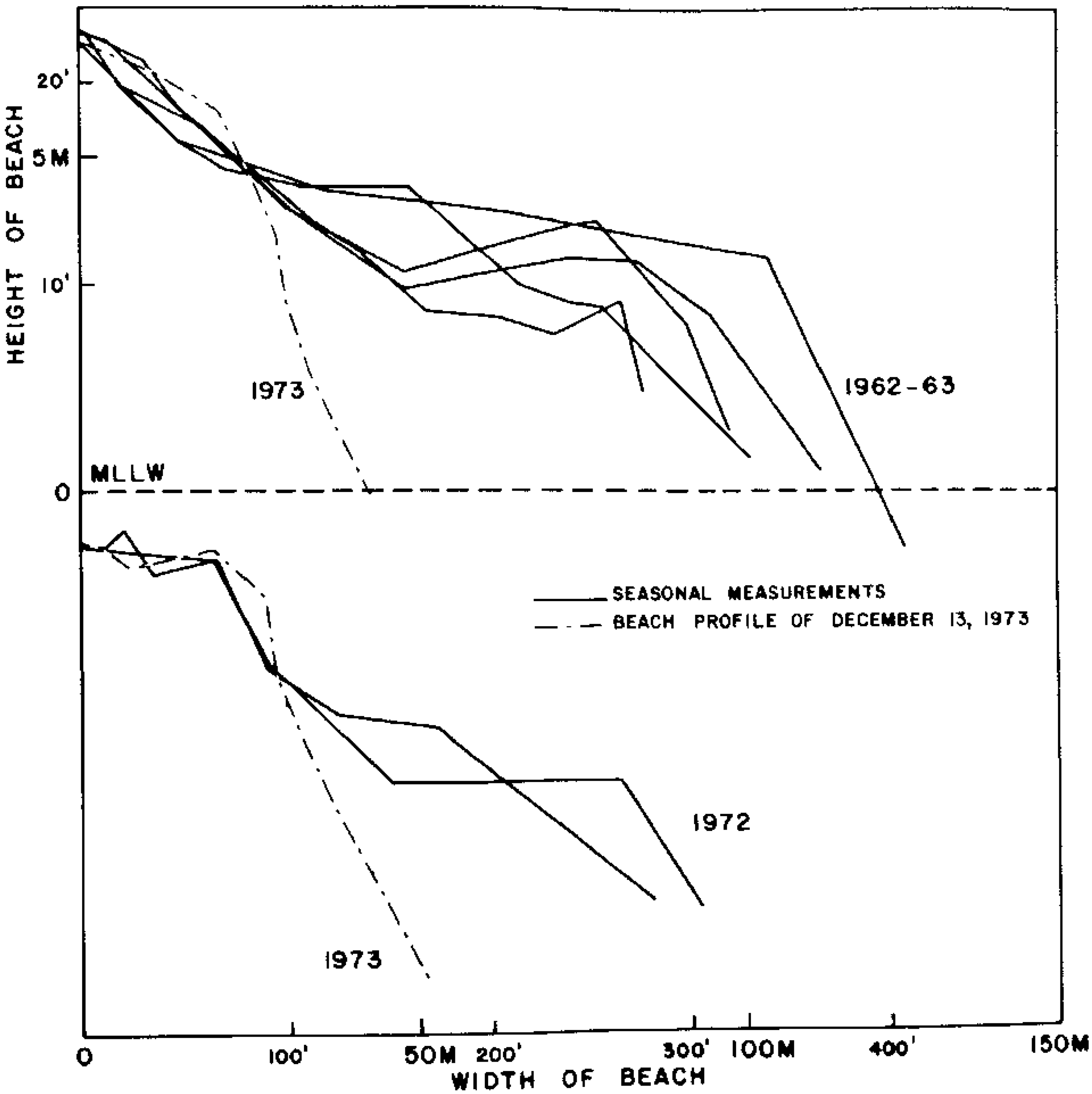

Figure 7. Topographic profiles of two localities at the south end of Papohaku Beach, western Molokai, Hawaii. Vertical exaggeration x 10. Upper diagram shows five seasonal measurements taken in 1962-1963 and seasonal erosion or accretion with limits of about 30 m (100 ft). Beach decreased in width by about 60 m (200 ft) during the 1963-1973 decade. Lower diagram cannot be tied directly to upper one, but is aligned in the figure to show the approximate trend. Two profiles for 1972 show the seasonal change. Beach decreased in width about 40 m (130 ft) in 1973.

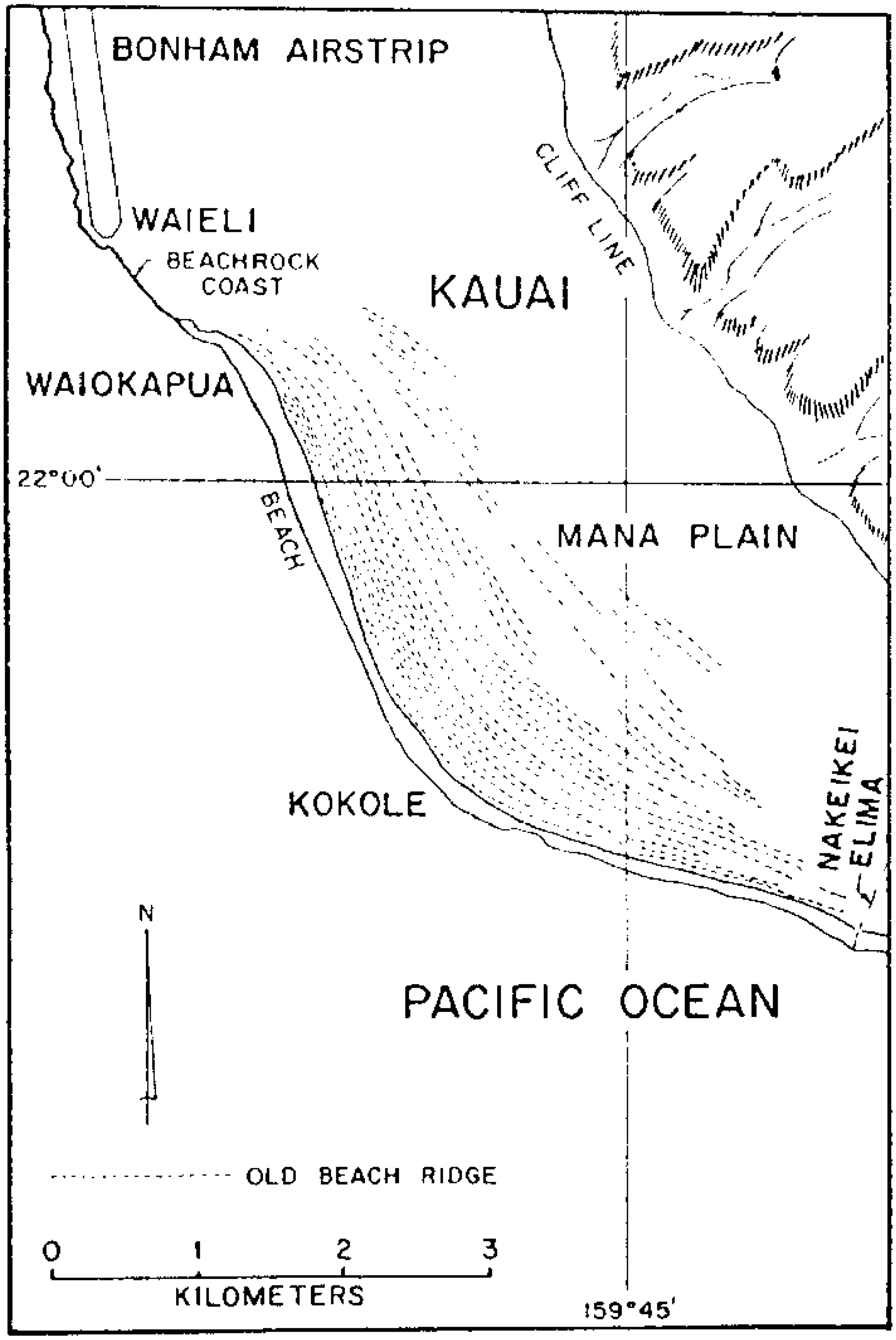

Figure 8. Sand resources in old beach ridges, Mana Plain inland of Kokole Point, southwestern Kauai, Hawaii. From Moberly (1968).

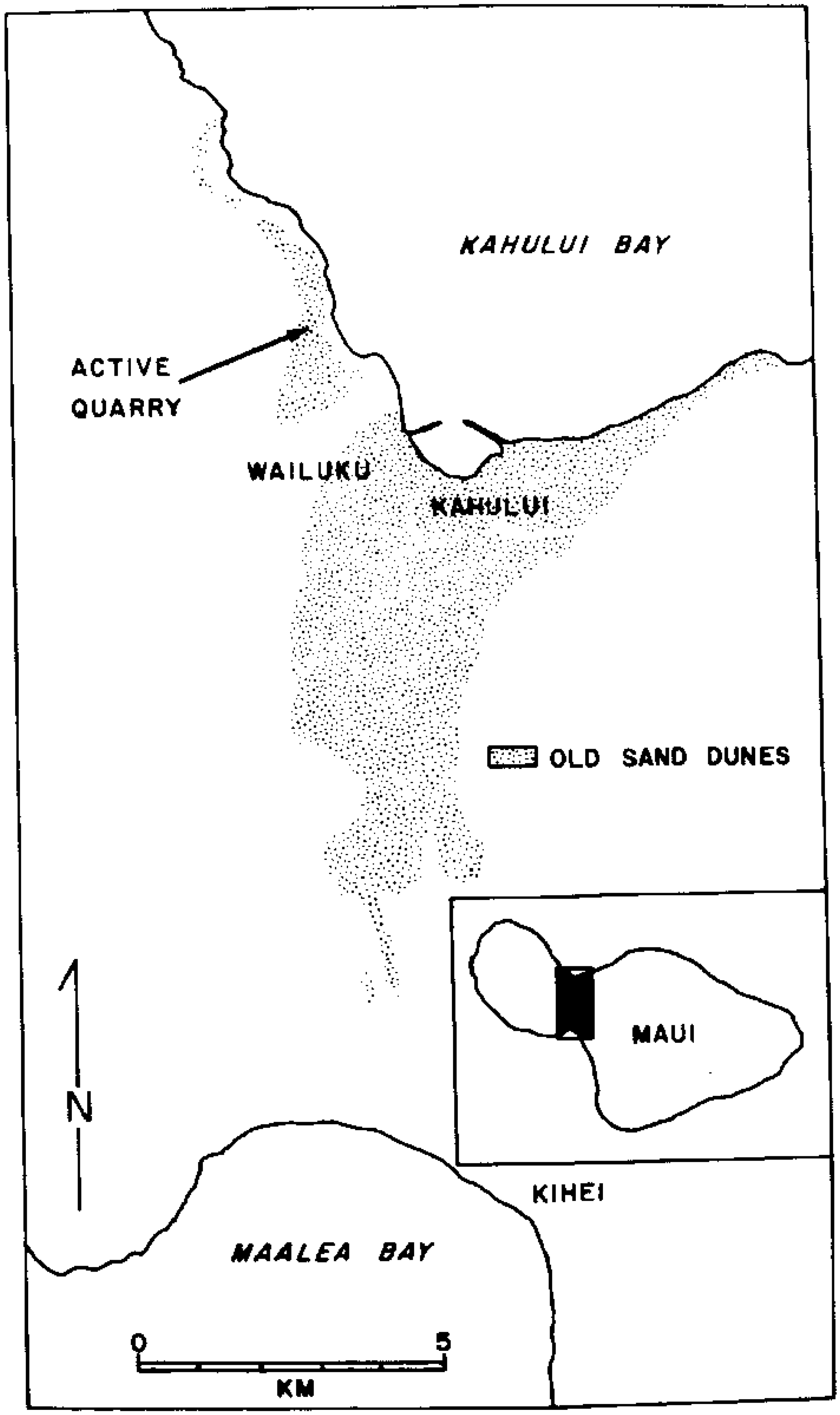

Figure 9. Isthmus area of Maui, Hawaii showing extent of old sand dunes, weakly to firmly indurated to eolianite.

Australia has large-scale beach mining now under way to remove titanium-rich ore sands from the common quartz sand along large sections of the coast. It might be possible to import quartz sand from Australia or from other coasts of the southwest Pacific. Quartz sand would be excellent for construction purposes but would be a poor choice for artificial nourishment of eroding beaches since it does not match our local beach sand. It is finer grained and would be removed by large waves that hardly affect the coarse local sand. Also, the quartz grains are so very much harder than local calcareous sand that perhaps the local component of the beach would soon be grounded up by abrasive action in the surf zone and thereby be readily lost as well.

DETAILED SURVEY AREAS

This presentation of the results of some offshore surveys is to aid the evaluation of which of the alternate sources of sand might be used in the future.

Sand Island

The area southwest of Sand Island was chosen as the site for a detailed study for several reasons. A major concern of anyone interested in mining offshore sand will have to be the economic aspect; a large part of the final cost will be the cost of transporting the sand from the mining site to the area where the sand will be used. Thus, a site close to Honolulu such as Sand Island would be preferable. A second reason for surveying off Sand Island is the indications of a large volume of sand there. Earlier reconnaissance work (Campbell et al., 1970), studies of sand channels (Inman et al., 1961; Moberly, 1968; Coulbourn, 1971), and studies of Pleistocene drainage patterns (Coulbourn et al., 1974) all indicated that large sand deposits occur where sand-bottomed channels cut through the fringing reef. Soundings across the reef made prior to dredging showed a channel that was the former extension of the drainage system of Kalihi Stream.

Another factor that needed consideration was what effects a sand mining operation would have on the environment. A literature review by Levin (1970) pointed out potential detrimental ecological effects on a coral reef community that could result from a sand mining operation. A large body of sand that could be mined in an area away from active reef growth would minimize possible effects on the coral reef community. The old drainage channels, which were cut through the reef while the sea was at a lower level and have subsequently been filled by sand, seemed ideal because they have large areas of sand with little or no active reef growth. Some change to the biota that inhabits this sandy environment probably cannot be avoided and will need to be evaluated by biologists prior to and during any large-scale dredging operation.

The area surveyed off Sand Island is shown in Figure 10. Although most of the area seaward of the 30-m contour shows some sediment on the bottom, the main concentrations are along the axis of the old stream channel and in a narrow band on a submerged terrace approximately parallel to the 30-m contour. The maximum thickness of the sediment in the buried channel is about 15 m (45 ft) and in the wedge paralleling the contours it is about 12 m (36 ft). Either area would make a good test site.

No attempt has been made to sample the sediment in this area but sampling elsewhere at similar depths (Campbell et al., 1970, 1971) has generally shown fine sand. Based on the information collected elsewhere, it is safe to assume that the top layer of sediment in this area probably has a median grain size in the fine sand range and, therefore, is not the size most suitable for use in concrete. However, geological evidence (Coulbourn et al., 1974) shows that nicks buried by the wedges of sediment were once shorelines and so it is possible that, under the fine surface sand, there are old beach deposits that contain sand of better quality.

There is approximately 20 million cu yd of sand in the figured area off Sand Island. Most of the sand is contained in the wedge and channel deposits. Even if only part of this is usable sand, it should be enough to meet Oahu's demand for several years.

North Shore

Reconnaissance geophysical surveys from Kawaihapai to Waimea Bay and from Punaluu to Kailua identified bodies of nearshore sand along several sections of the coast. Those off Mokuleia, Waimea, and Kahana were surveyed in more detail. These three sand deposits are similar to the Sand Island deposit in that they are associated with old stream channels that crossed the reef during lower stands of sea level. No doubt they would be more expensive to exploit than the Sand Island deposit because they are farther from Honolulu and the coastline is not protected from tradewind seas or North Pacific winter swell. However, those oceanographic conditions operating in the geologic past, when the now-submerged bodies were in the surf zone, very likely would have resulted in removal of fine-grained sand. If so, the improved quality of sand may offset the transportation and exposure costs.

In general, the reconnaissance showed that the sand along the windward coast is concentrated in areas where old drainage patterns cross the shallow water zone. Figure 3 shows the location of all channels that could be located from maps, charts, air photos, and aerial observation (Moberly, 1968). Pockets of sand on terraces are common but, between these channels, they are not as extensive or as continuous as the sand bodies along the leeward Oahu coast (Campbell et al., 1971).

Figures 11, 12, and 13 show the results of the survey at Mokuleia where the approximate volume of sediment is 20 million cu yd. At Waimea

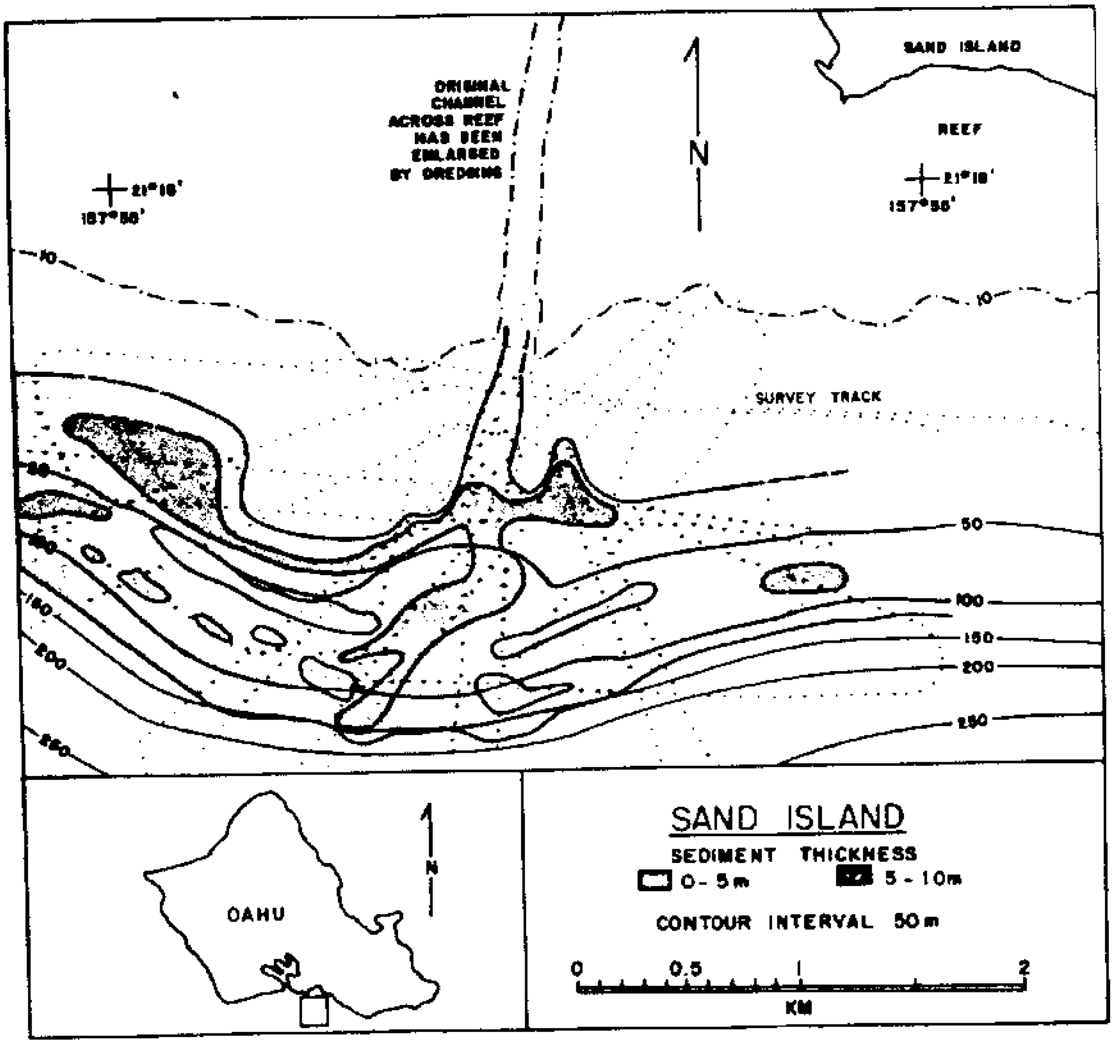

Figure 10. Bathymetry and sediment thickness near Sand Island, Oahu, Hawaii. Isopach interval 5 m of unconsolidated sediment, assuming Vp of sediment of 1.5 km sec^{-1} along survey track. Additional bathymetry from R.M. Towill Corporation, private communication, 1971, and from Pararas-Carayannis (1965). After Coulbourn et al. (1974).

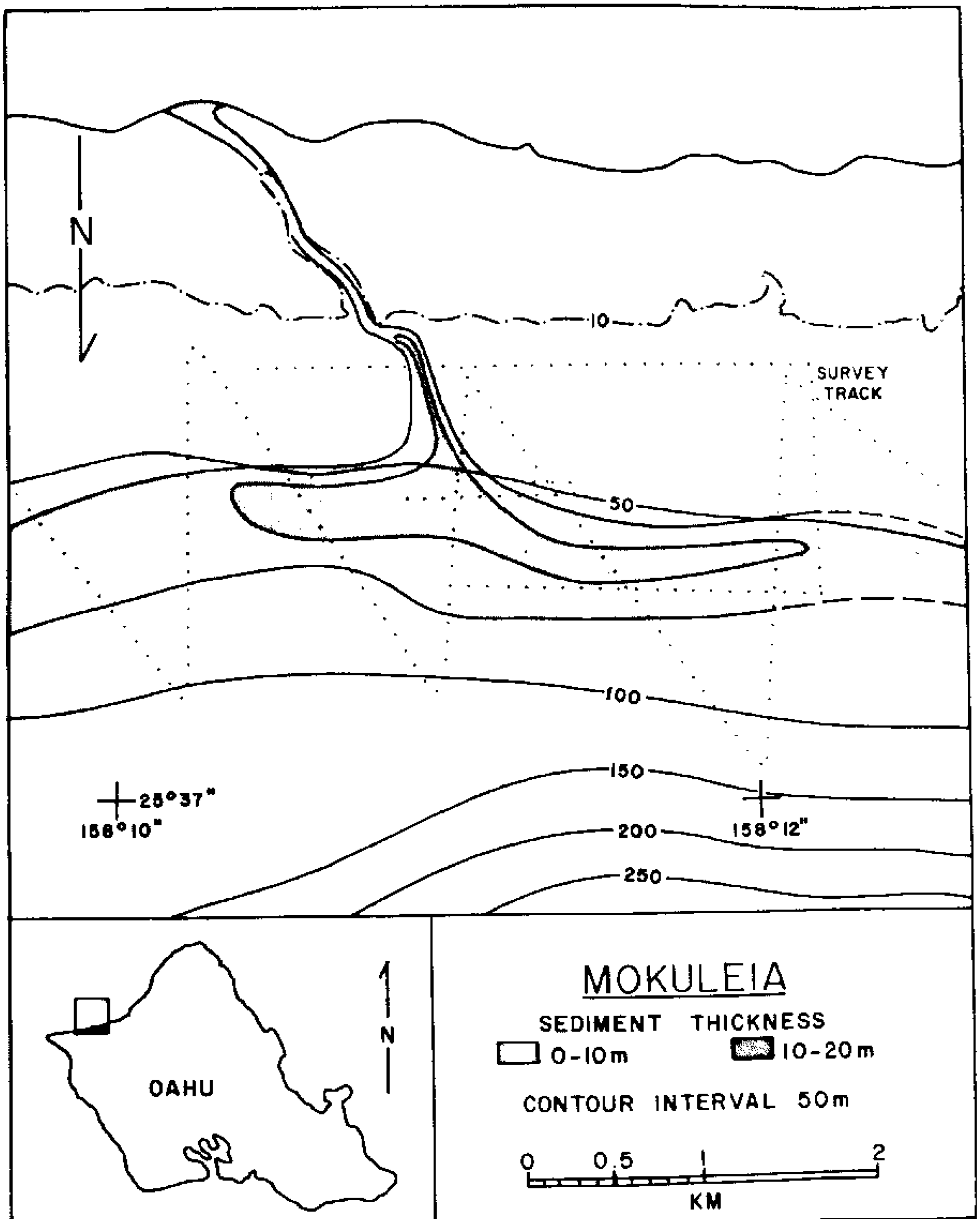

Figure 11. Present-day bathymetry and sediment thickness near Mokuleia, Oahu. Isopach interval 10 m of unconsolidated sediment, assuming Vp of sediment of 1.5 km sec^{-1} along survey track. Additional bathymetry from Pararas-Carayannis (1965). (Note that north is to bottom to aid viewing of Figures 12 and 13.) After Coulbourn et al. (1974).

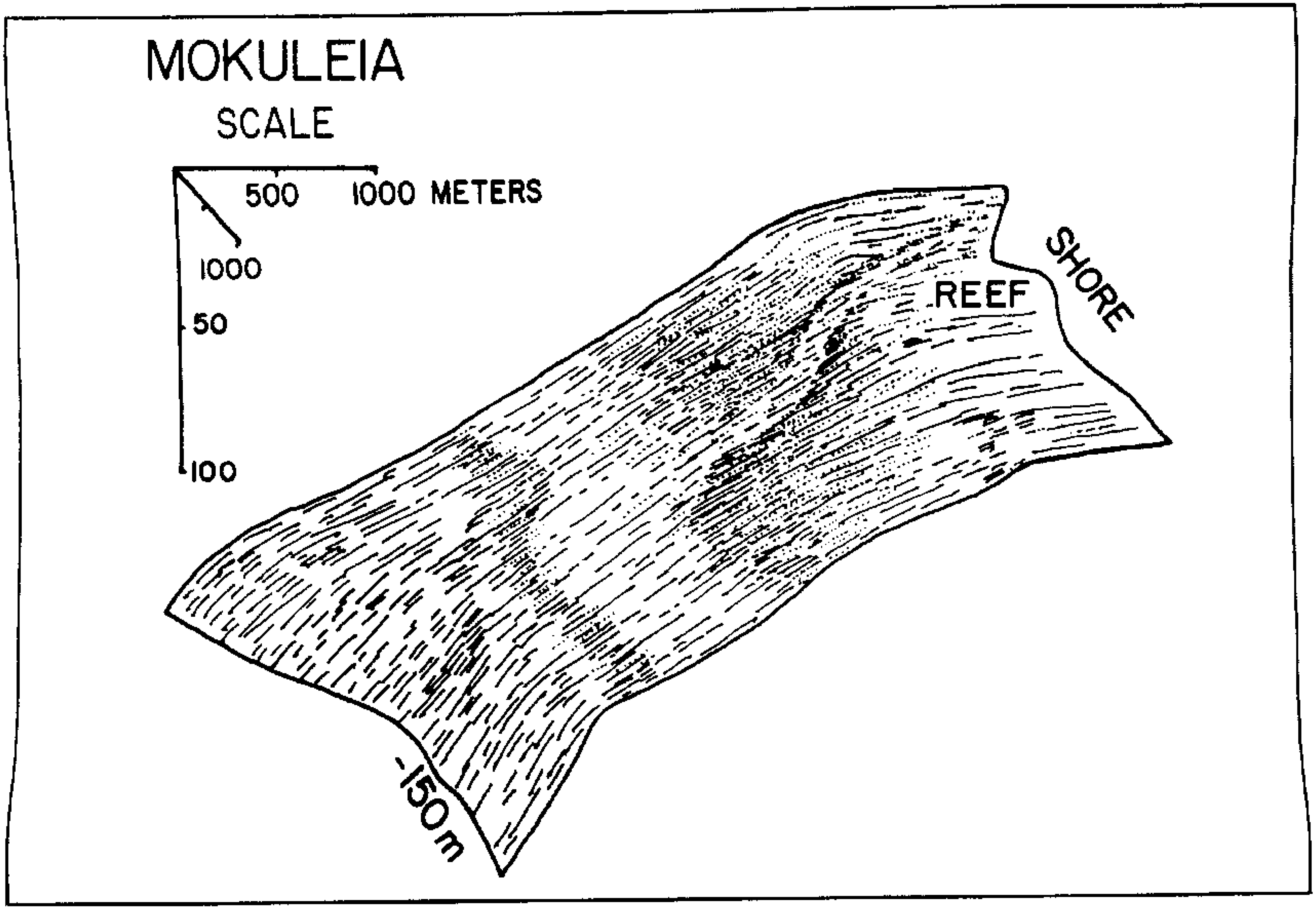

Figure 12. Perspective view with exaggerated relief of offshore topography near Mokuleia, Oahu. Coarse pattern indicates sandy bottom. From Coulbourn et al. (1974).

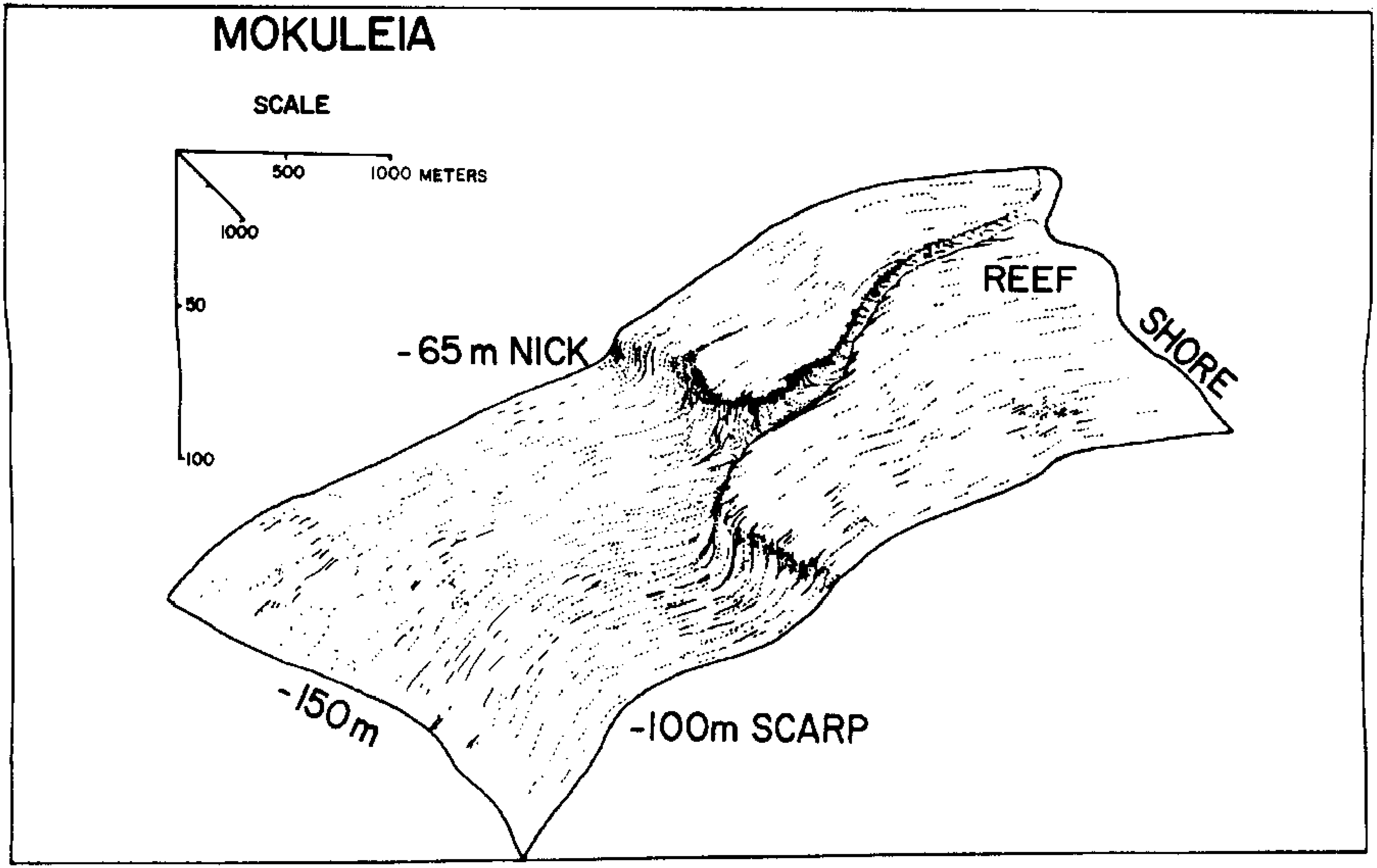

Figure 13. Perspective view of subbottom topography near Mokuleia, Oahu with unconsolidated sediment stripped away. From Coulbourn et al. (1974).

(Figures 14, 15, and 16) there is about 70 million cu yd. The Kahana-Punaluu area has about 25 million cu yd seaward of the reef edge (Figures 17, 18, and 19).

Pokai Bay appears to be a large reservoir, based on jetting and reconnaissance geophysical work but without a detailed survey.

Surface samples were dredged from these deposits and subjected to standard laboratory analysis. Although some of the samples have a mean grain size in the range required for concrete, representatives of the local cement products industry who examined the samples complained of their low specific gravity, friability, and flat grain shape. Further sampling will be necessary to prove the quality of the deposits. The sampling method, such as by vibration coring or by deep dredging, should be designed to obtain sediment below the surface of the sea floor.

Penguin Bank Reconnaissance Survey

Most of Penguin Bank is in the same depth range of the sand deposits found during surveys off Oahu, Maui, and Molokai and most of the spot samples located on the hydrographic charts of the U.S. Coast and Geodetic Survey list sand-sized material. This information, along with reports from divers, indicated that there might be large areas of sand on the bank.

The location of Penguin Bank is also a prime factor. There would be a minimal effect on the nearshore environment. Most of it is beyond the 12-mile territorial limit and thus probably out of the jurisdiction of the state of Hawaii and the United States government. This would simplify the procedures for obtaining permits for mining. The proximity of the bank to Honolulu also means that the cost of transporting the sand to the Honolulu market would be reasonable.

Figure 20 shows the survey pattern and also the areas with significant sediment deposits. The figure shows a band of sediment around the western end of the bank. This sand is located on a terrace similar to that found along the leeward Oahu coast. The surface of most of the bank appeared to be devoid of sediment except possibly for veneers too thin to be recorded. Several large deposits are at the Molokai end of the bank. The survey was not detailed enough to determine the true extent of the deposits but all were at least 1-km (0.6-mi) wide where they were crossed and only areas thicker than about 9 m (30 ft) were plotted. A conservative estimate of the volume of sediment discovered so far on the bank would be in excess of 4.7×10^8 m^3 (350 million cu yd).

No samples were collected during this reconnaissance survey so the nature of the sediment found on Penguin Bank is not known. One sample collected on a previous cruise was a very coarse sand with 36 percent of the sample being coarser than sand size (Campbell et al., 1971).

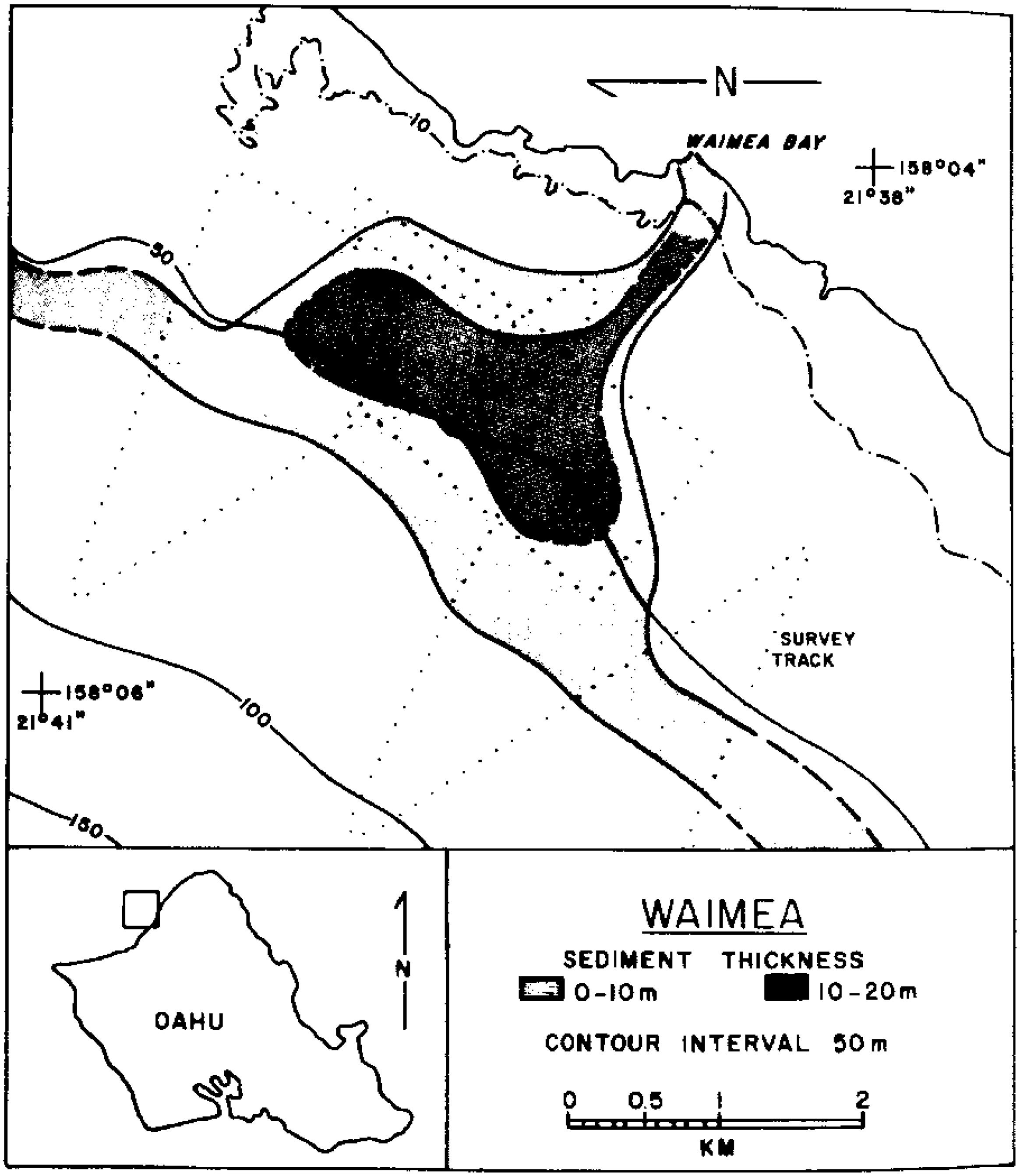

Figure 14. Bathymetry and sediment thickness near Waimea, Oahu. Sources, key, isobaths, and isopachs are the same as in Figure 11. North is at left to aid viewing of Figures 15 and 16. After Coulbourn et al. (1974).

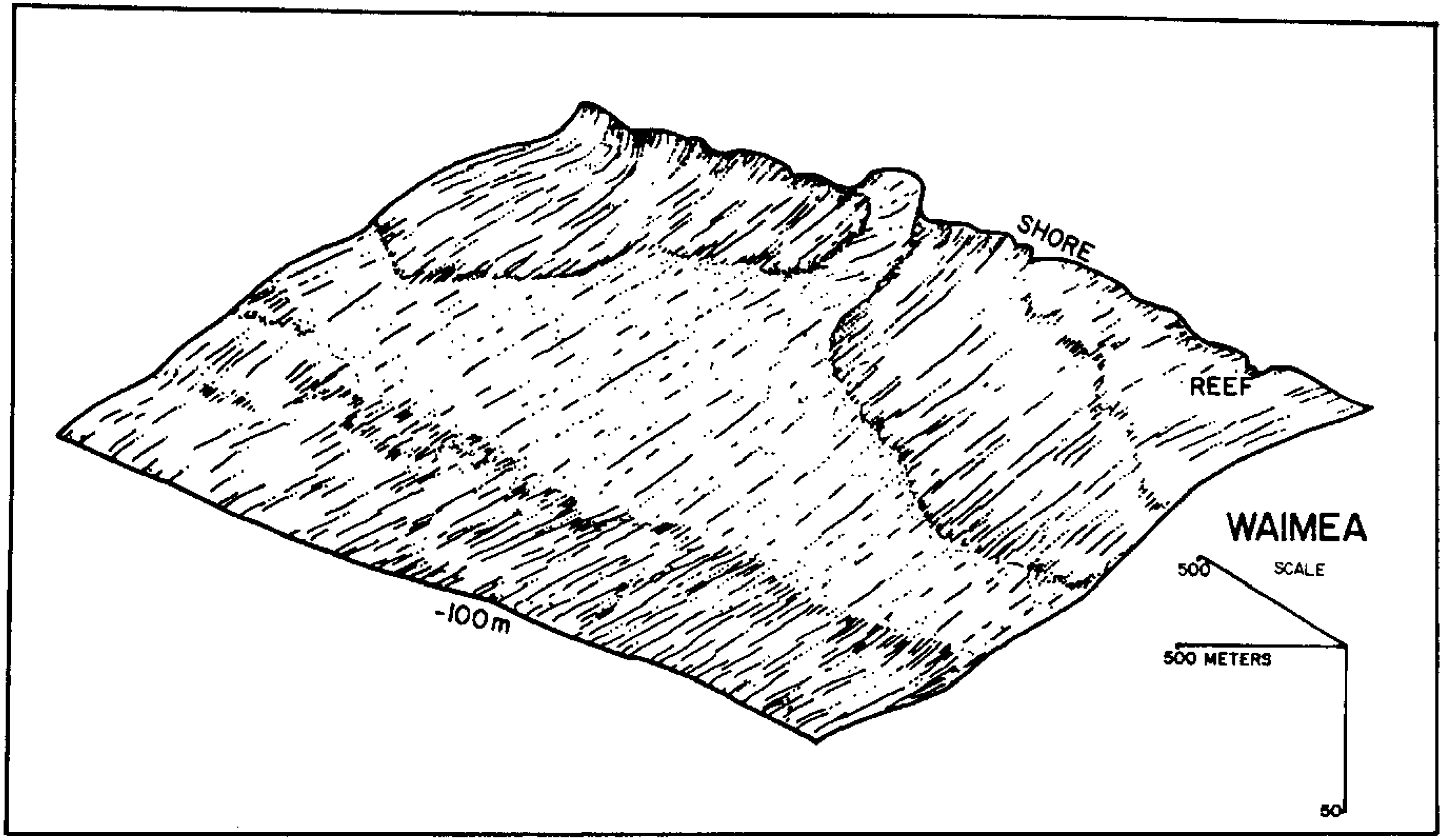

Figure 15. Perspective view with exaggerated relief of present-day offshore topography near Waimea, Oahu. Coarse pattern indicates sandy bottom. From Coulbourn et al. (1974).

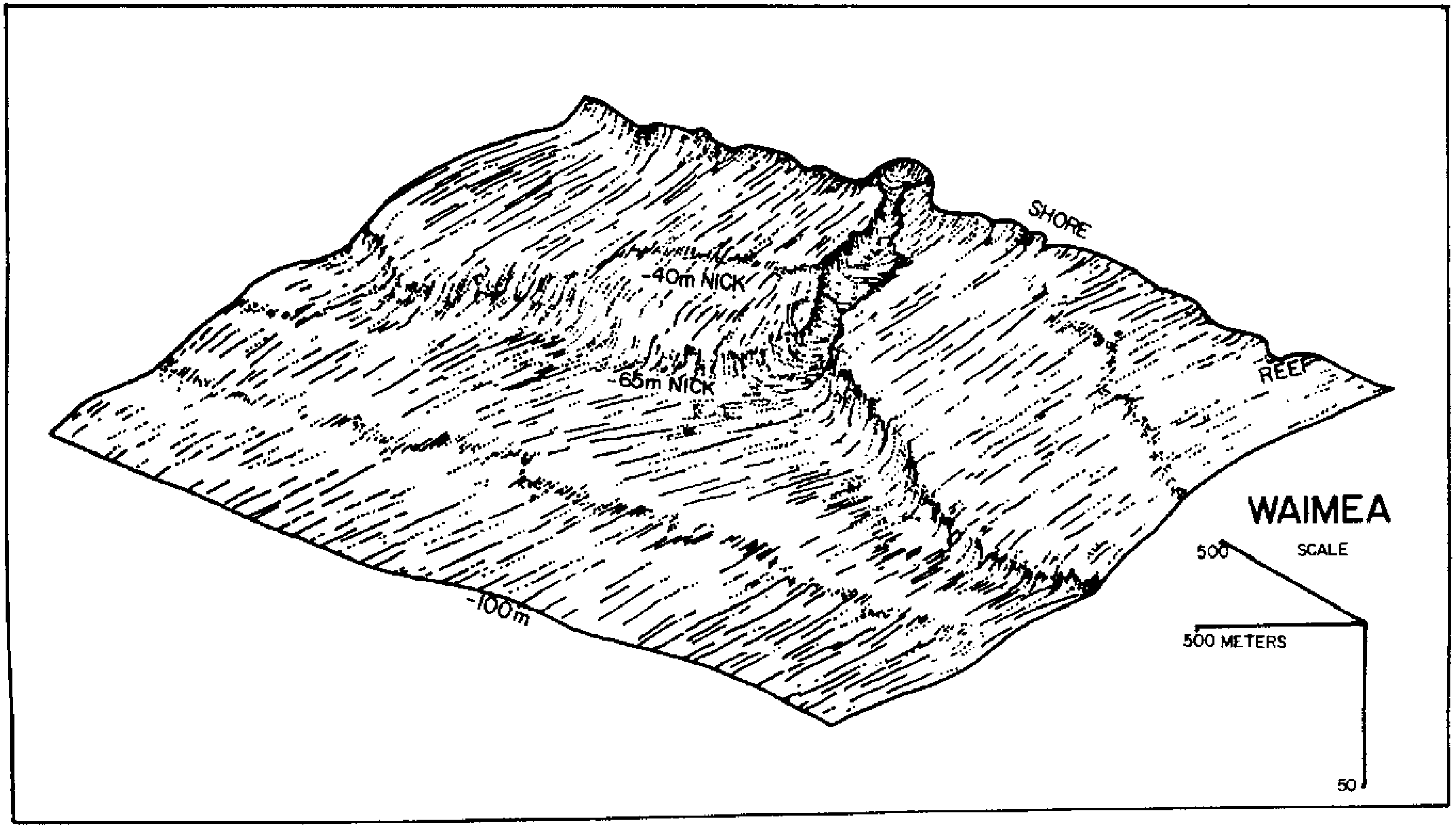

Figure 16. Perspective view of subbottom topography near Waimea, Oahu with unconsolidated sediment stripped away. From Coulbourn et al. (1974).

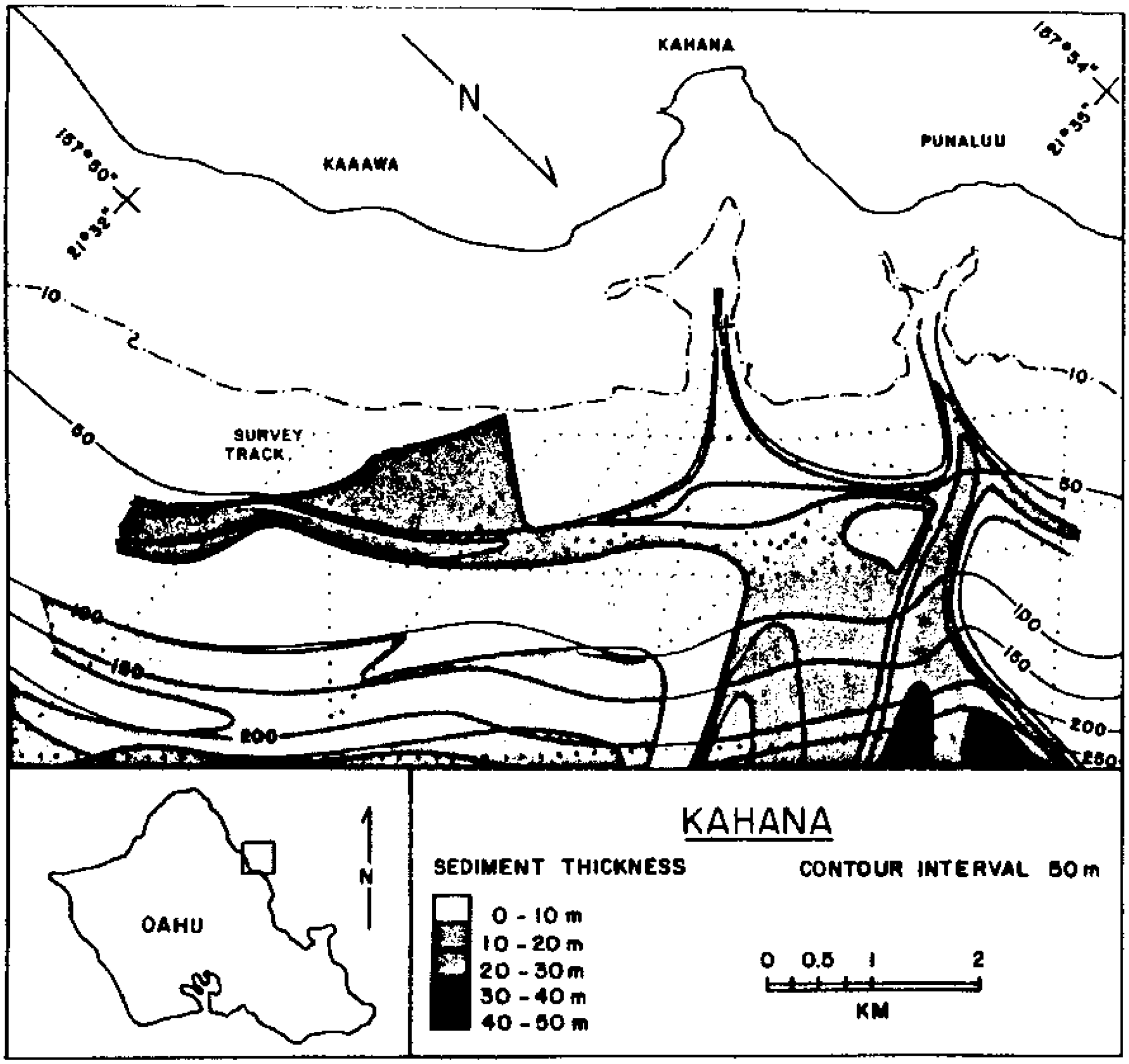

Figure 17. Bathymetry and sediment thickness near Kahana, Oahu. Sources, key, isobaths, and isopachs are the same as in Figure 11. North is to lower right to aid in viewing Figures 18 and 19. After Coulbourn et al. (1974).

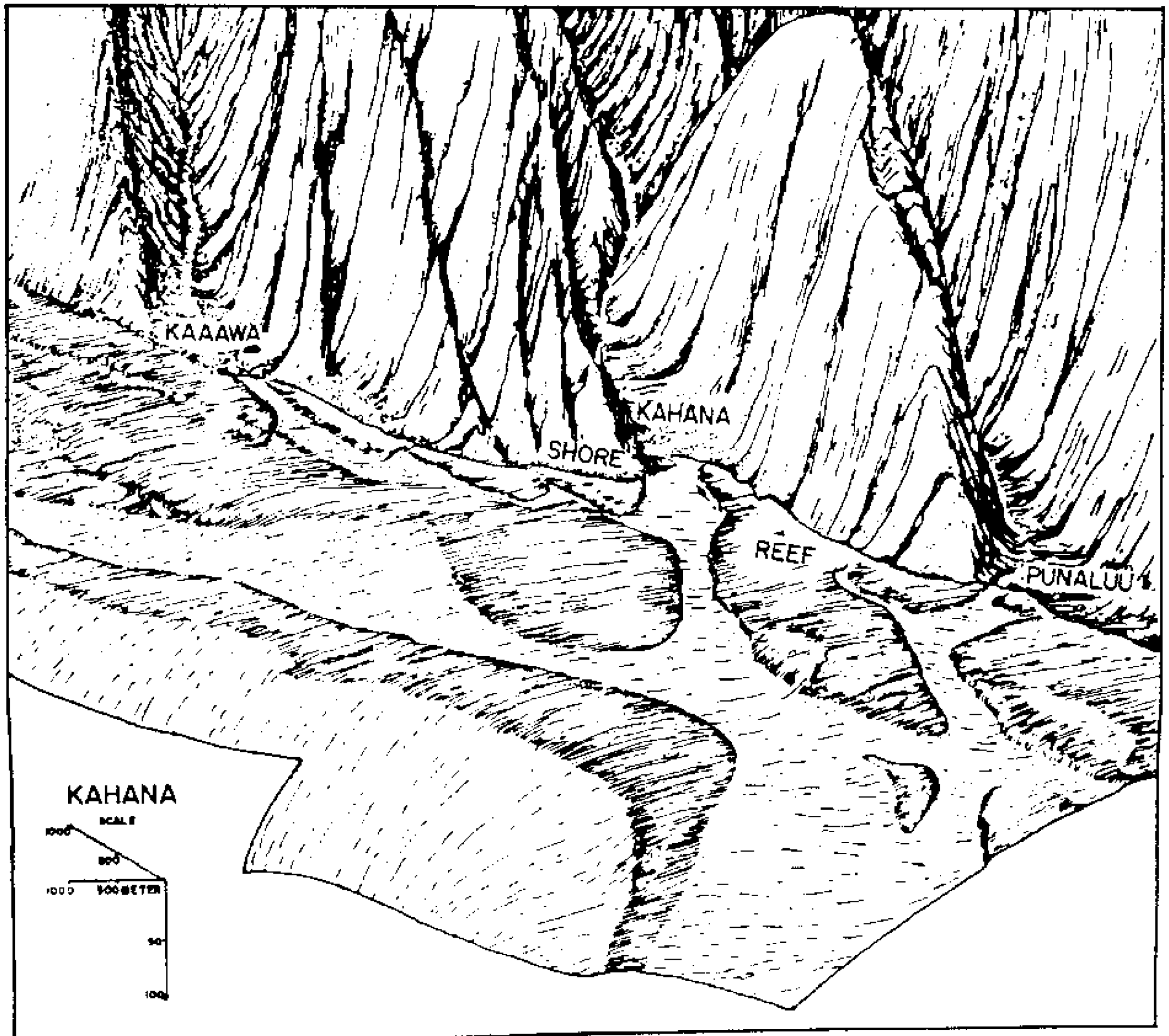

Figure 18. Perspective view with exaggerated relief of present-day onshore and offshore topography near Kahana, Oahu. Coarse pattern indicates sandy bottom. From Coulbourn et al. (1974).

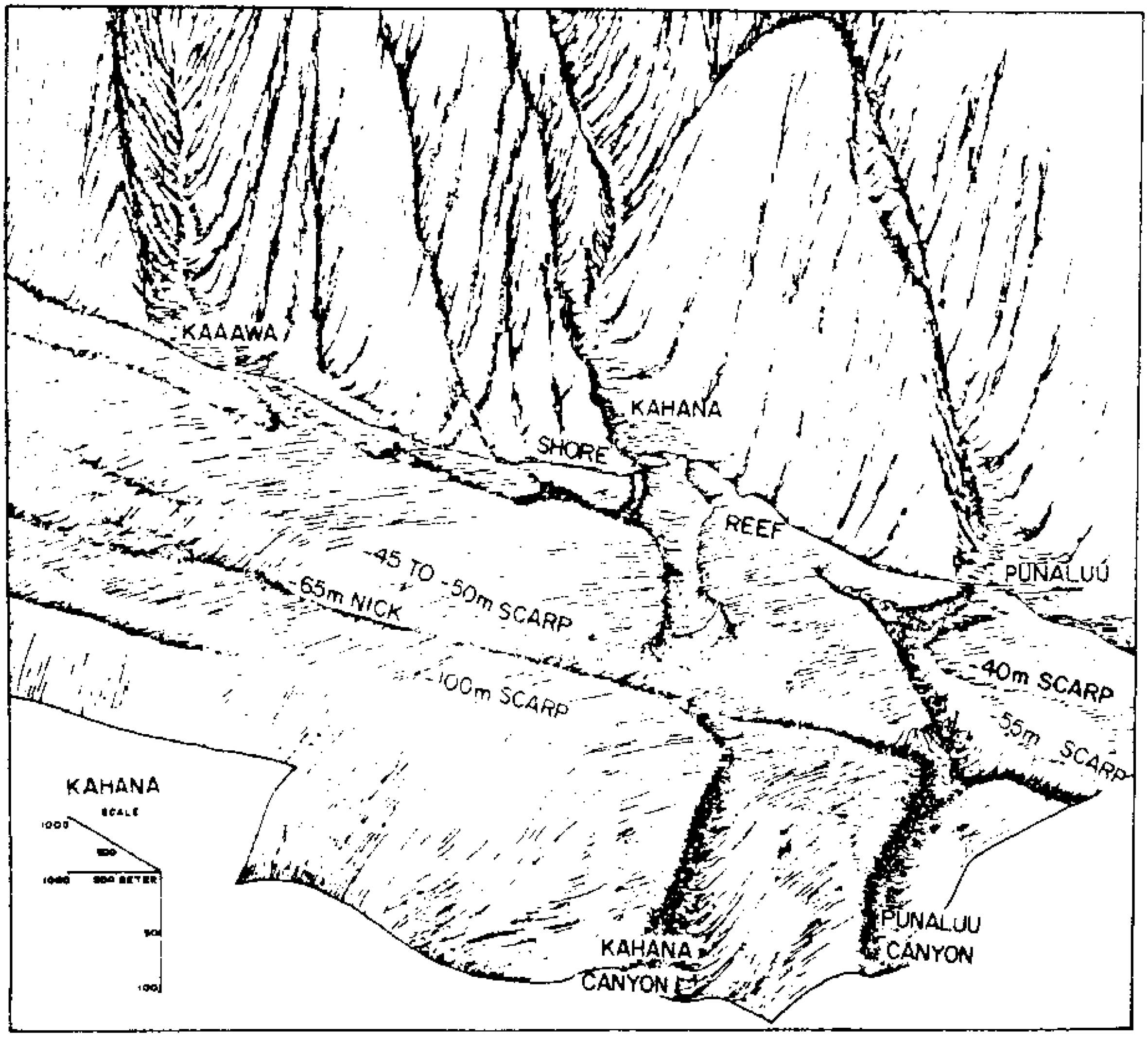

Figure 19. Perspective view of subbottom topography near Kahana, Oahu with unconsolidated sediment stripped from reef and lava bedrock. Exhumed Pleistocene terraces and headward extensions of submarine canyons are evident. These features have trapped the sediment. From Coulbourn et al. (1974).

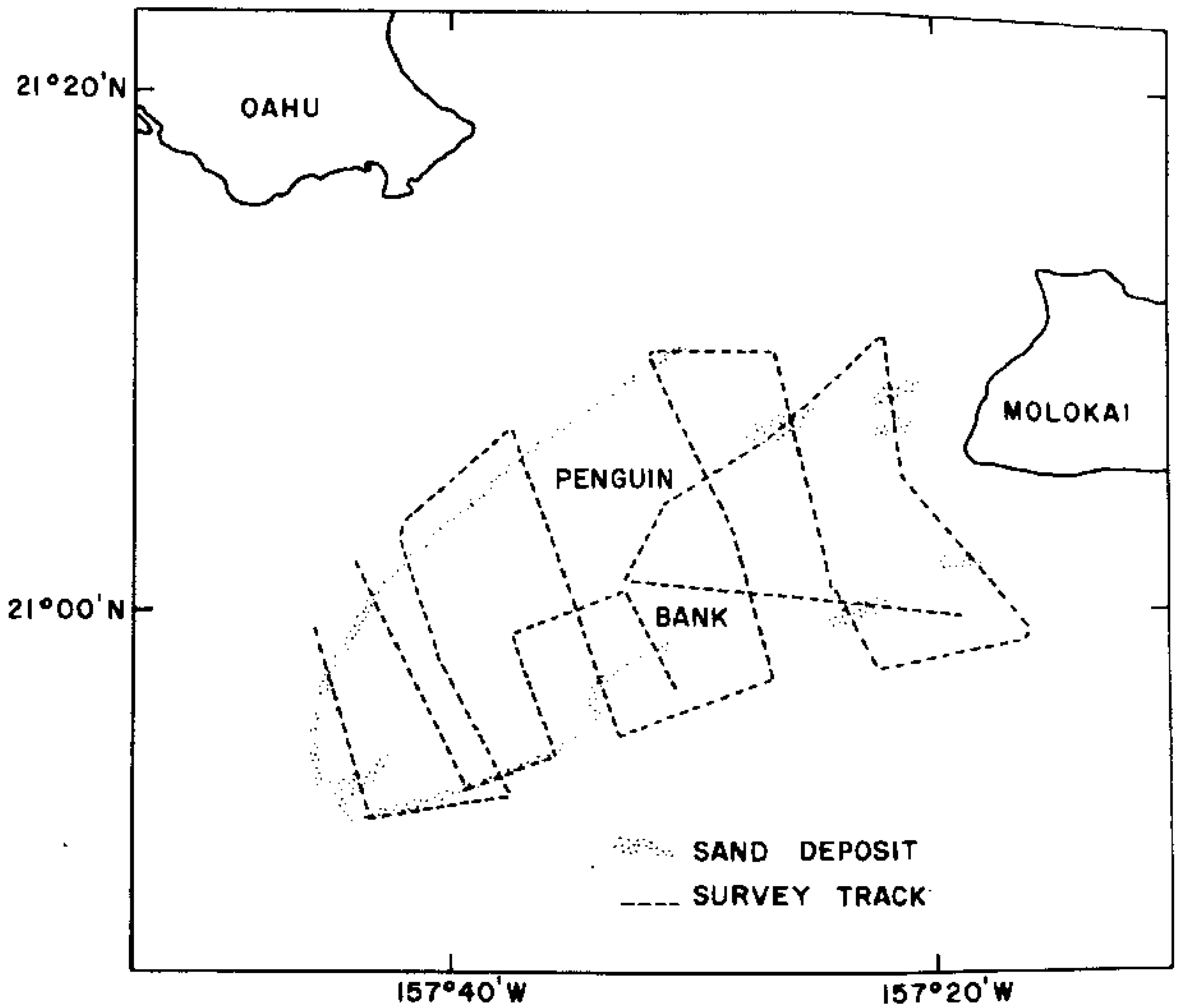

Figure 20. Reconnaissance sand inventory map of Penguin Bank, Hawaiian Islands area. Sand deposits on submerged terraces rim the edge of the Penguin Bank and a few patches occur on the end nearest to Molokai. Extent of sand is known only along the track of survey and has been interpolated elsewhere based on the general bathymetry of the bank edges.

RECOMMENDATIONS

Although there are several areas that have been surveyed in enough detail to show that there is a large volume of sediment present, there is as yet no proof that any of these deposits are of economic worth. A sampling program using equipment capable of sampling at various depths in the deposit is necessary.

The best method of sampling would be to conduct a pilot mining operation to show the type of material that would be obtained during a full-scale operation. If this method is not feasible, a coring program to collect continuous vertical samples through the deposit would suffice. An initial program of three or four pilot runs or long vibracores should be conducted to sample each of the following areas: (1) off Sand Island, potentially the most attractive from the viewpoint of mining costs; (2) off Mokuleia, potentially the most attractive from the viewpoint of quality; and (3) on Penguin Bank, potentially the most attractive from the standpoint of controls and harm to the environment.

A panel from industry, state and federal regulatory agencies, and marine scientists and engineers should be assembled to evaluate the analysis of the samples. That panel should then recommend whether offshore evaluation should be continued or dropped and if continued, whether it should include additional detailed geophysical surveys such as at Pokai Bay or Penguin Bank, additional sampling by coring or pilot runs of dredging in deposits now inventoried, or a test of weeks or months in a single deposit.

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