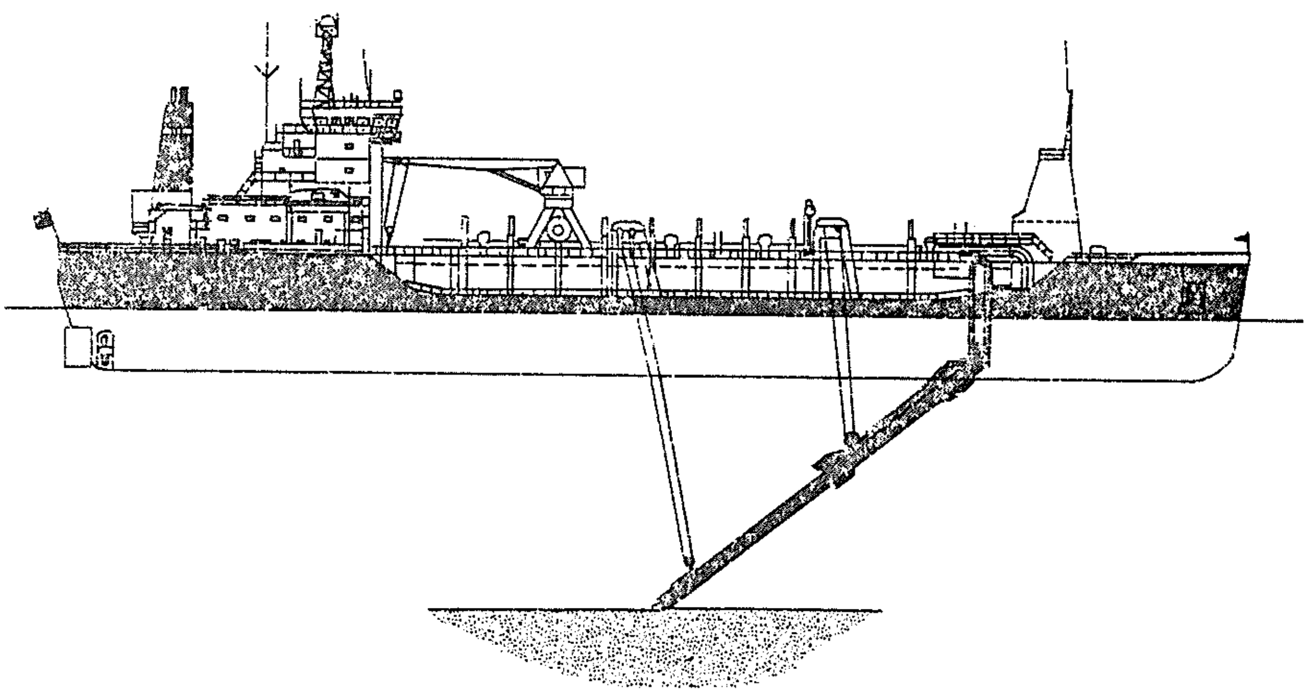
Open File Report 4-87

An Economic Reconnaissance of Selected Heavy Mineral Placer Deposits in the U.S. Exclusive Economic Zone



BUREAU OF MINES-UNITED STATES DEPARTMENT OF THE INTERIOR

AN ECONOMIC RECONNAISSANCE OF SELECTED HEAVY MINERAL PLACER DEPOSITS IN THE U.S. EXCLUSIVE ECONOMIC ZONE

By

Staff, Bureau of Mines

January 1987

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This Bureau of Mines open file report is one of two reports on selected deposits within the Exclusive Economic Zone (EEZ). The objective of this study and the companion sand and gravel study is to aid the Minerals Management Service (MMS) in their selection of specific offshore areas for consideration of near-term lease offerings. Three selected placer areas were investigated and evaluated using engineering and cost models. Sensitivity analyses were then performed in major physical and engineering parameters affecting the economic viability of mineral resources from these three locations.

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- gold
- titanium
- zirconium
- rare earth elements

engineering costs
dredge
mill
net present value

b. Identifiers/Open-Ended Terms

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deposit geology
deposit resources
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FOREWORD

This Bureau of Mines open file report is one of two resulting from a study of selected hard mineral deposits occurring within the United States Exclusive Economic Zone (EEZ). The study was initiated in response to a request by the Director of the Minerals Management Service (MMS) to the Assistant Director, Mineral Data Analysis, Bureau of Mines. The objective of this placer minerals report and the companion sand and gravel report is to aid the MMS in their effort to identify specific offshore areas for consideration as near-term lease offerings.

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LIST OF UNIT OF MEASURE ABBREVIATIONS

d/wk	days per week	nmi	nautical mile
d/yr	days per year	oz	ounce
ft	feet	pct	percent
ft/s	feet per second	ppb	parts per billion
h	hour	ppm	parts per million
h/d	hour per day	st	short ton
in	inch	st/yd^2	short ton per square yard
lb	pound	st/yd^3	short ton per cubic yard
m	meter	st/yr	short ton per year
mi	mile	tr oz	troy ounce
mi^2	square mile	wk	week
mm	millimeter	wt pct	weight percent
Mst	million short ton	yr	year
		°	degree

EXECUTIVE SUMMARY

Renewed interest in producing hard rock minerals from the Outer Continental Shelf (OCS) resulting in the March 10, 1983, presidential proclamation extending U.S. Federal jurisdiction 200 nmi seaward. As a consequence, the Department of the Interior's Minerals Management Service (MMS) was directed to manage hard minerals development within the newly-created Exclusive Economic Zone (EEZ).

The objective of this study and the companion sand and gravel study is to aid the Minerals Management Service (MMS) in the selection of purposed hard mineral lease offerings in the EEZ by means of an "economic reconaissance" of placer deposits. Three marine placer areas were investigated because of their perceived near-term potential for containing economically viable deposits. Resource analyses were conducted concurrently with development of engineering and cost models for mining and mineral processing. The models were constructed so that multiple dredging and processing scenarios could be considered.

The three offshore placer resources evaluated were: 1) gold-bearing placers offshore Alaska (also referred to as Nome Gold Placers), 2) chromite-rich black sands offshore southern Oregon (also referred to in this study as the West coast placer cases), and 3) titanium-bearing sands on the Atlantic continental shelf off Virginia and Georgia (also referred to as the East coast placer cases). Resource information in those areas is not definitive and, in the case of the Atlantic seaboard, is only speculative. Private sector interest in marine placers is currently reflected in an ongoing operation to recover gold from submerged gravel deposits off Nome, Alaska, and the issuance of two permits to explore in titanium-bearing sands offshore Georgia.

Evaluation of proposed mining and processing scenarios performed for the three resource areas indicate a wide range of economic viabilities. The newly active dredging operation off Nome, Alaska, is expected to be profitable at present market prices for gold. That expectation cannot be extended to areas beyond 3.1 miles seaward.

Cash flow evaluations indicate that West coast placer operations can be viable if deposits with ore grades (pct oxides of chromium, titanium, and zirconium) of more than 8 pct consisting of chromite grades of over 6 pct (Cr_2O_3) are associated with gold grades of at least 0.0048 tr oz/st and recoverable concentrations of titanium minerals and zircon. Under this situation, deposit sizes also must be above 50 million tons, within 40 miles of Coos Bay, Oregon and at a depth of no more than 150 ft. In addition, an annual mining capacity of at least 2.5 million tons is required. Larger deposits with increased operating efficiency and lower total grades could be economic. Figures E-1 and E-2 presents graphically the feasibility zone or for profitable operations as defined by the two key variables, grade or average revenue per ton of ore and operating cost evaluated in this study. The graphics were developed by linear interpolation from an analysis of profitability with 4 specific grades. Combinations above the lines indicate profitable conditions for the resource sizes shown.

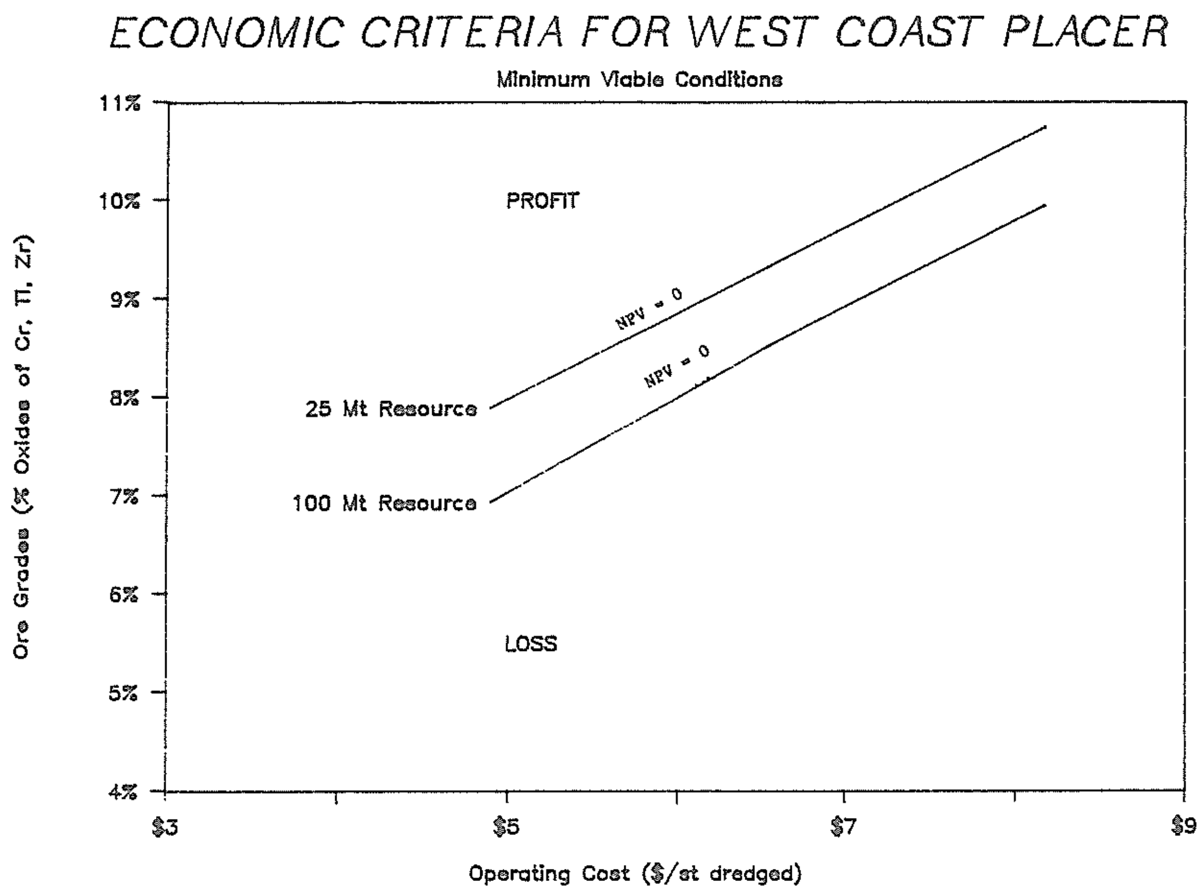

FIGURE E-1

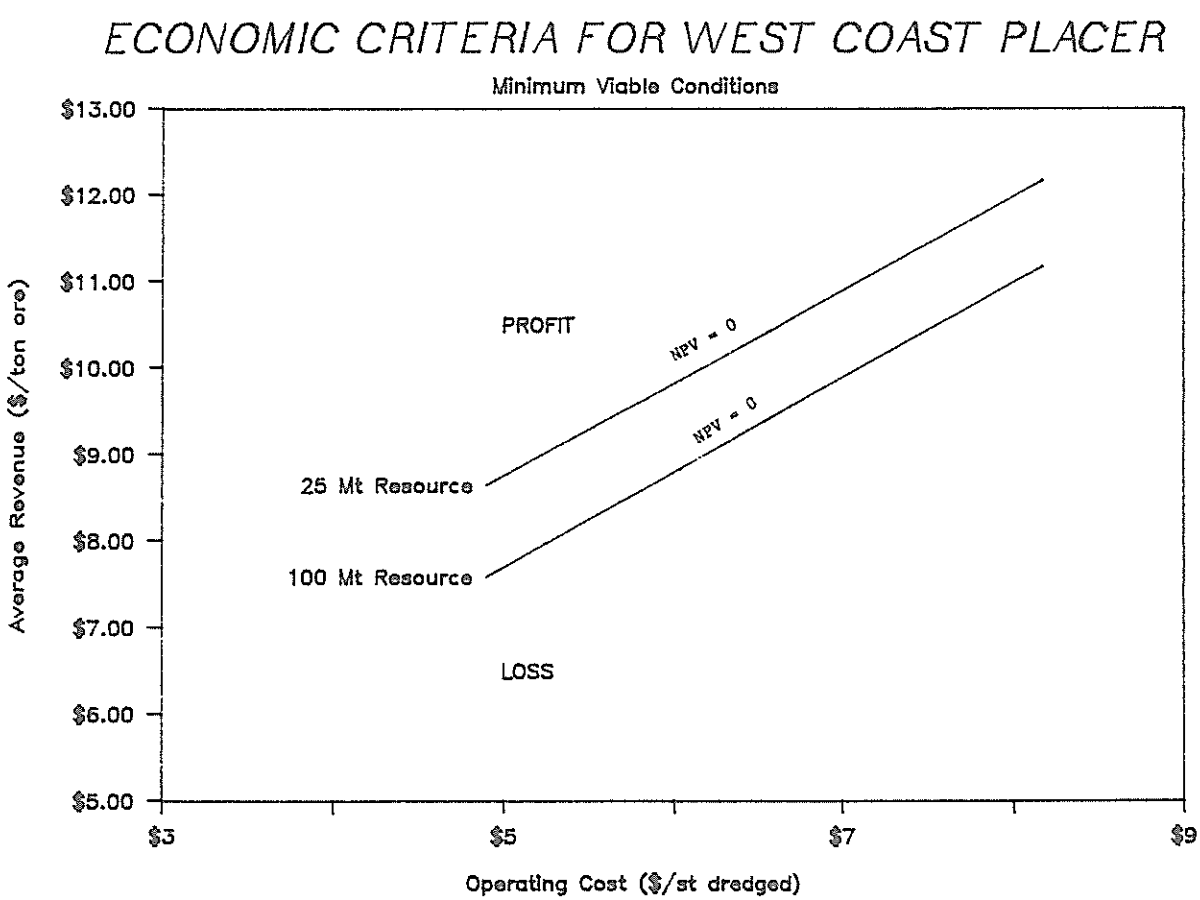

FIGURE E-2

At the present time, resource estimates of placers on the Atlantic Continental Shelf are speculative. As with the West coast evaluation, examination of possible grades in the context of plausible engineering and economic parameters indicate the approximate minimum conditions for viable offshore mining. Figure E-3 and E-4 presents the East coast feasibility zone, with points above the lines indicating profitable combinations of grade or average revenue per ton of ore and operating cost for the annual capacities shown. These conditions include deposits found within about 40 miles of a shore plant, containing ore grades twice (% oxides of titanium, zirconium, and rare earths) twice those currently being mined in Florida, with a distribution of grades similar to the world average for strandline titanium placer deposits. Such grades are found in only about one in four known strandline placer titanium deposits in the world. Recent samplings indicate concentrations that are equivalent to or higher than those needed for economic development of deposits on the Atlantic shelf, but the data are preliminary and no tonnages have been associated yet with the grades.

This study recommends that further economic reconnaissance investigations be performed on areas offshore Alaska that show potential for placer deposits of gold, platinum, and other minerals. For example, the Cape Prince of Wales area may contain significant offshore placer deposits of tin. Before initiating the leasing process in the Coos Bay, Oregon area, the likely occurrence of adequate resource grades and deposit sizes at feasible mining depths should be established. It is also recommended that black sand deposits off the coast of northern Oregon and southern Washington be investigated as potential West Coast sources of titanium. For the East coast, geological reconnaissance work should focus on identifying areas having total and constituent titanium mineral relationships comparable to average world strandline titanium placers. Concurrently, site-specific costing should be performed to defined specific location costs and constraints for offshore mining.

Finally, certain elements of the analytical methods used here should be refined and incorporated in economic reconnaissances of additional commodities and areas within the EEZ.

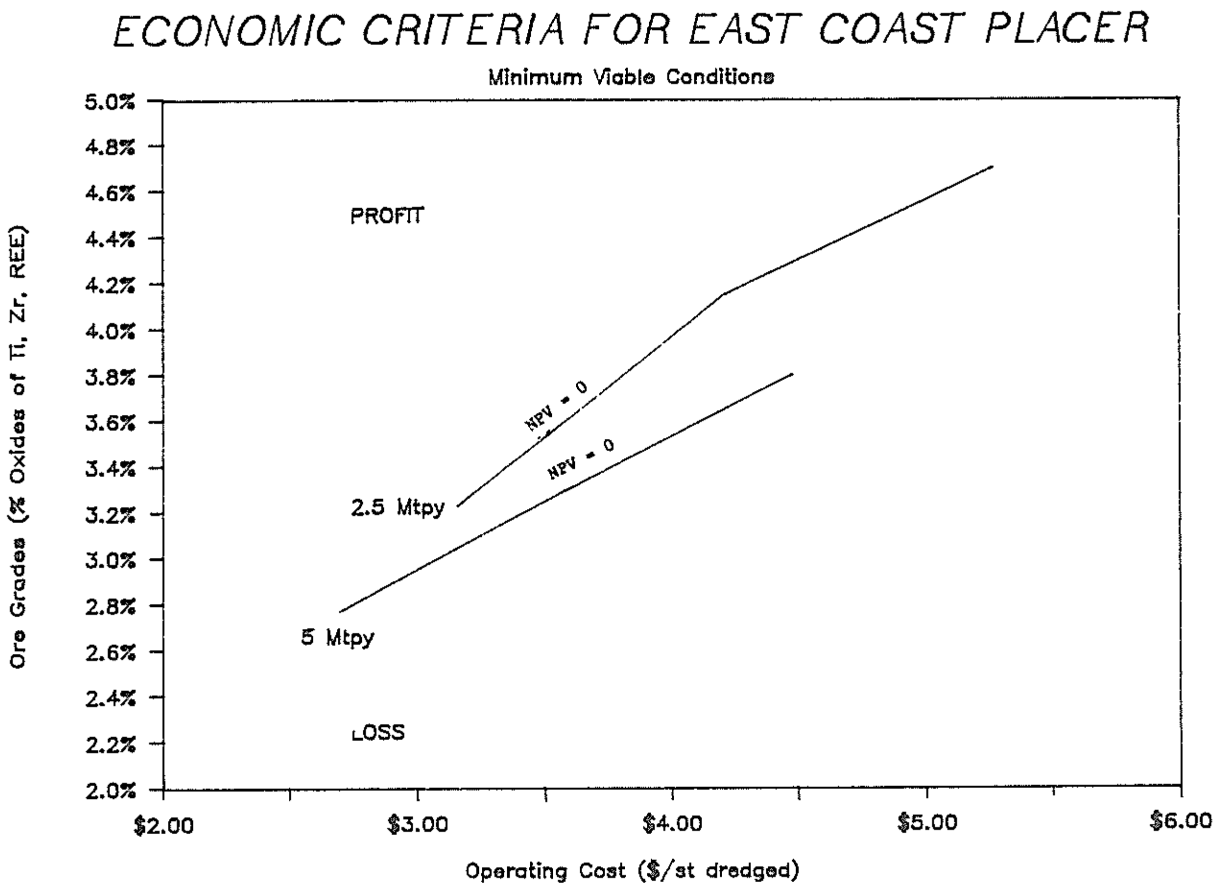

FIGURE E-3

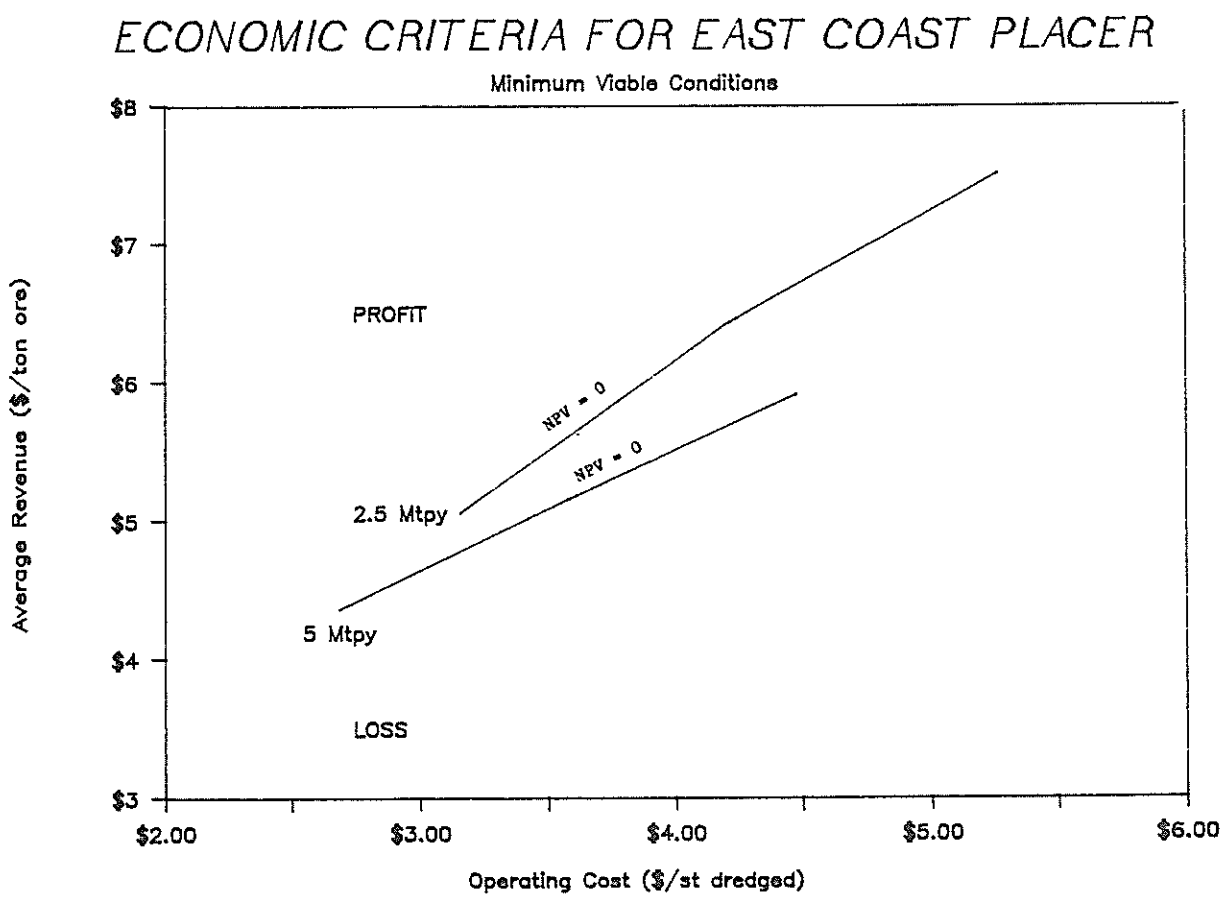

FIGURE E-4

INTRODUCTION

Placer deposits of heavy minerals, sometimes referred to as black sands, can form in any environment where a mechanism is available to concentrate mineral grains of high specific gravity. Such mechanisms include winnowing by high velocity winds, fluvial transport, and wave action. As a result, placer minerals are found in three primary environments: beach, river and continental shelf. The continental shelf of the United States is likely to contain a large number of these deposits, because all three of these mechanisms have operated on the shelf in the geologic past. During periods of continental glaciation in the Pleistocene epoch, lowered sea level exposed the shelf to the actions of wind and meteoric water. Rivers flowing across the exposed shelf delivered sediment weathered from the continental margin and concentrated heavy mineral fractions into elongated transverse placers. Winds created dunes of lighter mineral fractions by winnowing surface grains and leaving behind residual concentrations of heavy minerals.

Wave action and longshore currents created concentrations of heavy minerals in beaches along strandlines at the ocean/land interface. During interglacial periods and following the last glacial maximum, rising sea level led to further concentration of heavy mineral placers on the continental shelf by wave and current action. For this reason, placers presently lying offshore may be larger and of higher grade than those in adjacent onshore areas.

Heavy minerals of significance to this study include: gold, in it native state; chromite (commonly referred to by its Cr_2O_3 content), the principal ore of chromium (Cr); rutile, the more important of two mineral forms of titanium dioxide (TiO_2) (the other being anatase); ilmenite ($FeTiO_3$), the principal ore mined for titanium (Ti); luecoxene, an altered form of ilmenite from which the iron oxide content has been removed by weathering; monazite, a phosphate mineral [$(Ce,La,Y,Th)PO_4$] mined principally for thorium (Th) and rare earth elements (REE); and zircon ($ZrSiO_4$), the chief ore of zirconium (Zr), which is used extensively in foundry molds, and in refractory, abrasive, and ceramic applications.

Objective and Selection Criteria

The Bureau of Mines has been supporting several Exclusive Economic Zone (EEZ) and Outer Continental Shelf (OCS) related task groups by preparing a series of Technical Assistance Reports and by actively participating on various committees. This placer study, and its companion sand and gravel study, provide an economic assessment of deposits in selected U.S. coastal waters. The term "economic reconnaissance" is used to describes this analysis because precise economic appraisals are made difficult by the sketchy resource data available and the lack of mining experience in two of the three areas evaluated. The objective of this study is to aid the Minerals Management Service (MMS) in the selection of areas for proposed hard mineral placer lease offerings in the EEZ by isolating the key variables affecting the feasibility of mining these placers.

Consideration was given to several areas for examination of their potential for economic heavy mineral occurrences in the EEZ. Three areas on the continental shelf were chosen for this study off the shores of: Nome, Alaska, southwestern Oregon (West coast), and the coast of Virginia and Georgia (East Coast), see Figure 1. Historical land based mining and current efforts to mine placer gold in waters off Nome, Alaska give rise to possible extensions of the placer in EEZ territory. Previous mining of beach sands for chromite as well as for gold along the shores of southwestern Oregon, coupled with geological evidence of similar depositional and mineral environments offshore were reasons for selection of this site. Finally, while evidence for the existence of heavy mineral placer assemblages on the Atlantic Continental Shelf (ACS) is not as strong, the occurrence of and historical and current mining of titanium and other minerals from such placers on shore along the coastal U. S. suggest the possibility that such deposits may exist offshore. Descriptions and arguments for the potential occurrences of relevant minerals in each area will be discussed in the respective sections of each of the three sites.

General Approach

Because of the nature of the data available from the Nome, Alaska gold placer site, a different analytical approach was used for that site as compared to the other two. For the Nome gold placer, consideration was given to the possible extension of the existing gold placer now being developed. For that site, company data as well as data compiled by the Bureau of Mines and others were used to perform the engineering and economic appraisals.

For the Atlantic coast titanium placers and the heavy mineral sands off Oregon, despite the lack of hard data required for sound engineering and economic appraisals, an effort was made to replicate as close as possible, onshore or near shore mineral placers. For these two sites, engineering models were developed for calculating capital and operating costs. With these models, comparisons were made of the costs of partial beneficiation of the ore on vessel versus total beneficiation on shore. Consideration was also given to capital cost for a foreign built vessel.

Using costs derived from the engineering models and given prices for each of the mineral components, appropriate annual revenue and expenditures over the life of the reserves were developed. Discounted cash flow evaluations were then performed to measure the sensitivity of profits to plausible ranges of selected geological and engineering parameters. These parameters include ore composition and grade, deposit size, mining and processing capacity, haulage distance, and commodity prices. Combinations of these parameters which promise economically viable mining in the area, given the assumptions of this study are thus identified.

Assumptions and Limitations

Because of the many uncertainties of what actually may exist within the areas studied, several assumptions were required in both the engineering cost development and economic analyses. These assumptions are discussed in the respective sections of the text that follows. There are, however, some

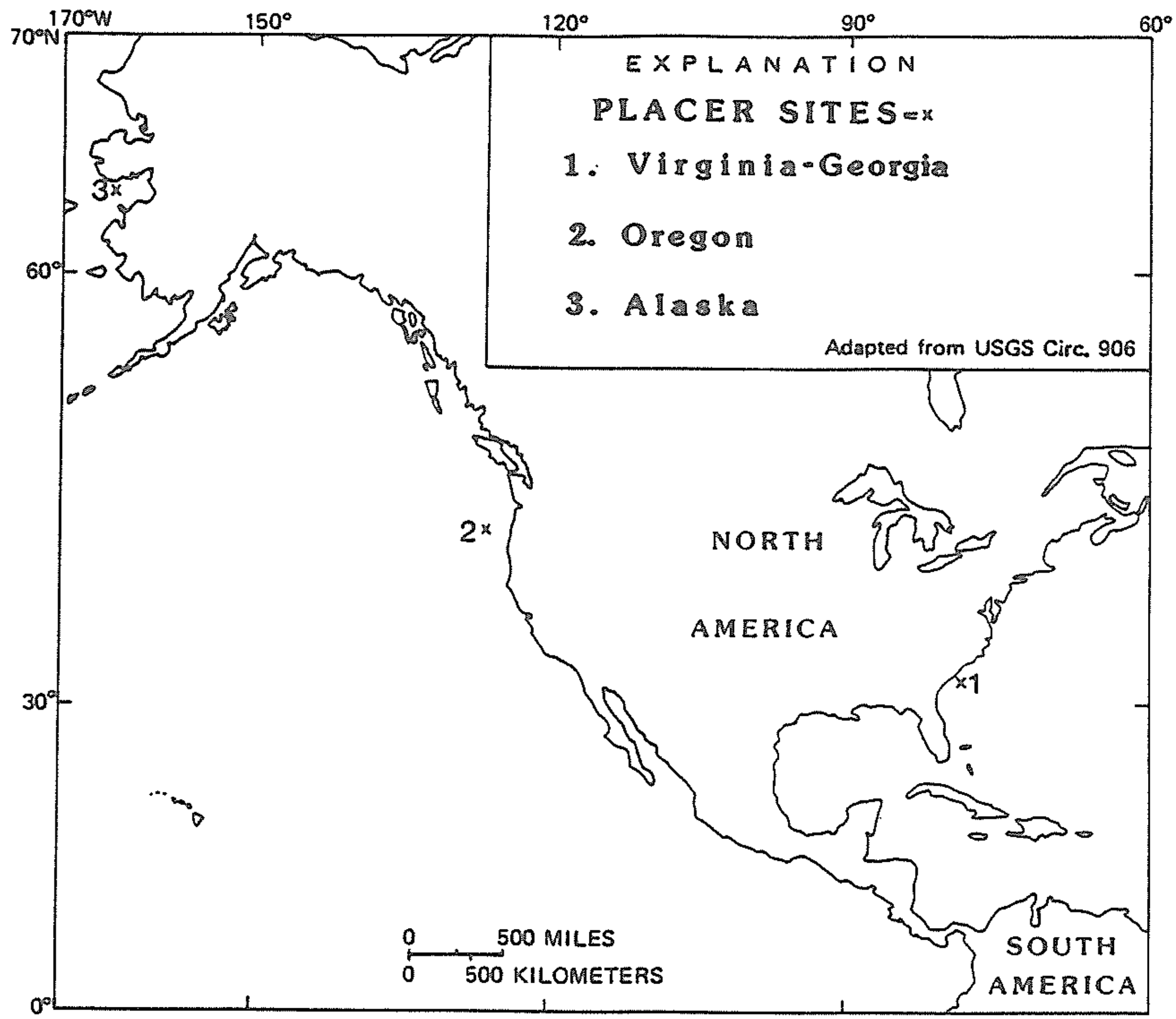

FIGURE 1. - Location map of study areas in the Exclusive Economic Zone.

general assumptions relevant primarily to the titanium and chromite placer sites, which should be mentioned here. Each site evaluation assumes a "stand alone " operation, that is, all revenues, costs, and tax treatments would apply to that mine site and plant facility as an individual corporation. All minerals identified in the ore, are of required market quality, and are processed and sold at or about current prices. Costs for exploration would be about $1 million. Acquisition costs only for onshore plant and docking facilities are included. Not included in the scenarios are costs for leasing offshore sites, legal fees and costs for any delays in order to comply with environmental regulations, and costs incurred from restrictions such as those due to local and maritime laws.

ACKNOWLEDGMENTS

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ALASKAN GOLD PLACERS, NOME REGION

Background

Several reported near-shore placers are present on the Alaskan continental shelf (fig. 2, table 1). The gold placers in the Nome region are the best known and appear to have the highest potential for near-term development. Past production from onshore deposits at Nome yielded over 5 million oz gold, and was accomplished by hand methods as well as draglining and dredging. Recently, Inspiration Mines Inc. (IMI) has announced their intention of mining offshore placers with a large bucket-line dredge.

The Nome offshore placer gold area extends 20 mi along the northern coast of Norton Sound, beginning from a point approximately 15 mi west of Nome and ending about 5 mi east of town. Potentially economic auriferous gravels extend from the coast seaward to just over 3 mi.

Water in Norton Sound is shallow, rarely exceeding 90 ft. In the Nome offshore placer area depths are between 10 and 45 ft. Bottom topography is gentle with a slope of approximately 7 ft/1,000 ft.

Several creeks and rivers flow into Norton Sound in the Nome area and relief of stream channels cutting marine sediments is minimal. Minor variations in offshore topography reflect the presence of reworked glacial morainal deposits extending out to about 3 mi offshore. Several outwash fans, particularly from the Nome River, are present.

Resources

Geology

The onshore and offshore Nome coastal plain area consists of Pliocene and Pleistocene marine and glacial sand and gravel. Coastal plain sedimentary deposits are underlain by the Nome Group which is composed of the Port Clarence limestone and the Kuzitrin Formation. The Kuzitrin Formation consists of undifferentiated limestones, slates, and schists.

Eight beach placer deposits are recognized locally onshore and are known as the Present Beach, Outer Submarine Beach, Inner Submarine Beach, Second Beach, Intermediate Beach, Monroeville Beach, Third Beach, and Fourth Beach. The Inner and Outer Submarine Beach, Intermediate and Third Beach, and Second Beach are separated from one another by glacial drift of the Iron Creek (Nebraskan or Kansan) glaciation and Nome River (Illinoian) glaciation. The glacial drift and marine sediment on the Nome Coastal plain are overlain by alluvium, colluvium, wind blown silt, and peat which have accumulated during

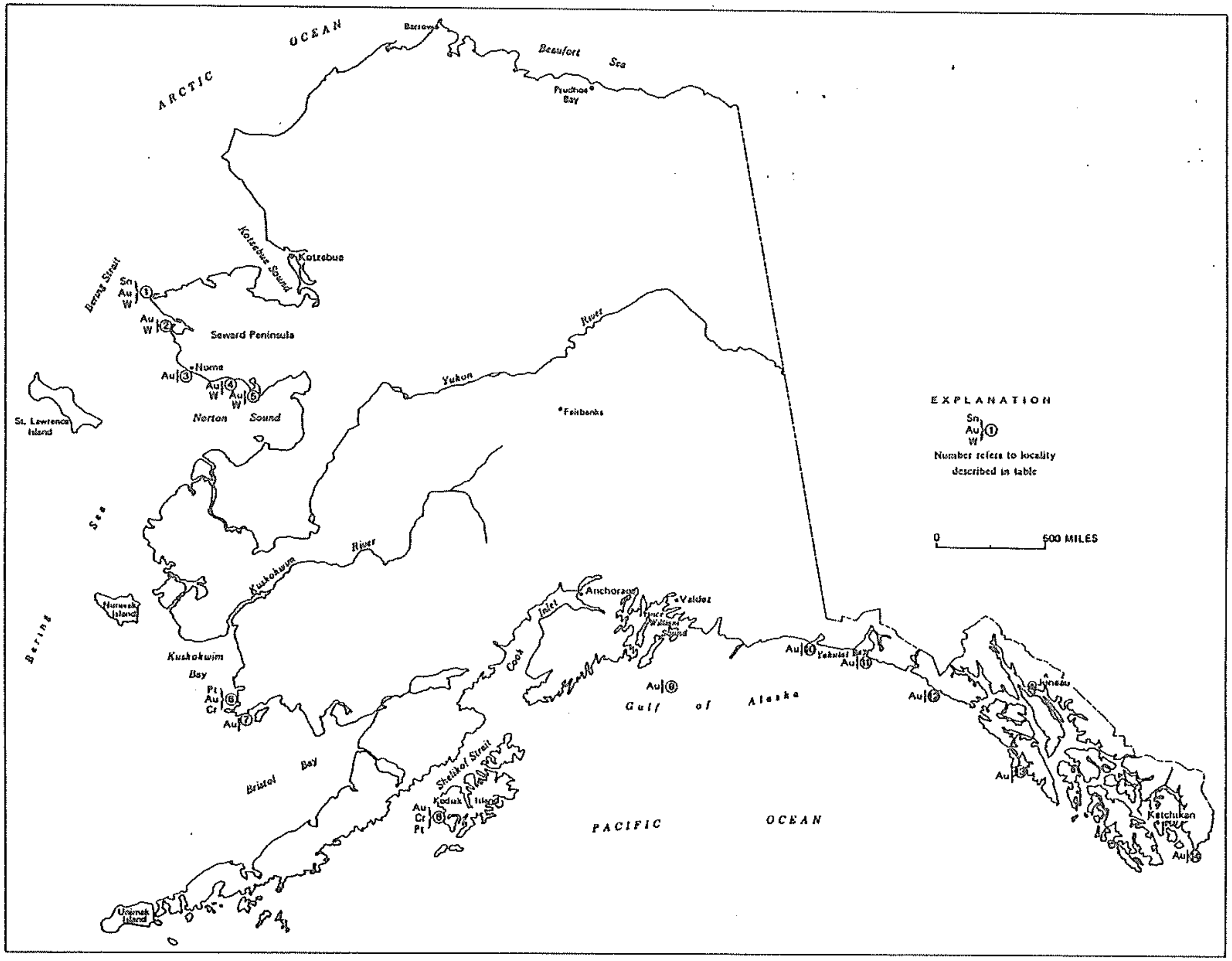

FIGURE 2. - Location map of reported placers offshore Alaska.

TABLE 1. - Distribution of known offshore placer areas, Alaska
(see figure 1 for deposit locations)

Map no.	Locality	Minerals present	Description	References
1	Cape Prince of Wales	Sn, Au, W(?)	High energy tin placers along a north-trending reef and on beaches. Mineral concentrations probably extend further offshore. Total tin production (1902-67) from nearby onshore placers is about 4 million lb.	Lu, 1968; Moore, 1979; Nelson, 1969.
2	Grantley Harbor	Au, W	High energy, shallow water placer. Minor onshore past production.	Cobb, 1981; Moore, 1979.
3	Nome Offshore Region	Au	At least three favorable paleobeach strands are offshore at water depths of 35-42 ft, 65-72 ft, and 80 ft. Deposits consist of reworked morainal material. Onshore gold production (1898-1985) is at least 5 million oz. Offshore dredging initiated by IMI in August 1986.	Bundtzen 1972; Lu, 1969; Harris, 1968; Nelson, 1969.
4	Bluff-Solomon Offshore	Au	Coarse-grained gold in high energy beach and nearshore placers.	Cobb, 1981; Lu, 1968; Moore, 1979; Nelson, 1969.
5	Golovin Lagoon	Au, W(?)	Surficial gold in lag deposits overlying high energy placers. No reported production.	Lu, 1968; Moore, 1979; Nelson, 1969.
6	Goodnews Bay	Pt, Au, Cr	Possibly economic concentrations of platinum and gold in offshore sands. Significant concentrations of chromium associated with platinum placers. Favorable environments include paleofluvial channels, paleostrand lines, and tidal ridges. Hypothetical subeconomic resources in offshore placers are estimated to be 5 million oz. Offshore sampling by the Bureau is in progress. Total onshore production of PGM (1927-81) from Goodnews Bay District is about 650,000 oz.	Bond, 1982; Owen, 1975; Ulrich, 1984; Welkie, 1976; Zelenka, 1986; Barker, 1986; Berryhill, 1963; Cook, 1969; Coonrad, 1978.
7	Hagemeister Strait	Au	Reported minor beach placers. Production unknown.	Capps, 1937; Cobb, 1973; Smith, ____.
8	Kodiak Island Beaches	Au, Cr, Pt	Reported past production of less than 8,000 oz Au from west coast beaches.	Capps, 1937, Cobb, 1972, 1973; Gassaway, 1935; Maddren, 1919.
9	Middleton Island	Au	Reported production of a few thousand ounces of gold.	Cobb, 1972; Moore, 1979; Nelson, 1969.
10	Yakataga District	Au	High and low energy placers. Production of about 15,000 oz Au from beaches.	Cobb, 1972, 1984; Reimnitz, 1970; Renshaw, 1978; Reimnitz, 1976; Thomas, ____.
11,12	Lituya and Yakutat District	Au	Past production of less than 4,000 oz Au.	Cobb, 1972, 1984; Reimnitz, 1970; Rossman, 1957; Reimnitz, 1976; Thomas, ____; Wright, 1969.
13	Kutchuma Islands	Au	Reported coarse-grained gold in high energy placers overlain by fine-grained sediments.	Moore, 1979.
14	Cape Fox	Au	Reported high and low energy placers.	Moore, 1979.

Wisconsinian and Holocene time (Hopkins, 1960). Figure 3 indicates the location of onshore Nome beach deposits, offshore paleobeach strands, and the southernmost extent of glacial morainal deposition. A cross section showing the stratigraphic relations between the beach and glacial deposits is shown in figure 4.

Regressive and transgressive marine cycles are associated with glacial advances and interglacial periods. Four offshore beach strands were formed on glacial drift during the last marine regression. Beach shoreline features are found at 35 to 42 ft, 55 ft, 65 to 72 ft, and 80 ft below sea level as shown in figure 4 (Nelson and Hopkins, 1969).

Evidence from seismic profiling and drill hole data indicate that glaciers originating in the mountains north of Nome during the Iron Creek and Nome River glaciations extended 3 mi beyond the present shoreline (Tagg and Greene, 1973; Nelson and Hopkins, 1969). Glacial transport of heavy minerals, including particulate gold, is apparently the most important mechanism for deposition of auriferous gravels offshore. This conclusion is supported by assay data which indicate offshore sands and gravel of glacial origin contain approximately 25 times more gold than finer-grained deposits of marine or fluvial origin. Outwash and stream channels extending offshore and incised into glacial drift usually contain gold values higher than background levels as a result of reworking of the auriferous till (Nelson and Hopkins, 1969). Additionally, some buried beach gravel deposits contain significant gold values. However, the highest gold concentrations are reported in gravels sampled from the upper 6 ft of glacial till units (Nelson and Hopkins, 1969). These relict lag gravels veneering glacial drift contain mostly coarse gold particles; more than 85 pct are larger than 65 mesh. Auriferous lag gravels were derived from glacial drift by a winnowing process as the shoreline migrated during transgressive and regressive marine cycles. Gold concentrations near bedrock, unlike classical fluvial placers, are discontinuous and generally low.

Gold Distribution

The uppermost 6 in. to 3 ft of offshore sediments contain the highest gold values in the Nome offshore placer area. Typically, gold concentrations in the upper foot of these sediments contain approximately eight times the average values in the same sediment type buried at depth. The eight-fold concentration factor suggests that the upper 8 ft have been reworked to form high grade lag gravel deposits (Nelson and Hopkins, 1969). The average gold content of offshore sediments is dependent upon the source and degree of reworking. Table 2 lists background, average, and maximum gold concentrations in types of sediment found in the Nome offshore placer area, as indicated from limited drilling and clam shell sampling data.

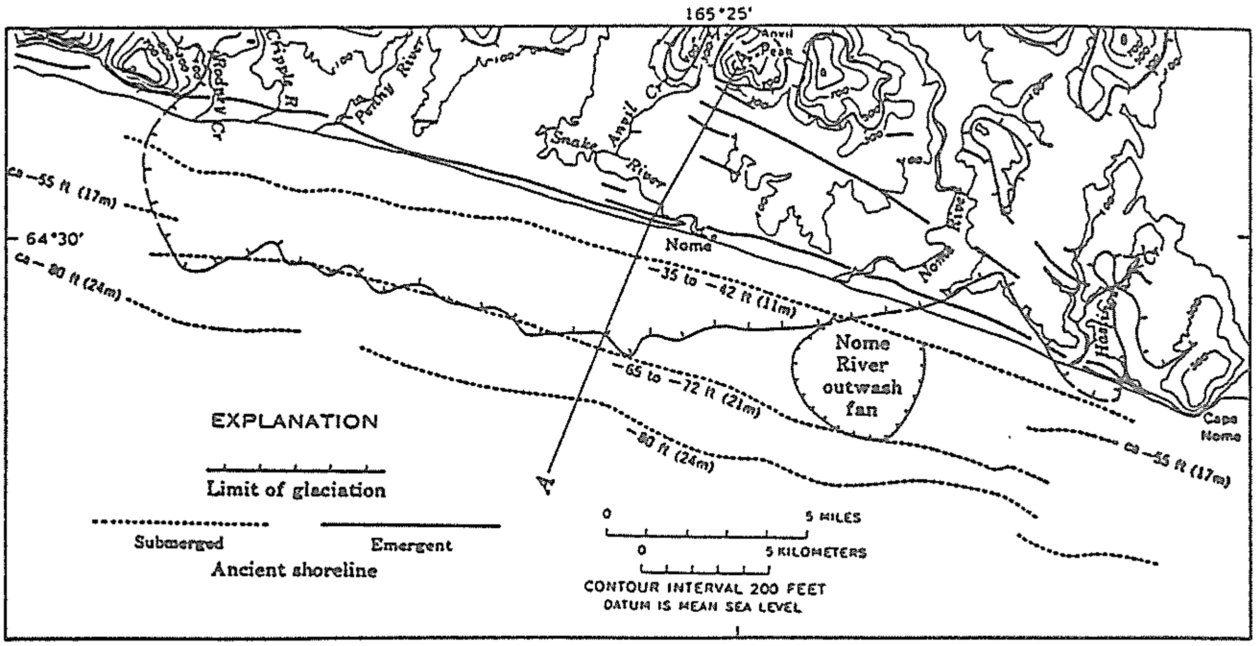

FIGURE 3. - Location of offshore and onshore beaches and limit of glacial deposition (Adapted from Nelson and Hopkins (1972).

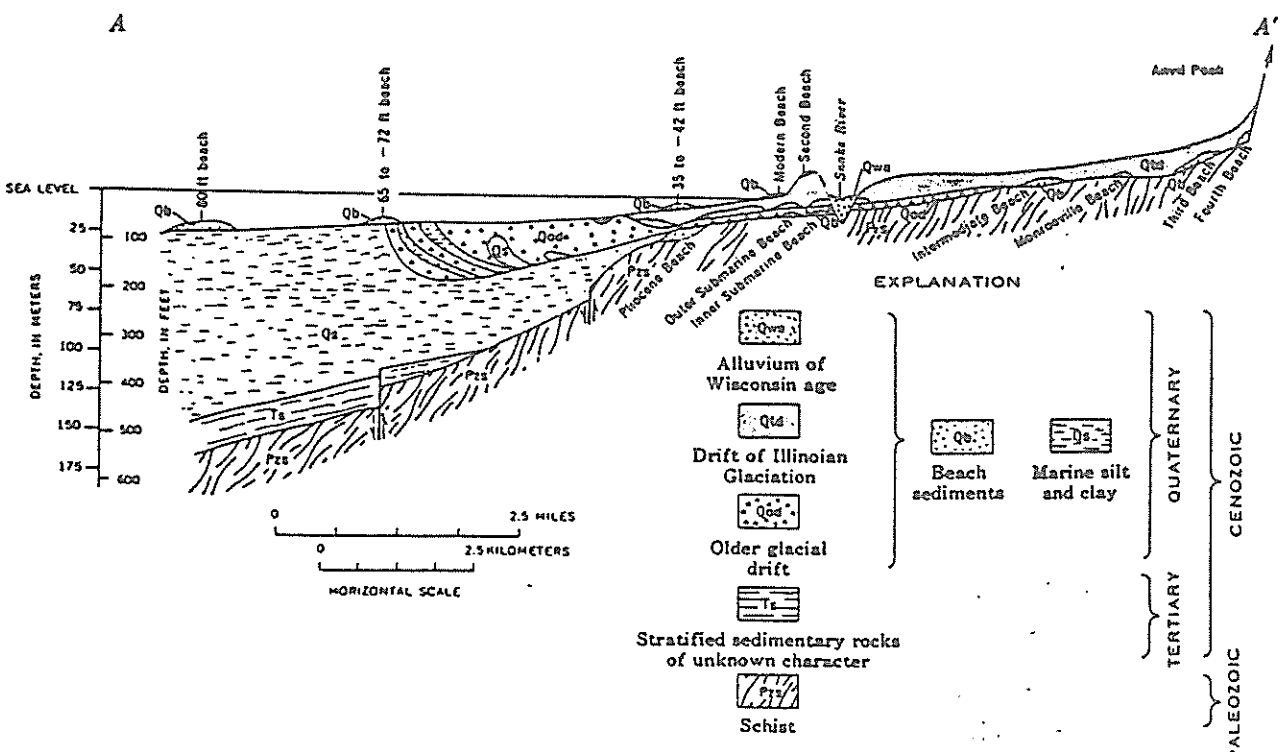

FIGURE 4. - Geologic cross section across the NOME coastal plain. Location of section A-A' indicated in figure 2. Geology compiled by Nelson and Hopkins (1972).

TABLE 2. - Distribution of gold in different sediment types in the Nome offshore area

Description/ sediment type	Gold content (ppm) Background	Average	Maximum
Nome near-shore relict gravel:			
Over glacial till...............	0.114	0.556	2.500
Over outwash....................	.003	.004	.012
Over bedrock....................	nil	nil	nil
Submerged beach sandy gravels.....	.003	.016	.058
Glacial till (unworked)...........	NA	.070	NA
Open Bering Sea sand and gravel...	.001	.003	.082

NA Not available.

Source: Nelson and Hopkins, 1969.

The data presented in table 2 suggest that glacial till is the principal source of gold in the Nome offshore placer area. Therefore, the areal distribution of significant gold deposits is probably limited to the extent of offshore glacial till as shown in figure 3. Sediment sampling data indicate that glacial sediments were deposited no further than 3.1 mi seaward of the present coastline. For this reason, the economic potential for placer gold mineralization beyond about 3 nautical miles is considered to be low.

Resource Model

Published reserve estimates are not available for the Nome offshore placer area. On the basis of 34 bottom grab samples collected by the USGS, an average gold concentration of 0.556 ppm (0.0219 tr oz/yd^3) in relict gravel deposits overlying glacial till was estimated (Nelson and Hopkins, 1969). For economic analysis, grades ranging from 0.1 to 1 ppm were assumed.

A minimum volume of at least 32,637,000 yd^3 of recoverable placer material is assumed for a hypothetical offshore deposit. An annual mining rate of 1,632,000 yd^3 and a 20-yr mine life is also assumed.

SOUTHWESTERN OREGON CHROMIUM PLACERS

Background

Assessment of mining and processing costs for offshore Oregon placer deposits are conjectural at the present time because of insufficient resource information. Correlation of potential offshore deposits with known onshore placers, such as the Seven Devils and Eagle-Pioneer deposits, was used to construct a hypothetical but plausible offshore deposit scenario for economic evaluation.

Offshore Potential

Published information on offshore black sand resources is sparse. Available data on continental shelf deposits offshore southern Oregon were compiled by Gray and Kulm (1985) and are presented in figure 5. Surface concentrations of greater than 10 pct heavy minerals have been found seaward of adjacent river systems at water depths of less than 650 ft (200 m). The total area covered is estimated to be at least 170 mi^2 (Phillips, 1979). Assuming a uniform distribution of heavy minerals and tonnage factor of 1.4 st/yd^2 (Peterson, 1986), this area represents a potential heavy mineral sand resource of approximately 730 Mst.

Heavy mineral fractions of surface sediments sampled offshore Oregon range from 1 to 56 pct (Kulm, 1968). The most extensive concentrations occur seaward of the mouth of the Rogue River and off Cape Blanco (fig. 5). Samples showed measured concentrations of heavy minerals above 30 pct in parts of both areas. With the exception of gold, data on the shares of various metals in the heavy mineral fractions are not available. Areas containing 5 to 150 ppb gold (0.000146 tr oz to 0.004375 tr oz/st) in surface sediments are shown in figure 5, and are coincident with the Rogue River and Cape Blanco black sand concentrations (Clifton, 1968). Surface sediments with greater than 10 pct heavy minerals or 5 ppb gold cover at least 125 mi^2 of the continental shelf off the mouth of the Rogue River and at least 40 mi^2 off Cape Blanco. Using a 1.4 st/yd^2 tonnage factor, these deposits represent potential resources of 530 Mst and 165 Mst, respectively. Although smaller in size, the deposit off Cape Blanco is more concentrated in heavy minerals than the deposit off the Rogue River (Kulm, 1968).

Magnetic anomalies associated with both the Cape Blanco and Rogue River offshore areas are narrow and steep, indicating shallow and narrow sources, consistent with magnetite-bearing placer deposits (Kulm, 1968). The most prominent anomalies are directly seaward of the mouth of the Rogue River and follow the projected line of drainage. Anomalies in both areas indicate a source close to the sediment-water interface and suggest the occurrence of black sand deposits with dimensions similar to adjacent onshore placers.

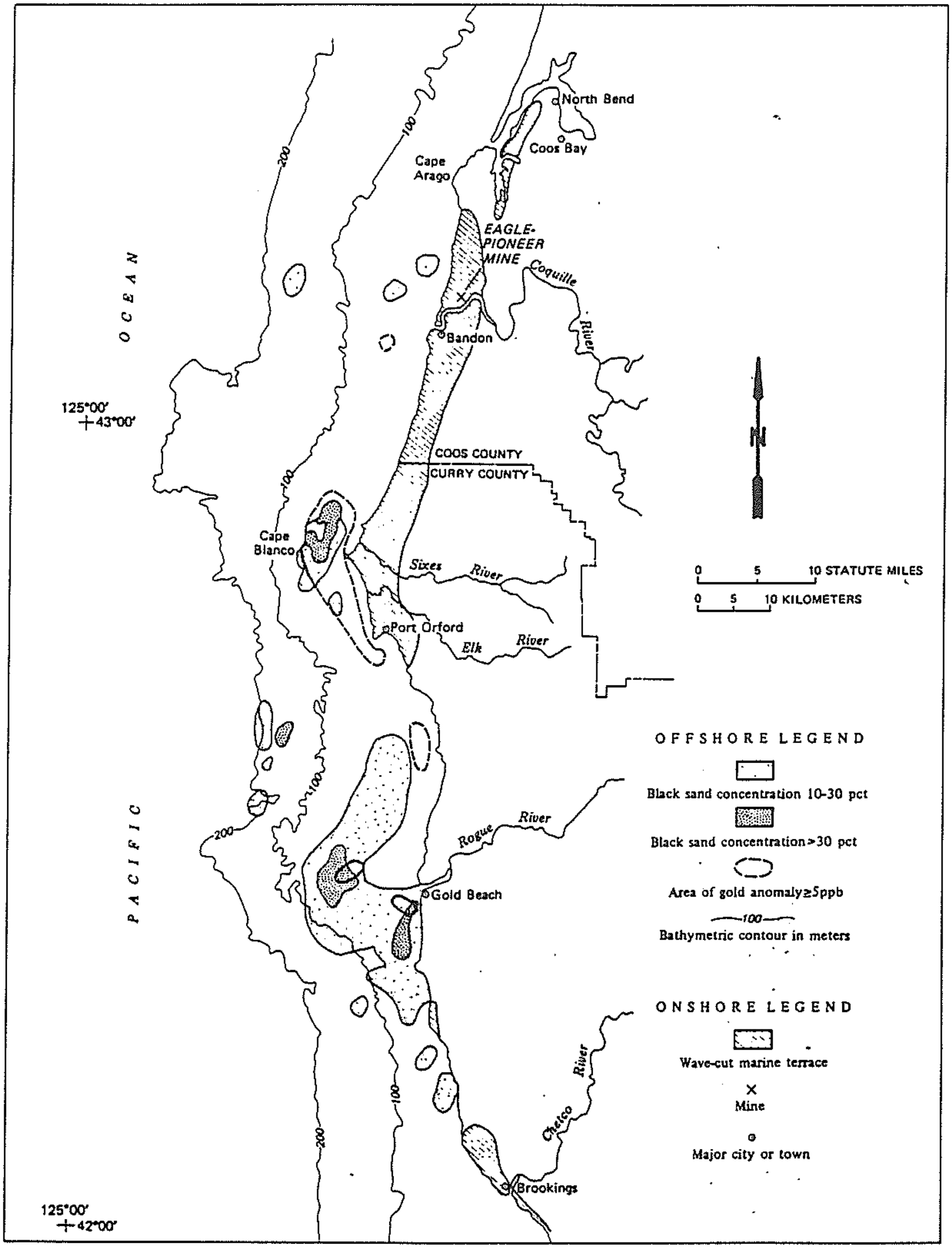

FIGURE 5. - Potential mineral resources on the southern Oregon continental shelf (after Gray and Kulm, 1985).

Onshore Terrace Deposits

Black sand deposits are found in elevated marine terraces along the Oregon coast from Coos Bay to Port Orford (fig. 5). Zones enriched in chromite, ilmenite, magnetite, zircon, rutile, and garnet are lens-shaped bodies varying in thickness from a few inches to more than 40 ft; average thicknesses are in the range of 5.0 to 10.0 ft (Griggs, 1945). These enriched zones either lie directly on bedrock or are separated from it by a layer of unconsolidated sand or a mixture of sand and gravel, usually less than a meter thick. Heavy mineral content of the black sand bodies, excluding garnet, varies from about 10 pct to more than 50 pct by weight, with an average value of approximately 30 pct. Mineral grain sizes are in the range of 0.004 to 0.01 inches in average diameter.

Production History

During World War II and the Korean War chromite was produced from high-grade deposits in the ohshore marine terraces between Cape Arago and Bandon, Oregon (fig. 6). A total of 2,033,500 st of black sands averaging 3.8 pct Cr_2O_3 was mined and 53,600 st of concentrates averaging 39.3 pct Cr_2O_3 with a Cr:Fe ratio of about 1.5 were shipped during this period (Wetzel, in press). One government stockpile of concentrates near Coquille, Oregon, in 1954 averaged 54 to 58 pct chromite, 12 to 20 pct ilmenite, 12 to 17 pct garnet, 3 to 5 pct zircon, and 3 to 4 pct magnetite, with minor amounts of rutile, gold, and platinum (Hunt, 1960). In 1955-56, Pacific Northwest Alloys, Inc. recovered chromite (42 to 43 pct Cr_2O_3) for ferrochromium alloy, zircon (66 pct ZrO_2) for foundry ceramics, and garnet for abrasive use from this stockpile , but were unable to economically recover the rutile, gold, and platinum. However, in 1918 concentrates from the Eagle-Pioneer Mine (fig. 7) were reported to contain 1.43 oz/st gold and 1.60 oz/st platinum (Hornor, 1918). Between 1903 and 1929, a total of 2,848 oz gold and 100 oz platinum were recovered from Oregon beach placers (Brooks, 1968).

Resource Estimates

Investigations of black sand deposits in marine terraces along the southern Oregon coast have been made intermittently from the early 1940's to the present, and included drilling of more than 100 holes by the Bureau during the 1970's. Based on investigations of explored deposits, demonstrated resources are estimated to contain 423,800 st Cr_2O_3 in 8,394,200 st black sands (Wetzel, in press). If these concentrations are typical for the whole area, total black sand resources in the marine terraces between Coos Bay and Port Orford could be vastly larger.

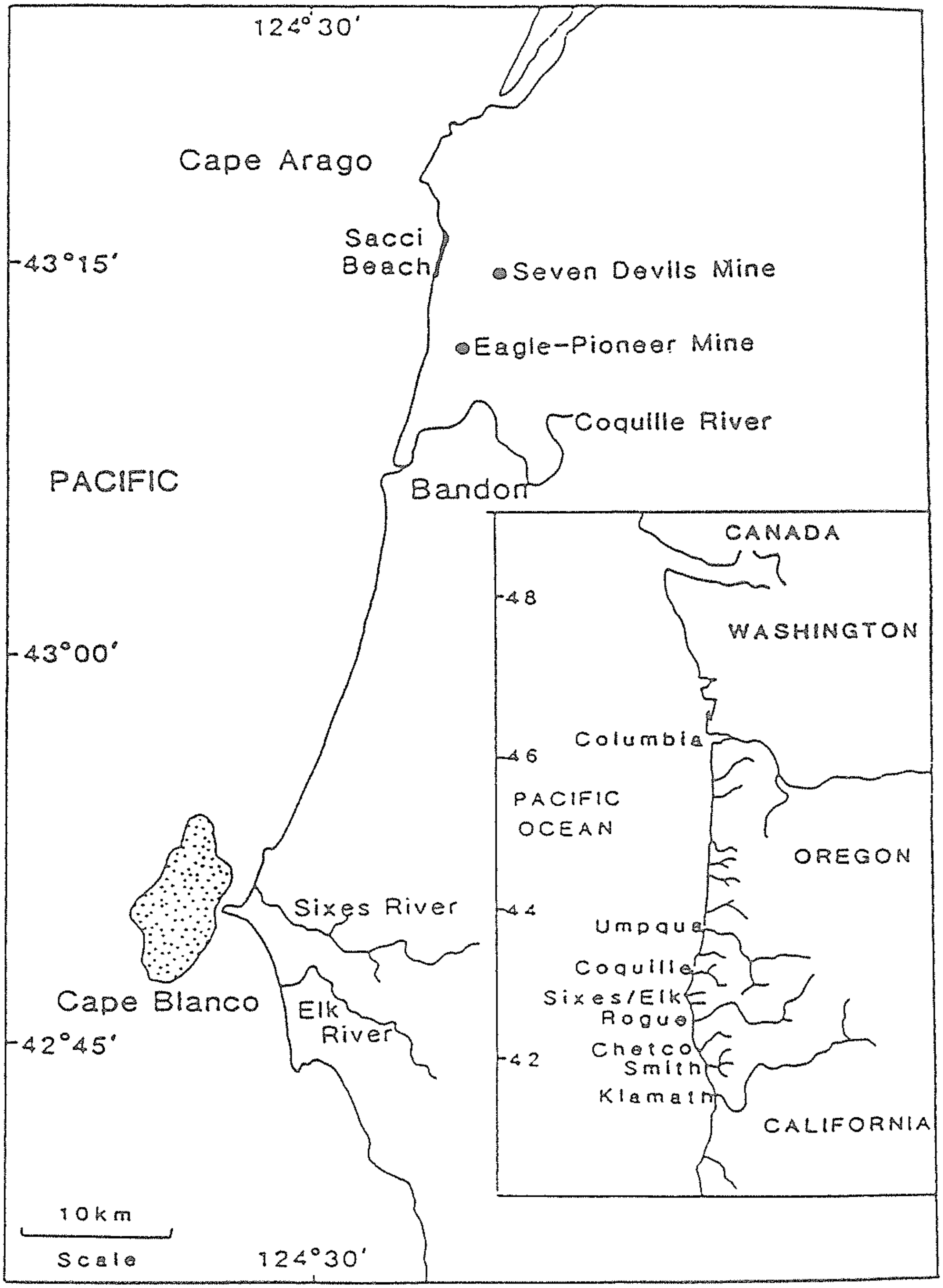

FIGURE 6. - Location map of marine placers in the Cape Arago-Cape Blanco area, OR (from Peterson, 1986). Marine placers (black circles) on uplifted coastal terraces, modern beach placer (thick black line), and a zone of heavy mineral enrichment (stippled pattern) on the modern seafloor are shown.

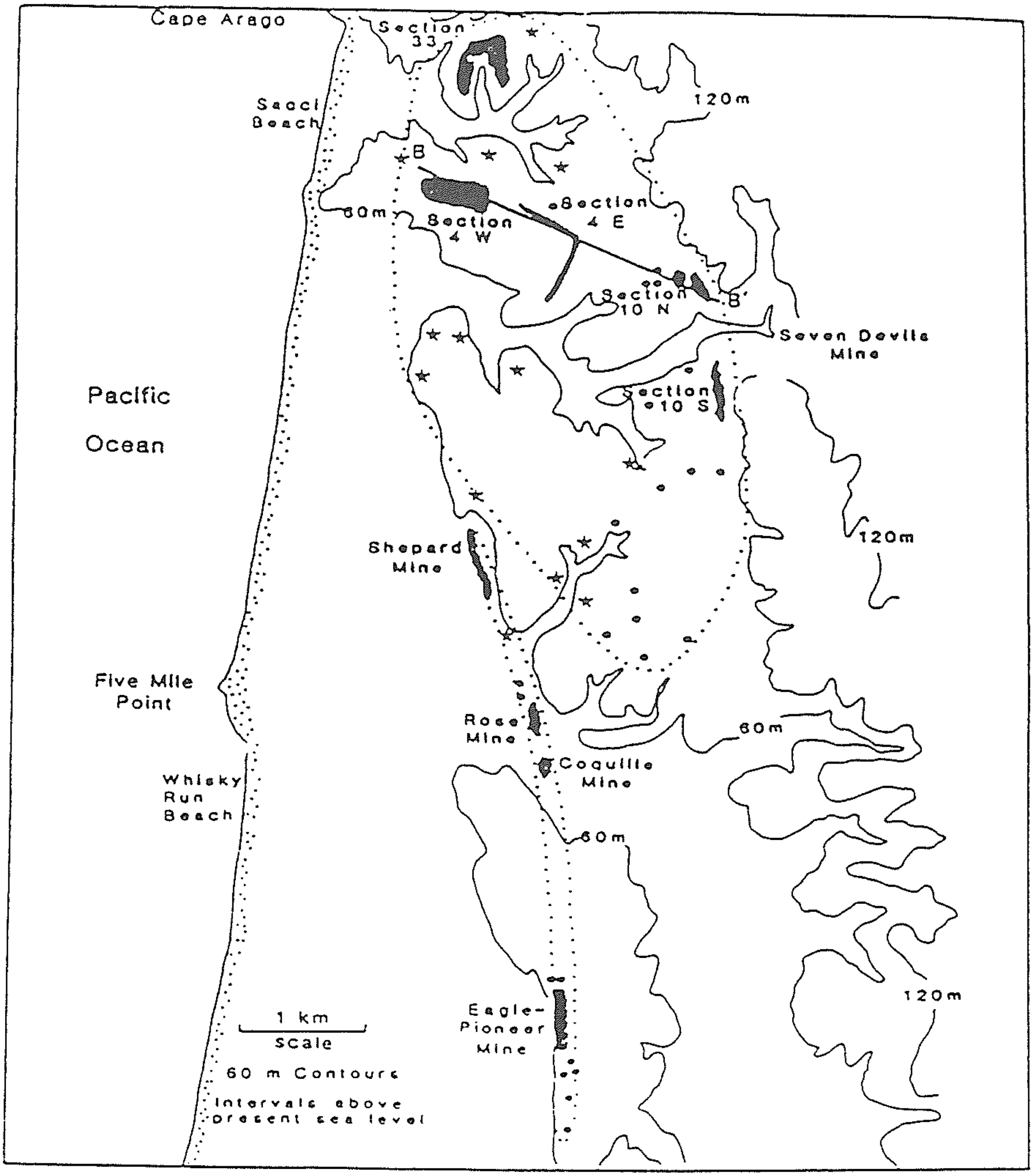

FIGURE 7. - Distribution of placer sands in the Seven Devils and Pioneer terraces (from Peterson, 1986). Known ore bodies are outlined in black, Bureau of Mines drill hole sites are shown as black dots, and surface sample locations are represented by stars. Dotted lines enclose probable extent of Seven Devils and Pioneer placer deposits. Cross section B-B' is shown in figure 7.

Recent sampling in the vicinity of the Seven Devils and Pioneer terraces (fig. 8) indicate of black sand resources with greater than 50 wt pct heavy minerals of 17.6 Mst and 1.8 Mst, respectively (Peterson, 1986). Terrace cross sections constructed from drill-hole data show lateral variations in thicknesses and average grades of placer zones (fig. 9). Based on an analysis of geomorphic and stratigraphic features, Peterson, Gleeson, and Wetzel (1986) conclude that the Seven Devils terrace deposit represents a transgressive inshore placer formed against a coastal headland, whereas the Eagle-Pioneer placer is a beach placer developed during a former still stand in sea level (figs. 9 and 10). The larger Seven Devils placer covers an area of about 4.2 mi^2 enclosing an estimated 22 Mst of black sands with an average grade greater than 3 pct Cr_2O_3 and 2.2 Mst with grade greater than 5 pct Cr_2O_3. Laboratory-scale processing of black sand samples from the Eagle-Pioneer Mine recovered an average of 0.016 oz/st gold; analyses of samples showed an average Cr_2O_3 grade of 7.83 pct and for $FeTiO_3$ of 2.01 pct (Wetzel, unpublished Bureau of Mines data).

Offshore Deposit Scenario

The principal source of heavy minerals for both the onshore and offshore deposits are the Klamath Mountains of southern Oregon and northern California (Peterson, 1986; Chambers, 1969). Formation of the placer deposits appears to be the result of interaction between fluvial transport, tectonic uplift, and rise and fall of sea level during the Pleistocene and Holocene Epochs (Bowman, 1972, 1973). Temporary halts in the rise of sea level (still stands) during the Holocene Transgression were of sufficient duration for creation of wave-cut terraces and the accumulation and reworking of placers on ancient beaches (fig. 11). Terraces formed in this manner are postulated to occur off the present coast of southern Oregon in water depths of 60, 95, 150, 230, 275, 330, and 490 ft, based on a combination of evidence (Chambers, 1969). Recent work by Peterson, Komar, and Scheidegger (1986) shows that the richest placer concentrations on beaches are produced by a combination of wave action and longshore currents in areas of maximum shoreline curvature south of prominent headlands such as Cape Arago (fig. 10). Bowman (1973) has suggested that offshore placers may be larger and more enriched than the onshore terrace deposits, because of repeated reworking of heavy minerals during successive cycles of sea level rise and fall. However, available offshore resource data is not sufficient to inform this suspicion.

Resource Model

Resource parameters assumed for this study are presented in table 3. Several parameters are based on onshore terrace deposits, and are considered reasonable approximations of deposits expected offshore. Geometry and origin are assumed to be similar to the Seven Devils placer (fig. 10) and chromite, ilmenite, rutile zircon, and gold are assumed to be the recoverable minerals. To reflect uncertainly about actual ore tonnage, grade and dilution during mining, four sets of feed grades reflecting low and high mineral assemblage values comparable to onshore values were selected for evaluation. These parameters will be examined in the engineering and economic analysis sections that follow.

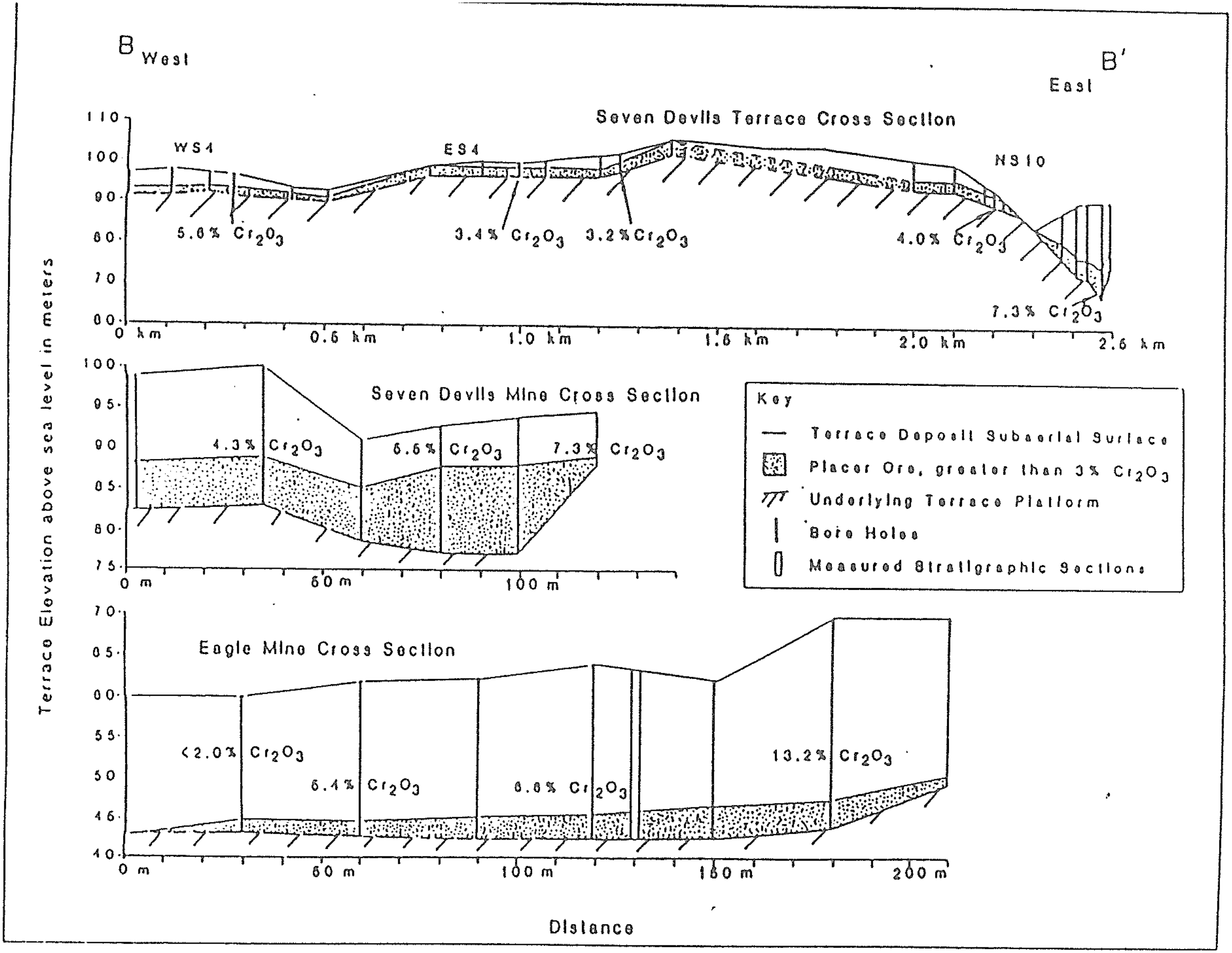

FIGURE 8. - Cross section of Seven Devils and Eagle-Pioneer placer deposits (from Peterson, 1986). Placer sands (stippled pattern) are defined above a cutoff grade of 3 pct Cr_2O_3; values shown are representative averages from drill hole (vertical lines) samples. The Seven Devils Terrace cross section (B-B') has a 10:1 vertical exaggeration.

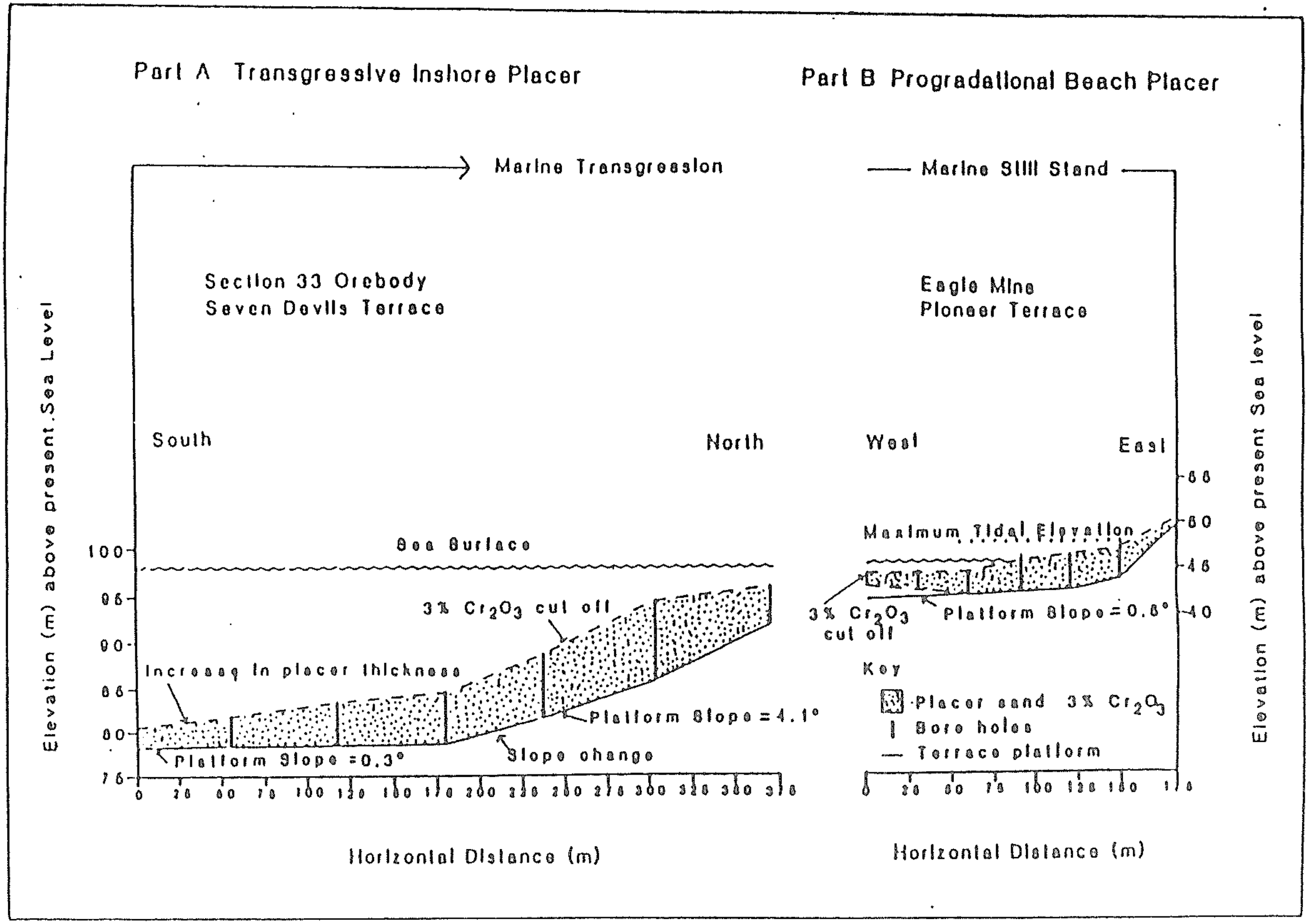

FIGURE 9. - Paragenetic profiles of Seven Devils and Pioneer Terrace deposits (From Peterson, 1986). A, Development of Seven Devils placer (stippled pattern) thickness as a function of platform gradient following marine transgression. B, Development of Pioneer progradational placer (stippled) as a function of tidal range (dotted lines) during still conditions of a relative sea level.

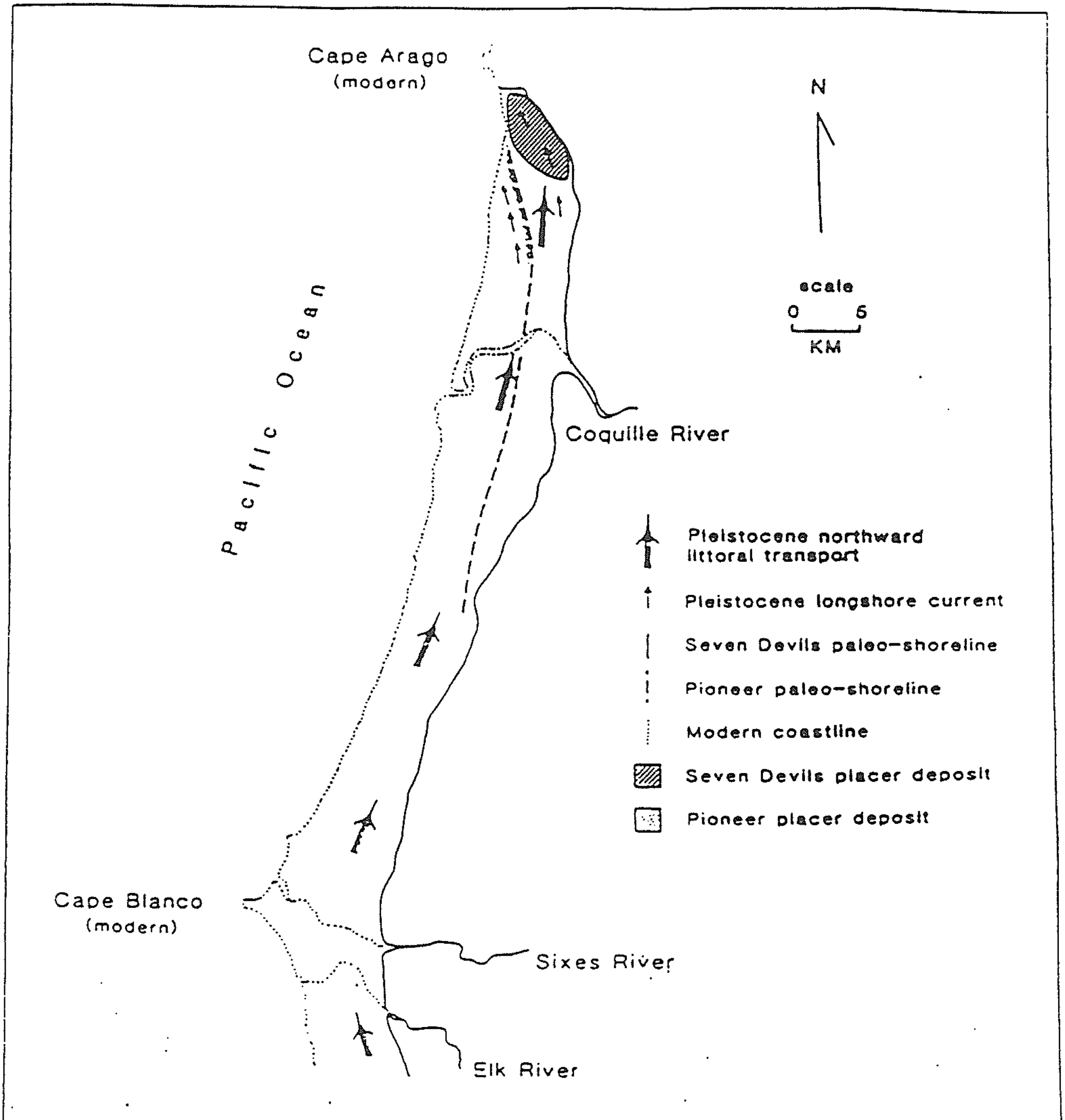

FIGURE 10. - Paleo-Shorelines of the Seven Devils, Pioneer, and modern beach terraces south of Cape Arago (from Peterson, 1986).

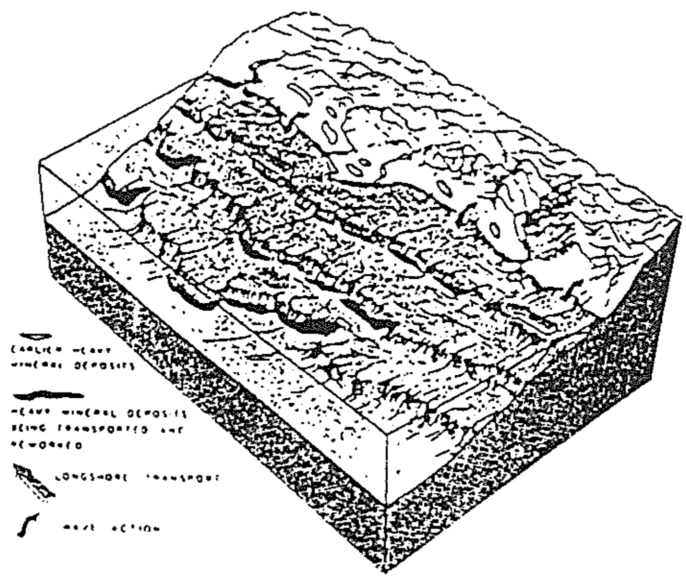

FIGURE 11. - Diagrammatic presentation of submerged wave-cut terraces and associated placers, offshore southern Oregon (After Bowman, 1973).

TABLE 3. - Assumed parameters for a hypothetical offshore placer site based on investigations of black sand deposits in onshore marine terraces near Bandon, Oregon

Deposit geometry:	lenticular body elongated parallel to shoreline.			
Average thickness:	8.2 ft unconsolidated sand lying directly on bedrock.			
Deposit size range:	25 - 150 Mst			
Deposit Grade Range	Low Grades	Low-Mid Grades	High-Mid Grades	High Grades
Feed Grades				
chromite (% Cr_2O_3)	2.60%	5.20%	6.30%	9.50%
ilmenite (% TiO_2)	0.40%	0.80%	1.00%	1.50%
rutile (% TiO_2)	0.08%	0.17%	0.20%	0.30%
zircon (% $Zr\ O_2$)	0.29%	0.58%	0.70%	1.00%
gold (tr oz/st)	0.002	0.004	0.005	0.01
Total oxides of Cr, Ti, Zr	3.37%	6.75%	8.20%	12.30%

Minesite Characteristics

Environmental conditions affecting mining operations on the continental shelf off southern Oregon include seafloor bathymetry, ocean currents, and meteorological conditions. The continental shelf south of Coos Bay has a width ranging from 10 to 20 mi, maximum water depths at the outer edge of 540 to 600 ft, and an average slope of 0.3° to 0.7°. Surface sediments consist of a nearshore sand facies that extends to approximately 240 ft water depth and a deeper water mud-silt facies. The boundary between these two facies exhibits seasonal variation, moving into deeper water during the winter months (Phillips, 1979). Water circulation offshore southern Oregon is dominated by the California Current flowing south parallel to the coast during spring and summer, and by the nearshore, north-flowing Davidson Current during fall and winter. Maximum current velocities within 20 mi of the coast range from 0.8 to 3.3 ft/sec (MMS, 1983). Similarly, longshore currents reverse with the seasons, flowing north in winter and south in summer. Upwelling of bottom water during summer months is estimated to be 0.0003 ft/sec (MMS, 1983).

Wave-generated bottom currents on the continental shelf develop velocities of greater than 1.3 ft/sec at depths of 120 ft (Phillips, 1979). Currents varying from 0 to 0.8 ft/sec are present at midshelf depths (295 ft) and at the shelf edge (600 ft). Rare surface storm waves have been reported to reach 95 ft in height, but average wave heights are between 10 and 20 ft (Phillips, 1979). Heavy seas of greater than 16 ft from the southwest are expected November through March; during the summer months, seas of generally 3 ft or less travel from the north-northwest (MMS, 1983). For purposes of the following mining scenario, 60 days of stormy weather exceeding operational conditions are assumed between October and April.

Other environmental and socio-economic factors affecting development of placers offshore Oregon are discussed in detail elsewhere (MMS, 1983). Continental shelf areas within 3 nmi of shore fall within the Oregon Coastal Management Zone. Most of the surface anomaly off Cape Blanco is within 3 miles of the coast, as is the majority of the seafloor lying less than 164 ft below sea level (fig. 5). Conflict of mining operations with fishing industry activities, recreational activities, and commercial shipping is probable. Existence of inactive waste dumps on the continental shelf is unknown, but possible. The nearest deep water port is Coos Bay, Oregon, about 37 mi from Cape Blanco.

VIRGINIA-GEORGIA TITANIUM PLACERS

Background

Heavy mineral placer resources are known to occur on the Atlantic Continental Shelf (ACS), though, commercially exploitable deposits have yet to be delineated. For this reason, detailed site-specific economic analyses are not possible. Hypothetical offshore deposits can be broadly evaluated based on onshore beach-sand deposits because the offshore deposits are expected to be geologically similar in occurrence.

Onshore Beach-Sand Deposits

Three onshore beach-sand deposits are presently being mined in Florida and one deposit in New Jersey is being reopened. There are also three "explored" deposits that have been sufficiently drilled to justify probable grade-tonnage calculations, and several deposits that have been mined out (fig. 12).

Subaerial deposits of heavy minerals in modern and ancient beach sands presently constitute nearly exclusive sources for rutile, zircon, and monazite. Economic beach-complex titanium placer deposits are generally several miles in length, up to 1.2 mi in width, and a few to several tens of feet in thickness (Grosz, 1986). Heavy mineral concentrations in these deposits are variable, typically containing 3 to 6 wt pct heavy minerals, about half of which are currently of economic value (Grosz, 1986). Commercial viability of a deposit depends more on the relative proportions of mineral constituents than upon total heavy mineral content. Deposits containing only 0.5 wt pct heavy mineral that consist of equal amounts of rutile and zircon have been profitably mined in Australia (Grosz, 1986).

History and Production

The first Southeastern beach sand mining operation began in 1916 near Mineral City and Pablo Beach, Florida, for the purpose of making titanium tetrachloride for World War I use in tracer bullets, flares, and smokescreens. By 1928, a large part of the domestic production of ilmenite, rutile, and zircon came from Florida, but production stopped abruptly in 1929 with the mining of newly developed deposits in Virginia (Giese, 1964). The Virginia deposits were mined from hardrock sources, primarily anorthosite, intermittently until 1971 (Lynd, 1975). Mining began again in Florida in 1940 by Riz Mineral Company at West Palm Beach and Melbourne. These deposits were thin, relatively rich, naturally concentrated beach sands. They were mined continuously to 1946, intermittent until 1948, and then sold. The company was reorganized as Florida Ore Processing Company, Inc., and mined the deposits until 1955.

In 1942, the Rutile Mining Co. of Florida was organized to mine low-grade terrace sand deposits about 10 miles east of Jacksonville (Griese, 1964). The Jacksonville deposit was approximately 6 mi long, half mi wide, and 20 ft thick. The sand contained 4 pct heavy minerals, of which 40 pct was ilmenite, 4 pct leucoxene, 7 pct, rutile, 11 pct zircon, and less than 0.5 pct monazite (Detweiler, 1952). This mine has been shut down for many years.

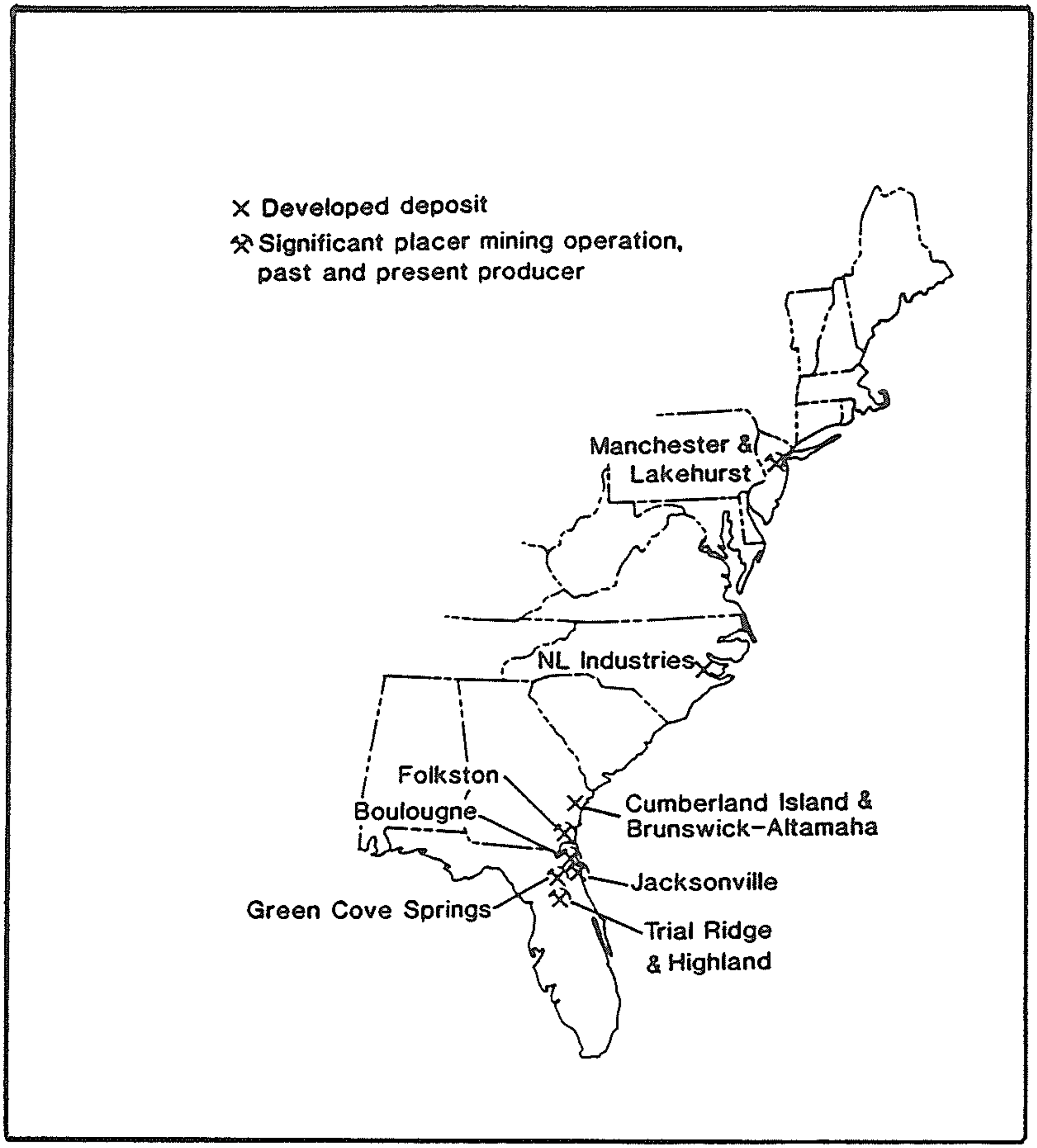

FIGURE 12. -Location of titanium placer mines and deposits along the Eastern Coast of the United States

Development of the north-central Florida deposits began in 1948. E. I. duPont de Nemours and Company, Inc., began production from the Trail Ridge Operation, and opened the Highland Operation in 1955. The Highland deposit is the northern extension of the Trail Ridge deposit. Together, the total dimensions would be approximately 17 mi long, one mi wide, and 25 to 70 ft thick. The grade presently averages about 1.2 pct contained TiO_2. Both of these properties are currently operating. Their combined production for the period 1971-80 was approximately 188,000 st per year of 66 pct TiO_2 concentrate.

In 1962, production in New Jersey began from the Lakehurst deposit by Glidden-Durkee Division of SCM Corp., and continued until 1972-73 when ASARCO began mining the Manchester Unit. The Manchester Unit borders the Lakehurst on the south. It is not known whether ASARCO purchased the Lakehurst property or if there are any reserves left for the Lakehurst. ASARCO did operate the Manchester Unit from 1973 to 1982 when they shut down for economic reasons. At the time they shut down, the mineable reserves were approximately 110 Mst at 1.95 pct TiO_2. The orebody varies from 25 to 40 ft thick; planar dimensions are not known. Presently, a private party is involved in reopening the mine.

In Georgia, beach sand mining began in 1965 by the Humphreys Mining Company. The Folkston Mine was operated until 1974, when the deposit was mined out. The mine produced a concentrate averaging approximately 71 pct TiO_2. The dimensions were approximately 2.5 mi long, 0.75 mi wide, and 8 ft thick. The grade averaged about 1.3 pct TiO_2. Before the Folkston deposit was mined out, Humphreys Mining Company began mining the Boulougne deposit in 1973. This deposit is considered to be a southern extension of the Folkston deposit and is located just over the Florida border (Pirkle, 1974). The reserves were estimated to be approximately 20 Mst at an average grade of 1.14 pct TiO_2. The deposit dimensions approximate 3 mi long, 0.5 to 0.75 mi wide, and 5 to 25 ft thick. The deposit was mined out in 1979.

The Green Cove Springs Mine is located in northeastern Florida and is owned and operated by Associated Minerals (USA) Ltd., Inc. Production began in 1972 and continues to date. The deposit dimensions average 11 mi long, 0.75 mi wide, and 20 ft thick (Pirkle, 1974). The ore grade has been estimated to be 1.3 pct TiO_2. From 1972 to 1980, the mine produced approximately 35,000 st of 71.5 pct TiO_2 concentrate per year.

Several Atlantic coast deposits considered to be potentially economic include the Brunswick-Altamaha and Cumberland Island deposits in Georgia, and the NL Industries deposit in North Carolina. It should be noted that the Cumberland Island deposit has since become incorporated within the National Park Service's Cumberland Island National Seashore, so this deposit will probably never be mined. Resources for these deposits are estimated to be:

Brunswick-Altamaha	72 Mst @ 1.17 pct TiO_2
Cumberland Island	265 Mst @ 0.64 pct TiO_2
NL Industries	19 Mst @ 1.3 pct TiO_2

Offshore Resources

Geology

The continental shelf, defined as the area between the shoreline and the 650-ft isobath, varies in width from less than 3 mi off southern Florida to about 90 mi offshore Cape Cod, MA. Because sea level fluctuated considerably during Pleistocene and recent times, the shelf is considered to be a submerged coastal plain and the Atlantic Coastal Plain is partly an emerged continental shelf (Grosz, 1986). The continental shelf off the middle and southeastern United States is uniform in slope and smooth, with local relief less than 160 ft and seaward gradient less than 1:1,000 (Hollister, 1973). For these reasons, geologic, geomorphologic, and geophysical methods currently used for exploration of Atlantic Coastal Plain sediments may also be applied to ACS sediments (Grosz, 1986).

Bottom currents on the continental shelf are variable in direction and velocity, but have a distinct inshore component between Cape Hatteras and southern Florida (Hollister, 1973). Between Cape Hatteras and the shelf off Georgia, water circulation forms large-scale eddies caused by the interaction of the north-flowing Florida Current with south-flowing nearshore water (Milliman, 1972). Between Cape Hatteras and New Jersey, the dominant directions of bottom currents on the inner and middle shelf are to the south and landward (Milliman, 1972). The effects of southerly drift can be seen in the general trend of spits and sandbars. Outer shelf currents are not well known, but the net direction of bottom transport is presumed to be offshore (Milliman, 1972).

Sediment Description

Sand covers nearly all the continental shelf between New Jersey and Florida. The sand is mainly unimodal, well-sorted, and has a symmetrical grain-size distribution curve (Hollister, 1973). Mean grain size generally increases toward the shelf break. Most of the shelf north of Cape Hatteras is covered with a relict low-carbonate feldspathic sand, whereas shelf sediments south of Cape Hatteras are characterized by relatively high carbonate and low feldspar contents, the result of warm coastal waters and southern river sedimentation (Milliman, 1972). Sediments immediately adjacent to the mouths of large piedmont rivers tend to have relatively low carbonate and high feldspar contents (Milliman, 1972). Shelf sands containing appreciable amounts of calcium carbonate south of Cape Hatteras are texturally similar to sands consisting mainly of quartz and feldspar north of Cape Hatteras, suggesting that composition does not strongly influence grain-size distribution (Hollister, 1973).

The impressive characteristic of the sediments of the continental shelf is that most are residual or relict deposits. Fine-grained, nearshore sediments probably represent the only modern (post-transgressional) sediments on the shelf (Milliman, 1972). Residual sediments have been weathered from underwater outcrops, and may be forming at the present time in areas of outcrops on the continental shelf (Hollister, 1973). Modern shelf sediments are unstained fine sands and muds that are generally found in a zone less than

12 mi wide. The zone is marked by a rather abrupt seaward boundary with coarser relict sediments (Milliman, 1972). Rivers delivered sediment to the emerged continental shelf during the Pleistocene, but at the present time very little sand is transported onto the shelf by runoff. Most is trapped in drowned river valleys or estuaries, though an occasional flood may eject fine-grained sediment onto the shelf (Hollister, 1973). Modern detrital sediment is not an important sand source for the continental shelf; the sediment that does escape from the estuaries appears to be transported parallel to the nearshore area or, in the case of fine-grained sediment, bypasses the shelf and is deposited in deeper water (Hollister, 1973; Milliman, 1972).

Three inter-gradational heavy mineral provinces (northern, central, and southern) characterize the ACS of the United States. The heavy mineral suite of the northern province is dominated by pyroxenes and amphiboles; titanium minerals and zircon are minor components. In the central province, titanium minerals, zircon, and monazite are more abundant, whereas in the southern province titanium minerals dominate. Rutile, zircon, monazite, and phosphorite are also significantly more abundant in the south than in the north (Grosz, 1986). The southern part of the ACS from Virginia to Georgia holds the most promise for commercially attractive deposits (Grosz, 1986), and is the focus of this report. Heavy mineral concentrations of potentially economic interest are shown as shaded areas in figure 13.

The principal variables of marine placer formation are: 1) a heavy mineral source terrace, such as igneous or metamorphic highlands; 2) a conduit from source to depositional site which not only transports the minerals but weathers them, thereby upgrading the economic component of the assemblage; and 3) a mechanism for vigorous hydraulic sorting, such as wave, tidal, or wind action, which concentrates the economic components (Grosz, 1986; Attanasi, 1986). In addition to these variable, climatic conditions will influence the quality, grade, and size of the deposits (Grosz, 1986).

Offshore Potential

Large areas of the ACS are covered with an estimated 1,080 billion yd^3 of sand and gravel (Dep. Interior, 1979). Results from preliminary studies by Grosz (1986) indicate that these sediments contain an average of 2 wt pct heavy minerals. Assuming an average tonnage factor of 1.5 st/yd^3 for the sediments, this suggests a potential of as much as 33 billion st of heavy minerals on the ACS. This estimate is much larger that a previous one of 4.3 billion st (Dep. Interior, 1979). At the present time, two companies are exploring for heavy mineral placers on the southern ACS under Geological and Geophysical permits issued by the Department of the Interior's MMS.

Hypothetical Resource Model

There are presently no identified placer deposits on the ACS; therefore, descriptive grade-tonnage models developed by Attanasi, DeYoung, Force, and Grosz (1986) are used to construct a hypothetical deposit model. Engineering and economic assessments for offshore development are based on this derived model.

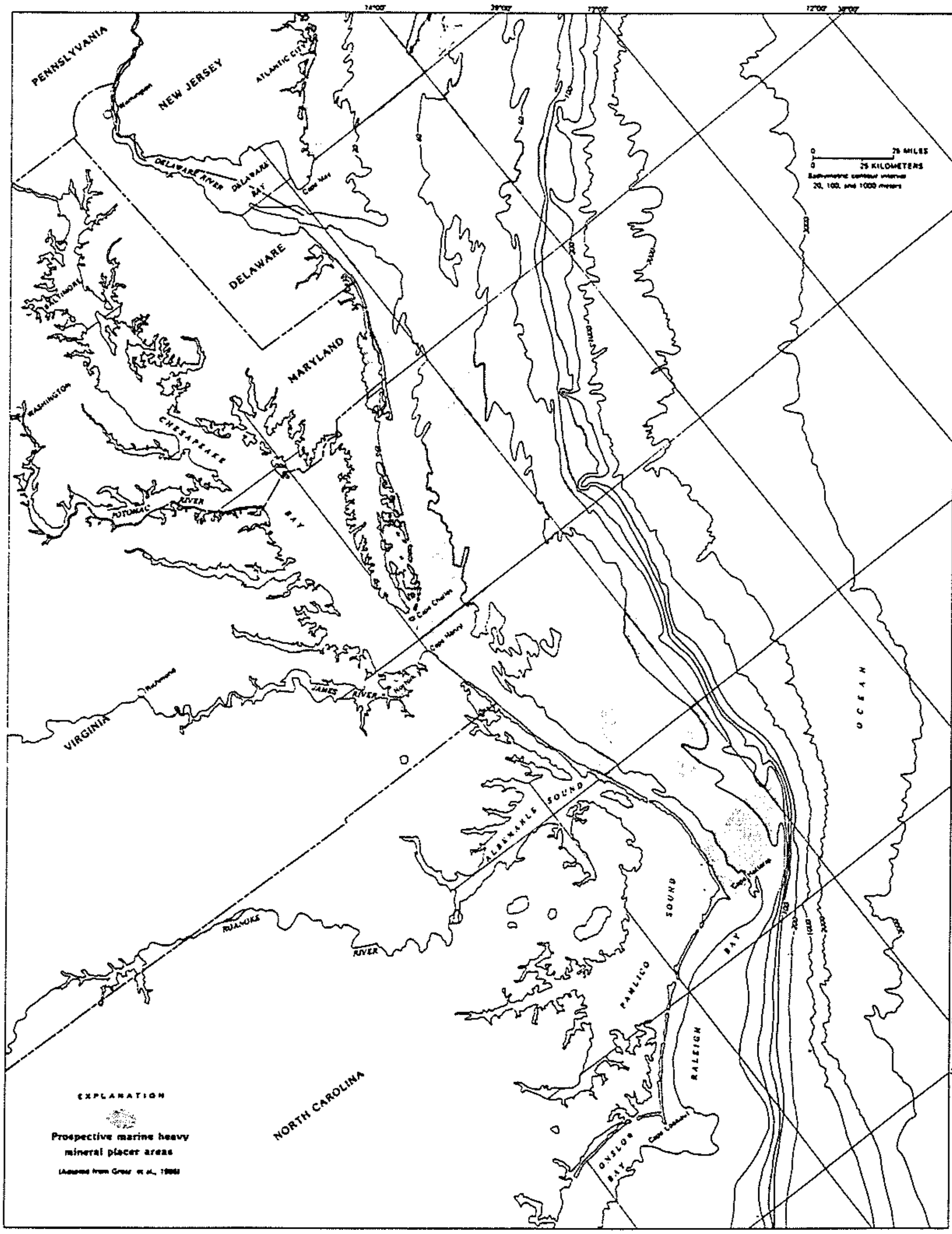

FIGURE 13. - Heavy mineral concentrations of potentially economic interest on the Atlantic continental shelf, New Jersey to Florida.

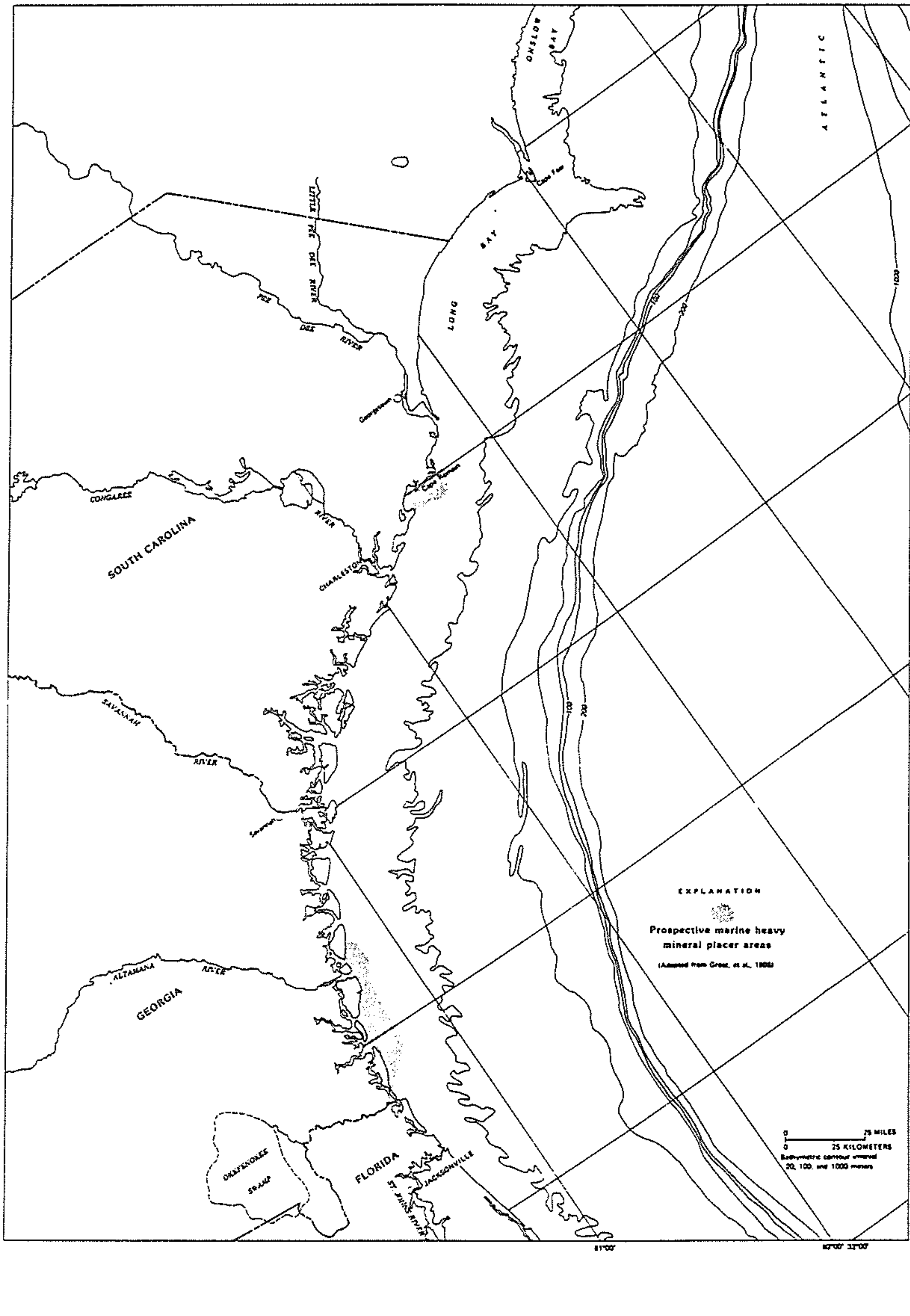

FIGURE 13. - Continued.

The models describe placer deposits of detrital titanium minerals and associated coproducts and byproducts that occur in beach-complex or strandline deposits, broadly defined to include beach, aeolian dune, inlet, and washover-fan deposits (Attanasi, 1986). This type of placer deposit is a major source of the world's supply of titanium, zircon, and other minerals. Most of the deposits used to develop these models were formed within the last million years or so (some are still forming) during stands of sea level that are at the same elevation or above that of the present day. Because major strandline deposits included in the models are located throughout the world, the models are assumed to be applicable globally.

Table 4 is a statistical summary of grade-tonnage relationships. The data set on which table 4 is based includes grade and tonnage figures for 62 strandline titanium placer deposits. Data sources are the Bureau's Minerals Availability System, Federal government (USGS and Bureau of Mines) files, publications, and industry sources, and include currently operating and closed mines, as well as prospects or occurrences that have not been mined to date (Attanasi, 1986). The grades in table 4 are specific to recoverable mineral components and are not equivalent to bulk chemical analysis of the host sand. As with the Oregon chromite sands model, a range of ore grades was preferred. Therefore, in the absence of any real data, assemblages equivalent to those of the 1st quartile, the Median value, the Mean value, and the 3rd quartile of table 4 were selected. By doing so, the economics of grade variance within the range of known strandline placers can be considered and measured within the limitations of this study. The size of the deposit was set at 100Mst which is comparable to the size of those currently being mined. Again, as with the offshore Oregon chromite sands scenario, no assumption was made about overburden. These parameters, along with other engineering and economic factors will be examined in the next sections.

TABLE 4. - Grade-tonnage statistics of strandline placer titanium deposits worldwide
(Grades are percent oxide in ore body, not percent oxide in the mineral.)

Variable	n	Mean value	Standard deviation	Median value	1st quartile (Q1)	3rd quartile (Q3)
Ore tonnage, (10^6 st)	62	277	470	112	40	241
Grades:						
Total TiO_2, %[a]	62	3.25	4.36	1.98	0.840	3.50
Rutile, % TiO_2	50	0.332	0.339	0.206	.107	0.423
Ilmenite, % TiO_2	62	2.76	3.95	1.39	.68	3.17
Leucoxene, % TiO_2	25	.552	.923	.270	.079	.480
Zircon, % ZrO_2	53	.398	.368	.280	.125	.530
Monazite, % REE	29	.181	.477	.020	.010	.120

(Source Attanasi, 1986)

[a] weighted

ENGINEERING AND COSTS

Introduction

Although uncertainties exist as to the nature of offshore placer resources, general mining and processing costs have been developed and evaluated for each of the three types, East Coast placers, West Coast placers, and Alaskan gold placers. The East Coast and West Coast deposits have been referred to elsewhere in this report as titanium and chromium placers, respectively, indicating the principal recovered commodity. However, in both instances the designated principal commodity is one of several for which marketable products can be produced. Important minerals in the East Coast placers are the titaniferous minerals ilmenite, rutile, and leucoxene; rare earth-bearing monazite; and the mineral zircon. West Coast placers contain chromite, ilmenite, rutile, zircon, and native gold. While other potential products may exist, neither costs for recovering nor revenues from their potential impact on additional minerals were considered. Analysis of the Alaskan placers addresses sole recovery of gold. The technology selected for the Alaskan ore processes the deposit on-site, discarding all but the resultant auriferous concentrate. No analysis has been made of other potential products for this operation, and in light of the remote location, few minerals would sufficiently remunerate the additional costs for their recovery.

The viability assessment part of the economic reconnaissance included three stages: 1) determination of what must be considered today the most likely technological scenario to be used, 2) cost estimation of these models for relevant throughput levels, and 3) assessment of potential profitability based on assumed tonnages and grades for each of the resource types.

With the exception of the Nome gold placers, lack of detailed data clearly characterizing an actual deposit and recovery operation limits the reliability of this preliminary assessment. Thus, following general model development, the approach has been to assess variables such as deposit characteristics, grade, tonnage, costs, etc., that significantly affect economic viability. Further geological and engineering investigations will be required to confirm whether any offshore deposits exist that meet the economic requirements and whether more complex or efficient mining methods significantly alter the feasible set of deposit characteristics.

Methodology

Differing technologies have been proposed for dredging along the continental coast of the conterminous states and off the coast of Alaska, near Nome. Unique conditions essentially dictated the use of different dredging technology in Alaska. Unlike the general cases that have been developed for dredging in open water along the east and west coasts of the lower 48 states, the Alaskan cost model is specific to a, semi-protected area near Nome, where the impact of storms are minimal. Also it is based on an existing ex-tin-mining, bucket ladder dredge, currently at the dredging site.

There is more uncertainty, in the remaining two instances, as to what type of dredge would be most suited. Seagoing trailing-suction-hopper dredge technology appears to be the most amenable method to mine offshore black sand placer deposits in the unprotected waters of the EEZ. This type of dredge is a self-propelled, self-contained, and wholly self-sufficient plant that does not require anchors, mooring devices, or tug assistance while dredging, and therefore, has maximum operational flexibility. More importantly, seagoing hopper dredges can operate in moderately rough seas with wave heights up to 12 ft. Other possible techniques to dredge heavy minerals, such as a semi-submersible suction dredge or a cutterhead dredge mounted on a walking platform, have been proposed; however, these units remain largely untested. Submersible suction dredges are still in the conceptual stage of development and the only walking platform dredge built was not economic.

Other dredge designs have been considered technologically inadequate. For example, an ocean-going cutterhead dredge would be able to operate less than 45 pct of the time during a normal year. Changes being made in the design of the dredging arm for the cutterhead dredge would allow it to work in rougher sea conditions, but, these advances have not yet worked. Therefore, without the benefit of this new technology and given the severe operational limitations of the ocean-going cutterhead dredge, it was not considered in this cost model.

The maximum dredging depth of U.S. hopper dredges in use is 94 ft. For this mining simulation, the total mining depth, including water column height and deposit thickness, will be assumed to be 150 ft based on the assumption that near-term technological improvements will allow economic mining to this depth. This maximum mining depth is exceeded within a few miles of the Oregon but not the Virginia and Alaska coast. Other technology such as that utilized by the Japanese, is capable of dredging in much deeper water, possibly greater than 300 ft (Rogich, 1986).

Separate models with accompanying cost equations or cost estimates have been developed for dredging and for processing facilities for each of the proposed nine sites. Remembering that the Alaska placer model is costed at a single tonnage level and utilizes a specific technology, the following discussion of general model development is applicable to the East and West Coast resources only.

Cost equations were developed using of actual or estimated processing capital and operating costs. Capital cost information on 12 private U.S.-built hopper dredges constructed between 1977 and 1985 were gathered from published (World Dredging and Marine Construction, vol. 15-11, and Martin and Mauriello, 1986) and company sources (Ouwerkerk, 1986). From this information, dredge capital cost equations were developed based on the geometric regression of point estimates of six dredges with hopper capacities ranging from 1,308 to 8,830 yd^3. Dredge operating cost equations were developed from actual cost data supplied by the U.S. Army Corps of Engineers as well as company sources.

These quoted capital and operating costs cover, in general, the range of capacities required for the ensuing analysis. It is clear, however, that although they may approximate the values for specific instances, they are not estimates at the specific tonnages. Therefore, as a means of improving the reliability of the estimates, regression analyses were conducted using the known values. The resultant equations allow cost estimates to be tailored more closely to the actual tonnages under investigation. Due to rounding during separate scenario calculations, comparable cost values for East coast and West coast may show a percentage point difference.

The dredging model allows determination of costs for variable combinations of daily tonnages and haul distances over a production range of 1 to 10 million st/year and a haulage distance up to 100 nmi. The plant model, which has been divided into separate onboard and onshore processing steps, allows determination of costs based on a similar capacity range adjusted for 350 operating days annually rather than the 250 days per year dredging schedule. Allowance has been made for estimating costs with all processing performed onshore. Costs, in all instances, are f.o.b. plant and do not include subsequent transportation to the consumer.

From these general models, the cost of mining and processing placer deposits at three specific annual tonnage levels were estimated. As distance from minesite to port is equally important, each of the tonnage levels was additionally analyzed for three separate haulage distances, 10, 40, and 80 nmi.

From haulage distance and desired daily haul capacity the required hopper capacity can be estimated. Daily dredge capacity is the annual capacity divided by 250 operating days per year. Daily haul capacity is the amount of dredged material transported from the minesite to onshore facilities. Hopper capacity depends on the specific gravity of the material mined - the general model specific gravity is 1.52. It was determined that this relationship is closely approximated by the following equations:

Dredge with onboard mineral processing facilities:

P (Hopper capacity) = daily haul capacity/$2.9607(L)^{-0.2923}$

Dredge without onboard mineral processing facilities:

P (Hopper capacity) = daily haul capacity/$10.5936(L)^{-0.4879}$

where L = one-way haul distance in nautical miles.

Example: Determine hopper capacity required for a dredge, without onboard mineral processing facilities, to mine 1.25×10^6 st/year from an offshore site 80 nmi from onshore processing facilities for a given distance.

P (hopper capacity) = $(1.25 \times 10^6/250\ /10.5936(80)^{-0.4879}$

= 4,004 st, use 4,000 st.

This relationship demonstrates that the daily capacities and the hopper capacities are related by a proportional constant. This constant holds mainly because larger loading and off-loading equipment minimize increase in load times for the large capacity dredges, which are further compensated for by the shorter haul times of the faster, larger dredges. Table 5 shows the assumed dredge capacity or hopper size for each instance analyzed. This chart holds for both the East and West Coast models.

TABLE 5. - Dredge hopper capacity per trip and daily capacity

	Annual capacity		
	1.25×10^6	2.5×10^6	5.0×10^6
DREDGE HOPPER CAPACITY (with onboard processing)			
One-way haul distance:			
10 nmi, st..................	1,700	3,300	6,600
40 nmi, st..................	2,500	5,000	9.900
80 nmi, st..................	5,000	6,100	12,200
Daily dredge capacity, st.....	5,000	10,000	20,000
Daily haul capacity, st.....	2,500	5,000	10,000
DREDGE HOPPER CAPACITY (without onboard processing)			
One-way haul distance:			
10 nmi, st..................	1,500	2,900	5,800
40 nmi, st..................	2,900	5,700	11,400
80 nmi, st..................	4,000	8,000	16,000
Daily haul capacity, st.....	5,000	10,000	20,000

NOTE.--For the cases without onboard processing, haul capacity and dredge capacity are equivalent.

These dredge hopper capacity values are used in the following equations to determine capital and operating costs in each instance.

Dredge capital cost:

With onboard processing $= 7{,}052(P)^{0.9421}$

Without onboard processing $= 11{,}541(P)^{0.8988}$

$$\text{Dredge operating costs} = \frac{2.7534(P) + 5{,}463}{\text{Daily capacity}}$$

where P is the payload or hopper capacity.

In all instances it is assumed that a single dredge will be used. If it is desired to analyze multi-dredge operations the models and accompanying cost backup data allow comparative evaluation of these scenarios; however, no attempt to do so was made at this time.

Comparable equations have been developed for processing plants. Two general models have been developed. One estimates cost of processing the material at a single plant onshore and the second includes pre-concentration on the dredge prior to transfer to the onshore plant. Differences in anticipated feed for the eastern and western placers concentrators affect costs for onshore processing considerably - therefore equations have been developed separately for the two resource models. The plant capital and operating cost estimation equations are:

PLANT CAPITAL COST EQUATIONS (base case)

East Coast Model

Onboard processing facilities = $319.12(X)^{0.960}$

Onshore processing facilities = $22{,}500(X)^{0.68}$

Onshore processing facilities when onboard processing not considered = $10{,}600(X)^{0.744}$

where X is the plant feed throughput in short tons per day.

West Coast Model

Onboard processing facilities = $319.12(X)^{0.960}$

Onshore processing facilities = $8{,}297.76(X)^{0.858}$

Onshore processing facilities when onboard processing not considered = $8{,}398(X)^{0.867}$

where X is the plant feed throughput in short tons per day.

PLANT OPERATING COST EQUATIONS ($ per short ton)

East Coast Model

Onboard processing facilities = $25.5(X)^{-0.520}$

Onshore processing facilities = $59.4(X)^{-0.345}$

Onshore processing facilities when onboard processing not considered = $51.0(X)^{-0.364}$

where X is the plant feed throughput in short tons per day.

West Coast Model

Onboard processing facilities = $20.89(X)^{-0.488}$

Onshore processing facilities = $31.13(X)^{-0.160}$
Onshore processing facilities when
onboard processing not considered = $35.56(X)^{-0.171}$

where X is the plant feed throughput in short tons per day.

For both the East Coast titaniferous sands and the West Coast chromiferous sands, dredging and processing costs were estimated from these cost models. Adjustments were then made for factors not considered in the models for calculation of total investment required and production costs. Table 6 contains summary figures for the given operating ranges and demonstrates the cost variations that can be anticipated. For these base cases, the model that includes both onboard and onshore processing was used.

The 80-nmi cases were not included in the west coast model because the assumed near-shore location of exploitable resources make it unlikely that a producer will travel more than 40 nmi from the dredge site to the onshore plant.

OPERATING COSTS include the dredge and plant operating costs generated by the models, the dock maintenance expenses and insurance charges. Dock maintenance was computed annually as 2 pct of the dock facility capital cost divided by the annual throughput. The insurance charge per ton of product was determined similarly, using 2 pct of the total fixed capital cost. These costs have been divided by annual throughput to determine cost per short ton.

CAPITAL COSTS include dredge, plant and dock facility construction, plant site acquisition, exploration expenses, and working capital. The dredge and plant costs are addressed through the equations. Construction of dock facilities was assumed to be modifications of existing facilities, rather than construction of new facilities. Exploration was assumed to be $1 million in all instances and working capital is based on a 2-month business cycle. Acquisition includes the cost of acquiring an onshore site for plant and docking facilities only. Because of uncertainty about actual dredge site acquisition costs, no attempt has been made to quantify lease agreement costs.

In the following section the models and cost estimation procedures for each of the resource types will be discussed in more detail.

TABLE 6. - East and West Coast placer operations[a]

(Synopsis of costs)

	Capacity (st/year)		
	1.25×10^6	2.5×10^6	5×10^6
	EAST COAST		
CAPITAL, $ x 10^6:			
10 nmi....................	$18.2	$29.9	$50.8
40 nmi....................	21.8	36.9	64.2
80 nmi....................	24.2	41.6	73.1
OPERATING, $/st:			
10 nmi....................	4.15	3.13	2.52
40 nmi....................	4.66	3.65	3.03
80 nmi....................	5.00	3.99	3.36
	WEST COAST		
CAPITAL, $ x 10^6:			
10 nmi....................	$24.2	$41.8	$71.9
40 nmi....................	27.7	48.2	85.7
OPERATING, $/st:			
10 nmi....................	7.36	5.89	4.90
40 nmi....................	7.87	6.41	5.42

[a]U.S. built dredge.

Individual Operations

Nome Gold Placers

System Description

Proposed mining of the auriferous lag gravels will be accomplished using a large capacity floating bucket-line dredge (fig. 14). No unusual dredging problems are expected with mining the Nome offshore placers. The dredging season, however, will probably be restricted to less than 5 months/year because of weather constraints. The submarine gravels are not frozen, as are the Nome onshore beach placers, and require no labor-intensive thawing prior to dredging.

Operations will be conducted in two phases. The first phase is deposit evaluation, which includes sampling with closely spaced drill holes. This phase is accomplished with the use of a ship or barge-mounted drill, or a skid-mounted drill used during winter months when shelf ice of suitable thickness has formed. Sampling marine sediments requires the use of casing or dual wall drill steel to reduce contamination and dilution of the sample. Drilling on 500-ft centers will probably provide enough control to determine deposit limits. A detailed mining plan is assembled using bathymetric data, drill logs, and assay results.

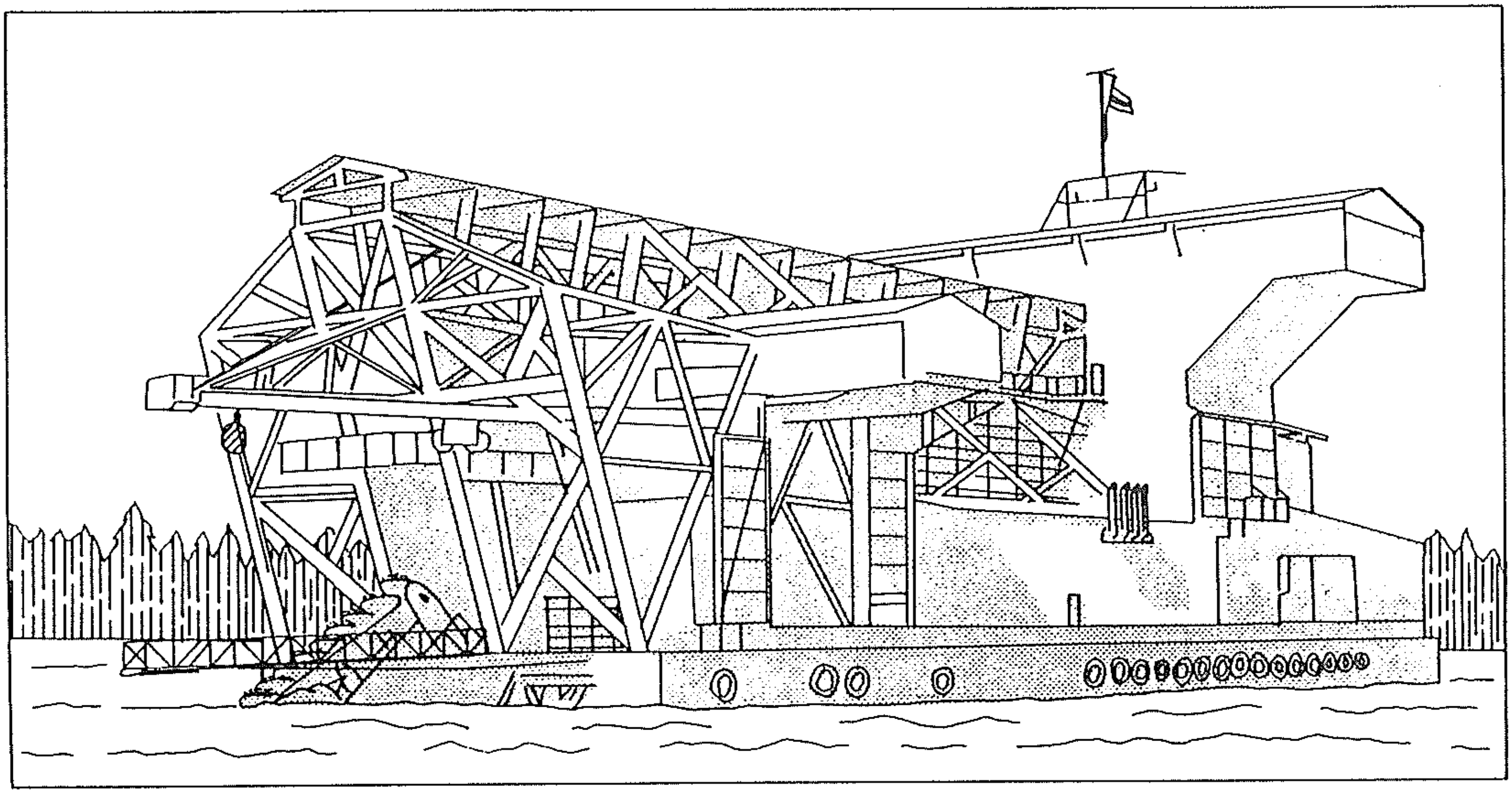

FIGURE 14. - Drawing of a large capacity bucket-line dredge.

The second phase is mining and processing of the auriferous lag gravels. Operations consist of dredging the gravels, followed by onboard processing to produce a gold concentrate. Dredge lateral movements are accomplished using winches to move anchored head, aft, and side lines. Anchors are moved periodically with the help of a support vessel. Additionally, the dredge will require tug boat support for remobilization within the Nome offshore area and for transportation to the ice-free Bristol Bay region for winter storage. Power for the dredge will be generated onboard with diesel-electric generators.

Dredging will be accomplished using three crews rotating around two 12-hr shifts per day. Transportation of personnel to the dredge requires helicopter or marine vessel support. All phases of mine operations and development drilling will require a total of 83 individuals.

Onboard processing begins where gravel leaves the dredge buckets and continues until waste is discharged through the stern gravel chute. The mill flow design is very simple because gold is efficiently concentrated using gravity processes alone (fig. 15). Mill processing of auriferous gravel first requires sizing and washing with a rotating trommel. Material coarser than 3/8 in. is rejected as oversized, passed over a nugget saver, and discharged out the stern gravel chute. The minus material is then passed through a series of rougher and cleaner jigs to make a gold-bearing concentrate. The concentrate is then tabled to separate gold from other heavy minerals. The number and size of jigs employed are determined by characteristics of the material processed.

Mill feed is assumed to have the same grade as the reserve assay value. If a horizon greater in thickness than the auriferous lag gravels is removed, a dilution factor must be calculated to predict the grade of the mill feed. It is estimated that ten individuals will be required to operate the mill 24 hours per day during the operating season.

Recovery efficiency of the mill is estimated to be at least 90 pct, because most gold in the lag gravels is coarser than 65 mesh and easily recoverable. Placer gold from the Nome district has a fineness ranging from 876 (87.6 pct) to 903 (90.3 pct). Processing 13,000 yd^3 per day at an average grade of 0.556 ppm (0.0219 tr oz/yd^3), with a recovery factor of 0.9 and a fineness of 900 will yield approximately 230 tr oz/d gold per day.

The gold concentrate recovered from the tables will be transported to Nome, and smelted to yield a gold bullion product. The bullion will probably be transported by air to Fairbanks or Anchorage, AK, for commercial refining.

Costs

Mine and plant capital and operating costs were calculated using the Bureau's computerized Cost Estimating System (CES) and unpublished information (Hamata, 1985). Adjustments to the CES costs were made through variations of the line item factors. An escalation factor of 1.8 was used to increase computer-generated costs to reflect actual Alaskan costs relative to similar expenditures occurring in the 48 contiguous states.

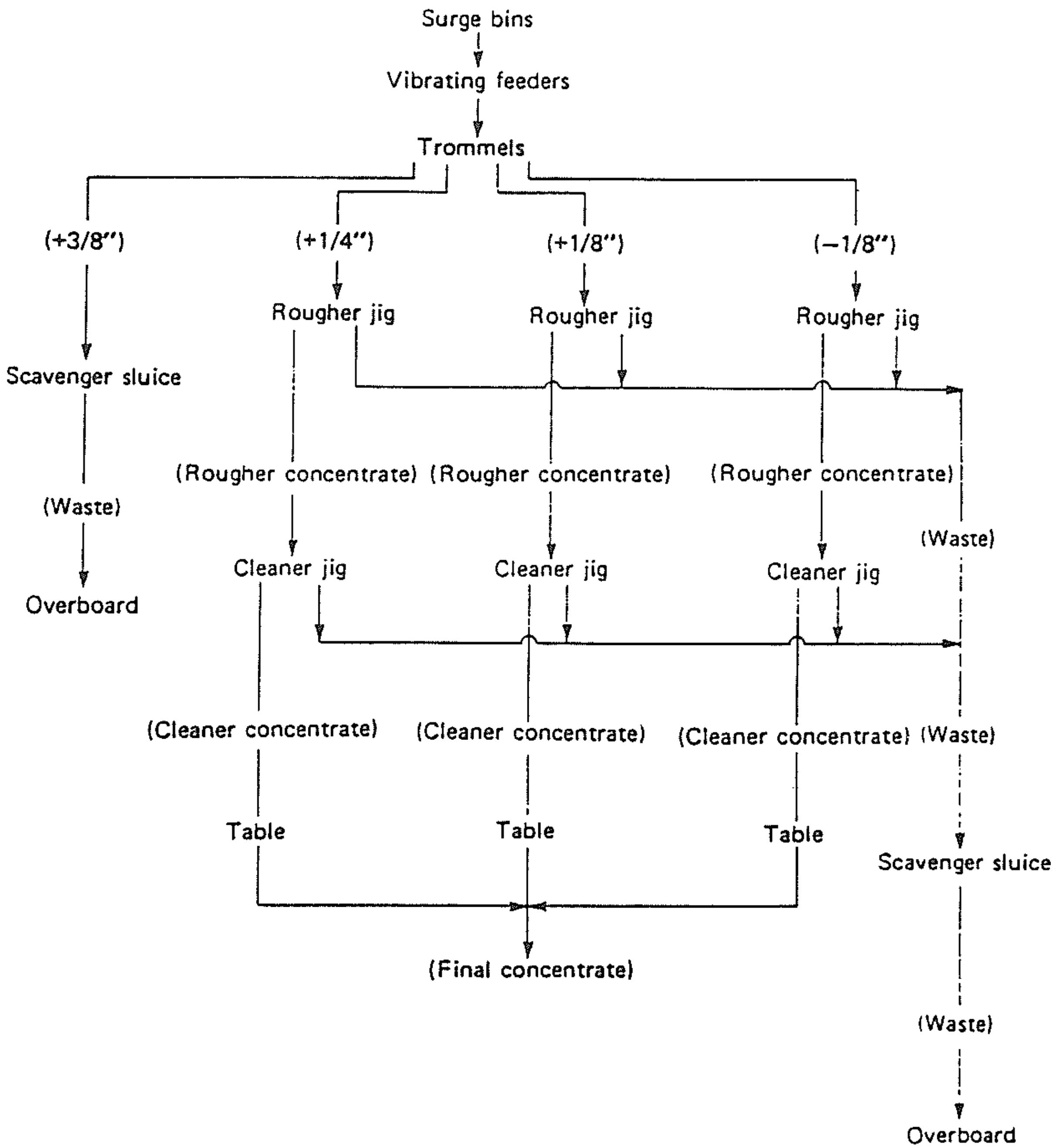

FIGURE 15. - Generalized flowsheet of a floating dredge gravity plant.

Two dredging models were costed; one utilizes a new dredge, while the other operates with a refurbished dredge. Both models assume 1 year of preproduction time, a mine life of 20 years, and processing of 1,632,000 yd^3 of gravel per year. Mine and plant capital and operating costs are summarized in table 7.

TABLE 7. - Estimated mine/mill capital and operating costs

Used equipment			New equipment		
Item	$ cost/year	Year	Item	$ cost/year	Year
Exploration......	$1,000,000	1	Exploration......	$1,000,000	1
Acquisition......	1,000,000	1	Acquisition......	1,000,000	1
Dredge...........	5,600,000	1	Dredge...........	16,400,000	1
Working capital..	1,564,800	2	Working capital..	1,564,800	2
Operating cost...	2.00/yd^3	2-21	Operating cost...	2.00/yd^3	2-21

The capital cost of used equipment was estimated by the Bureau. Investment costs of a new dredge were calculated using data obtained from Hamata (1985). Operating costs represent total costs for mining and beneficiation of the gravels. Used equipment operating cost is estimated from industry sources. The operating cost for new equipment was calculated using CES.

West Coast Placers

The West Coast chromite placers remain unconfirmed in that the no commercial concentrations have been found. The relatively high continental shelf gradient also restricts presently exploitable areas of any such deposits to a narrow band, paralleling the coast. In view of the limited information available for offshore deposits the exploitation models have been based on adjacent onshore deposits which have been discussed previously in the resource section for this area.

The trailing suction head, hopper dredge cost model was used to estimate costs for these deposits. This analysis assumes varying capacity dredges operating off the southwestern coast of Oregon. The plant facilities would be located at Coos Bay or one of the suitable ports near the deposit. As demonstrated in a preceding section, the distance between dredge site and processing plant has considerable impact on required dredge size. It will be shown how this also affects dredge costs.

System Description

The model is based on a suction head dredge, with an onboard screening and spirals, and storage for the onboard mineral concentrate. The two configurations analyzed included hopper dredges with onboard mineral processing facilities and hopper dredges without onboard processing facilities. In both cases, the dredge will operate continuously on a 24 hr/d, 7-d/wk schedule, with an average downtime of one day or less every 2 wk for fueling, provisioning, preventative maintenance, and crew changes.

One month per year is required for major repairs and shipyard overhaul. Because of probable periods of unscheduled maintenance and unfavorable sea conditions, the assumed production rate is based on 80 pct dredge availability and operating costs are based on 250 operating d/year.

The dredge will be completely self-contained with crew quarters, mess, and sanitary facilities sufficient to accommodate all operating personnel for a 2-wk period. Hopper dredge production is dependent on hopper volume and cycle time requirements (i.e., loading and unloading time and time in transit). For dredges with onboard mineral processing facilities, loading time is limited to throughput of the processing plant and, owing to space and weight considerations, is assumed to be twice that of a dredge without onboard processing facilities. Therefore, cycle time requirements for a dredge with processing facilities differs from cycle time requirements for a dredge without processing facilities.

The onboard plant is assumed to produce a rougher spiral concentrate of approximately 50 pct of the dredged material while recovering 90 to 92 pct of the economically desirable heavy minerals. Figure 16 is a general flowsheet for the onboard processing plant.

The onshore plant, which will further process the dredge rough concentrates, is designed to recover salable chromite, ilmenite, rutile, zircon, and gold. A garnet product could also be produced but has not been included in the following economic analysis because of the unlikelihood that it will prove financially prudent. Figure 17 is a flowsheet for the proposed onshore plant.

Material from the dredges will be stockpiled at the plant site. Conveyors will transport material reclaimed from stockpiles to vibrating screens where +48-mesh material is removed and sent to a rod mill for further size reduction. Rod mill discharge will be treated by cyclones to remove slimes, then returned to the vibrating screens.

Minus 48-mesh sand from the screens will proceed through a series of cleaner spirals, final spirals, and scavenger cones to produce a concentrate containing over 90 pct heavy minerals. Waste from the cleaner spirals and final spirals will be sent to the scavenger cones to recover additional heavy minerals. Scavenger concentrates will be returned to the cleaner spirals.

A fine split taken off the heavy fraction of concentrates flowing through the final spirals will be sent to a gold recovery table. Waste from the table is recycled to the cleaner spirals.

After removal of most of the magnetite using low-intensity wet magnetic separators, much of the ilmenite contained in the concentrate will be recovered using high-intensity wet magnetic separators. The remaining material is dewatered, dried, and heated prior to electrostatic separation.

Using high-tension electrostatic separators, conductors (chromite, rutile, and ilmenite) are separated from non-conductors (garnet and zircon). A middling fraction is recycled through the separators.

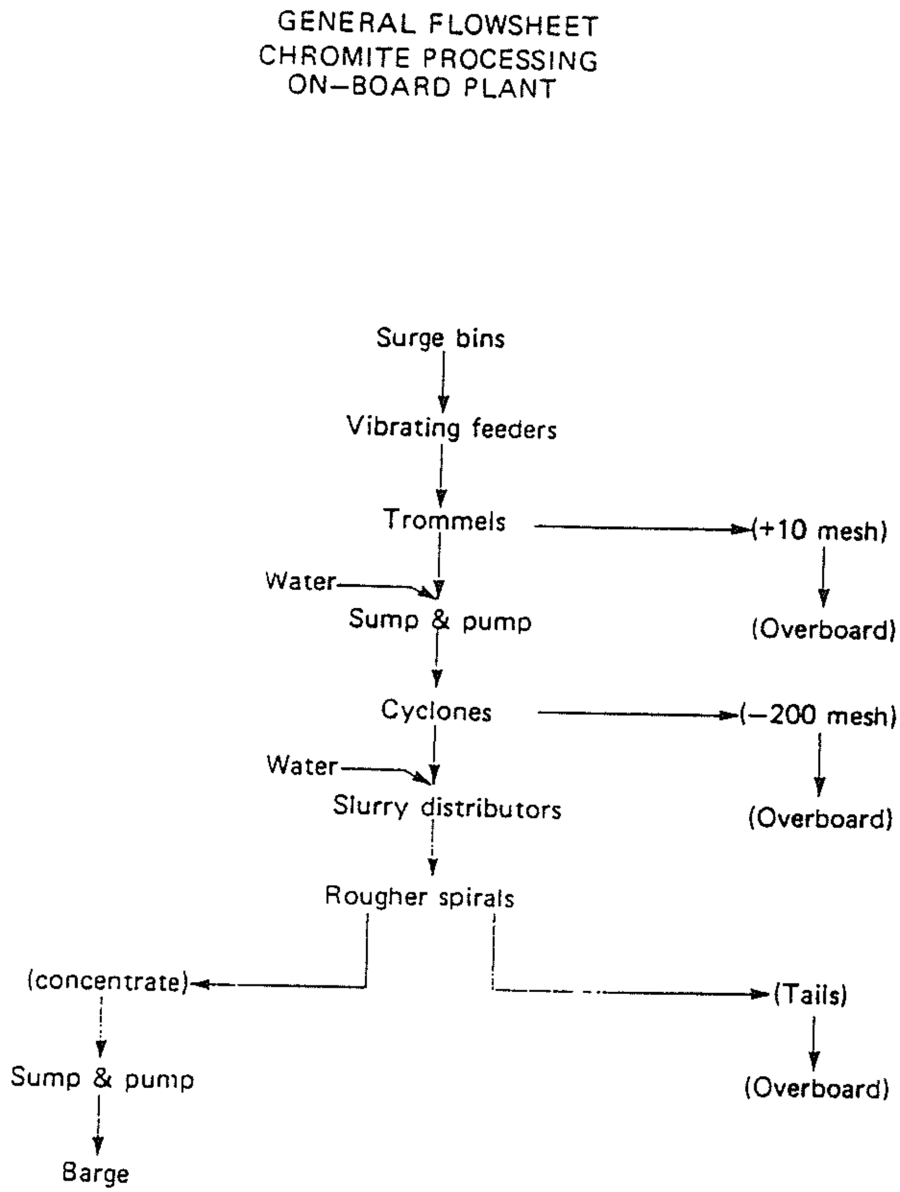

FIGURE 16. - General flowsheet, chromite processing onboard plant.

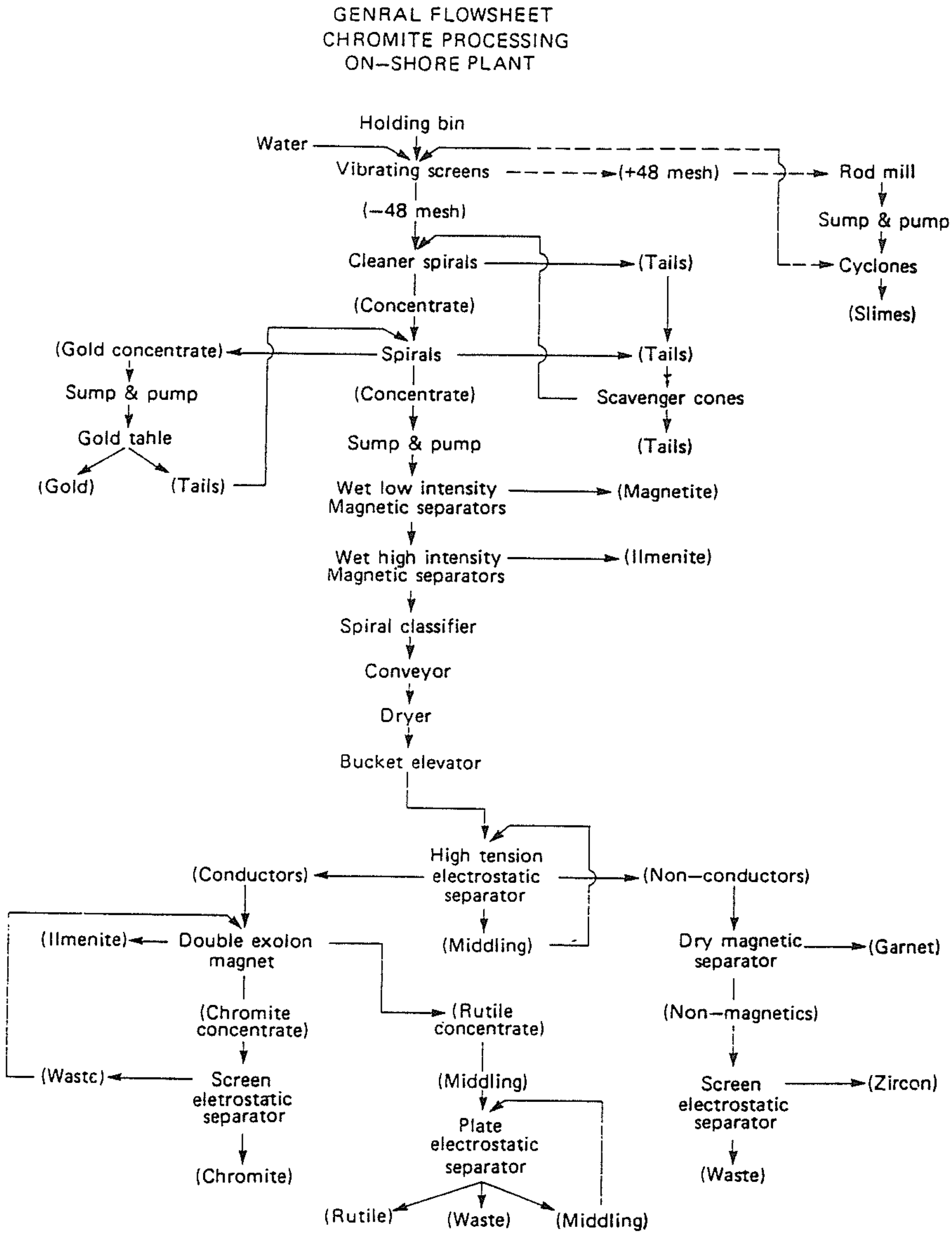

FIGURE 17. - General flowsheet, chromite processing onshore plant.

Conductors pass through a cross-belt magnetic separator to recover individual fractions of chromite, rutile, and any remaining ilmenite. The chromite fraction is further concentrated using screen electrostatic separators. Rutile concentrate passes through plate electrostatic separators for final concentration.

Non-conductors from the high-tension separators are fed to dry magnetic separators which recover the garnet fraction. The remaining material flows to a screen electrostatic separator where zircon is recovered.

Table 8 shows the metallurgical balance for one of the grade levels evaluated. Mineral feed grades are of the onboard plant feed. All values excluding gold are reported in percent oxides. Recovery of these minerals in the onboard plant rougher concentrator varies, depending on the species but ranges between 90 and 92 pct. Estimated onshore plant recoveries also vary, ranging between 84 and 94 pct. The resultant total recoveries are as low as 75 pct for zircon and as high as 85 pct for chromite, with the remaining three products falling between. Further metallurgical testing will be necessary to corroborate these values. It has been reported that thorough weathering of the source rock for the chromite has also altered their ability to respond to normal concentration methods but this will have to be ascertained by more detailed study.

TABLE 8. - Material balance, West Coast concentration plant (10,000 st/d)

Product	Feed, %	Recovery, %			Grade, %	Product st/d
		Onboard,	Onshore,	Total,		
Chromite, % Cr_2O_3	5.2	90	94	85	42	1,047.4
Ilmenite, % TiO_2...	0.8	92	89	82	52	126.0
Zircon, % ZrO_2.....	0.58	90	84	75	64	68.5
Rutile, % TiO_2.....	0.17	90	89	80	95	14.3
Gold, tr/oz Au.......	0.004	92	89	82	100	32.8[1]

[1] tr oz daily.

Costs

Costs have been calculated for six different cases. Three different daily mine and plant capacities for each of which, two different distances from minesite to processing facility (10, and 40 nmi) have been evaluated. The first mill model is used as a base case. Additional runs have been made to evaluate the second instance.

Annual capacities and corresponding daily mine and plant capacities, given in short tons, are:

Total annual capacity	1,250,000	2,500,000	5,000,000
Daily mine capacity	5,000	10,000	20,000
Daily plant capacity:			
Case 1			
Onboard, 250 d/year	5,000	10,000	20,000
Onshore, 350 d/year	1,800	3,600	7,100
Case 2			
Onshore, 350 d/year[1]	3,600	7,100	14,300

Two mill scenarios have also been considered. The first included two processing stages, an initial pre-concentration phase aboard the dredge, followed by processing in an onshore plant, and the second combines all processing in a single onshore facility.

Tables 9 and 10 contain estimated, base case capital and operating costs for dredge and processing facilities. These cases assume a U.S. built dredge is used and, as stated, processing occurs in plants both aboard the dredge and onshore. Capital costs include dredge, plant and dock purchase or construction costs, processing site acquisition, exploration expenses, and 2 month's operation charges for working capital. Operating costs include normal expenses associated with operations except taxes and debt retirement.

Plant capital costs require the majority of the total investment and dredge capital costs are relatively minor. This results from the requirement of relatively larger facilities for processing the high heavy mineral content of the West Coast.

[1]Processing occurs solely onshore in this case.

TABLE 9. - West Coast placer, dredge, and plant capital costs[1]
($ million)

Cost description	Annual capacity[2]		
	1.25 Mst	2.5 Mst	5 Mst
Mine to plant, 10 nmi:			
Exploration	1.0	1.0	1.0
Acquisition	1.0	1.5	2.0
Dredge	7.8	14.6	28.0
Dock	3.0	3.5	4.0
Plant--Onboard	1.0	2.0	4.0
--Onshore	8.9	16.0	28.8
Working capital[3]	1.5	2.5	4.1
Total	24.2	41.1	71.9
Mine to plant, 40 nmi:			
Exploration	1.0	1.0	1.0
Acquisition	1.0	1.5	2.0
Dredge	11.2	21.5	41.4
Dock	3.0	3.5	4.0
Plant--Onboard	1.0	2.0	4.0
--Onshore	8.9	16.0	28.8
Working capital[3]	1.6	2.7	4.5
Total	27.7	48.2	85.7

[1]U.S. built dredge.
[2]Annual capacities based on 250 operating days for the dredge and 350 for the plant.
[3]Working capital for 2 months.

TABLE 10. - West Coast placer operating costs ($/st dredged)[1]

Cost description	Annual capacity[2]		
	1.25 Mst	2.5 Mst	5 Mst
Mine to plant, 10 nmi:			
Dredge	2.03	1.45	1.18
Dock	0.05	0.03	0.02
Plant--Onboard	.30	.21	.15
--Onshore	4.62	3.89	3.28
Insurance	.36	.31	0.27
Total	7.36	5.89	4.90
Mine to plant, 40 nmi:			
Dredge	2.47	1.92	1.65
Dock	0.05	0.03	0.02
Plant--Onboard	.30	.21	.15
--Onshore	4.62	3.89	3.28
Insurance	.43	.36	.32
Total	7.87	6.41	5.42

[1]U.S. built dredge
[2]Annual capacities based on 250 operating days for the dredge and 350 for the plant.
[3]Plant costs include dock maintenance expenses.

Operating costs are affected similarly. They are largely determined by processing costs which represent 63 to 70 pct of the total cost per ton dredged. As a result the cost variation attributable to increased dredge haul distance is minimal. Comparison of the 10- and 40-nmi distances show that the operating cost for the longer haul increases by 11 pct or less in all three cases.

There is a demonstrable economy of investment at the greater capacities. Using the 40-nmi scenario, the total costs per installed short ton annual capacity for the 1.25 Mst and 5 Mst operations are $19 and $14, respectively. Selection of the optimum capacity will require more analysis than the determination of lowest cost option. Factors, such as markets, deposit availability, and quantity and grade, would have to be pursued before a meaningful capacity selection could be made.

In the initial cost analysis it was felt that it would be advantageous to reduce the bulk at sea to a limited degree. Therefore, onboard processing was initially assumed, with an attendant halving of the amount hauled daily from the dredge site to the plant. To more closely quantify this advantage, if it indeed exists, we have estimated costs for six cases in which all processing occurs at the onshore site. Thus, both onshore and onboard phases of processing contained in the previous examples are combined at a single onshore site. This necessitates delivering twice the daily tonnage to the plant to achieve the same product tonnage levels. Tables 11 and 12 show the costs that result.

Comparison of the results show that at the 10-nmi haul distance, there is no material change in operating and capital costs. At greater distances, the cost of purchasing a large dredge, as well as hauling twice the tonnage to shore, becomes more significant. It is to be anticipated that for this model this cost differential will continue to increase with increasing distance.

The effect of using a foreign rather than a domestically built vessel for dredging has also been quantified. Data acquired from foreign dredge owners suggests that the purchase cost for a vessel, built overseas would be approximately one-half of a comparable U.S. dredge. In the next calculation, the capital costs for the vessel have been reduced accordingly to demonstrate the impact of reducing such costs by 50 pct would have. Legal stumbling blocks may exist to using foreign-built vessels in U.S. waters, Since legislation exists which restricts dredging within U.S.-controlled waters to U.S. ships. Tables 13 and 14 show the cost estimates of this option.

TABLE 11. - West Coast placer, dredge, and plant capital costs with no onboard processing ($ million)—U.S.-built dredge

Cost description	Annual capacity[1]	
	2.5 Mst	5 Mst
Mine to plant, 10 nmi:		
Exploration	1.0	1.0
Acquisition	1.5	2.0
Dredge	14.9	27.8
Dock	3.5	4.0
Plant	20.6	37.2
Working capital[2]	2.4	3.9
Total	43.9	75.9
Mine to plant, 40 nmi:		
Exploration	1.0	1.0
Acquisition	1.5	2.0
Dredge	27.4	51.1
Dock	3.5	4.0
Plant	20.6	37.2
Working capital[2]	2.7	4.6
Total	56.7	99.9

[1]Annual capacities based on 250 operating days for the dredge and 350 for the plant.
[2]Working capital for 2 months.

TABLE 12. - West Coast placer operating costs with no onboard processing ($/st dredged)—U.S.-built dredge

Cost description	Annual capacity[1]	
	2.5 Mst	5 Mst
Mine to plant, 10 nmi:		
Dredge	1.34	1.07
Dock	0.03	0.02
Plant	3.96	3.30
Insurance	0.33	0.29
Total	5.66	4.68
Mine to plant, 40 nmi:		
Dredge	2.12	1.84
Dock	0.03	0.02
Plant	3.96	3.30
Insurance	.39	.35
Total	6.54	5.54

[1]Annual capacities based on 250 operating days for the dredge and 350 for the plant.

TABLE 13. - West Coast placer, dredge, and plant capital costs ($ million)—foreign dredge

Cost description	Annual capacity[1]		
	1.25 Mst	2.5 Mst	5 Mst
Mine to plant, 10 nmi:			
Exploration	1.0	1.0	1.0
Acquisition	1.0	1.5	2.0
Dredge	3.9	7.3	14.0
Dock	3.0	3.5	4.0
Plant—Onboard	1.0	2.0	4.0
—Onshore	8.9	16.0	28.8
Working capital[2]	1.5	2.4	4.0
Total	20.3	33.7	57.8
Mine to plant, 40 nmi:			
Exploration	1.0	1.0	1.0
Acquisition	1.0	1.5	2.0
Dredge	5.6	10.8	20.7
Dock	3.0	3.5	4.0
Plant—Onboard	1.0	2.0	4.0
—Onshore	8.9	16.0	28.8
Working capital[2]	1.6	2.6	4.5
Total	22.1	37.4	65.0

[1]Annual capacities based on 250 operating days for the dredge and 350 for the plant.
[2]Working capital for 2 months.

TABLE 14. - West Coast placer operating costs ($/st dredged)--foreign dredge

Cost description	Annual capacity[1]		
	1.25 Mst	2.5 Mst	5 Mst
Mine to plant, 10 nmi:			
Dredge..................	2.03	1.45	1.18
Dock.....................	3.0	3.5	4.0
Plant--Onboard...........	0.05	0.03	0.02
--Onshore...........	4.62	3.89	3.28
Insurance................	0.30	0.25	0.22
Total.................	7.30	5.83	4.85
Mine to plant, 40 nmi:			
Dredge..................	2.47	1.92	1.65
Dock.....................	3.0	3.5	4.0
Plant--Onboard...........	0.05	0.03	0.02
--Onshore...........	4.62	3.89	3.28
Insurance................	.33	.28	.24
Total.................	7.77	6.33	5.34

[1]Annual capacities based on 250 operating days for the dredge and 350 for the plant.

These estimates show that capital and operating costs using a foreign-built dredge are both less than for a comparable U.S. dredge. Operating costs are indirectly reduced through a reduction in insurance charges. Due to the insignificance of the operating cost change, working capital is unaffected and no additional capital cost adjustment need be made.

A final technological option has also been considered for West Coast placers which includes using a domestic hopper dredge with limited capacity that processes and stores the dredged material at the minesite. The rough spiral concentrates are periodically transferred from the dredge to ocean-going barges that deliver the material to the dock for processing. Tables 15 and 16 contain the results.

TABLE 15. - West Coast placer, dredge, and plant capital costs ($ million)--dredge, barge option

Cost description	Annual capacity[1]		
	1.25 Mst	2.5 Mst	5 Mst
Mine to plant, 40 nmi:			
Exploration..............	1.0	1.0	1.0
Acquisition..............	1.0	1.5	2.0
Dredge..................	9.1	18.0	35.5
Dock.....................	3.0	3.5	4.0
Plant--Onboard...........	1.0	2.0	4.0
--Onshore...........	8.9	16.0	28.8
Working capital[2].........	1.8	2.7	4.2
Total.................	25.8	44.7	79.5

[1]Annual capacities based on 250 operating days for the dredge and 350 for the plant.
[2]Working capital for 2 months.

TABLE 16. - West Coast placer operating costs ($/st dredged)--dredge, barge option

Cost description	Annual capacity[1] 1.25 Mst	2.5 Mst	5 Mst
Mine to plant, 40 nmi:			
Dredge..................	3.19	2.0	1.25
Dock.....................	0.5	0.3	0.2
Plant--Onboard...........	.30	.21	.15
--Onshore...........	4.62	3.89	3.28
Insurance................	.38	.34	.30
Total.................	8.54	6.47	5.00

[1]Annual capacities based on 250 operating days for the dredge and 350 for the plant.

The figures in these tables do not show the anticipated reduction in capital costs. It turns out that the purchase of a second required vessel, an ocean-going tug, more than offsets the savings from the purchase of a smaller dredge. Operating costs, surprisingly, are lower for the higher capacity operation shown. In fact, operating costs which at the lowest tonnage case are consistently higher than for the dredge alone option, drop sharply toward the upper end of the operating range. For the stationary dredge scheme, with barges performing the haulage function, it was more economical to operate at the upper tonnages. Due to the high plant operating costs, which are unaffected by this operational change, there was little difference in the total operating costs.

The preceding analysis has not considered the effect feed grade variance would have on operating costs. It can be assumed that a plant designed for richer feed, and thereby having either a larger or greater number of jigs, tables, dryers, etc., would in fact have a larger capital investment requirement as well as higher operating cost. To see the affect of feed grade, costs have been developed for three onshore plants alone, since it is assumed that modification of onboard dredge plants will be unnecessary. The plant feed grades are:

	Low Grade	Low-Mid Grade	High-Mid Grade	High Grade
Chromite, % Cr_2O_3	2.6	5.2	6.3	9.5
Ilmenite, % TiO_2	0.4	0.8	1.0	1.5
Rutile, % TiO_2	0.08	0.17	0.2	0.3
Zircon, %ZrO_2	0.29	0.58	0.7	1.0
Gold, tr oz Au	0.002	0.004	0.005	0.01

The resulting changes in capital and operating costs are illustrated in the tables 17 and 18, respectively.

TABLE 17. - Variations of West Coast plant capital costs, dredge and plant with onboard processing ($ million)

Cost description	Grade		
	Low	Low-Mid	High-Mid & High
Mine to plant, 40 nmi, 2.5 Mst/a:			
Exploration.................	1.0	1.0	1.0
Acquisition.................	1.5	1.5	1.5
Dredge......................	21.5	21.5	21.5
Dock........................	3.5	3.5	3.5
Plant--onboard..............	2.0	2.0	2.0
onshore..............	15.4	16.0	16.3
Working capital.............	2.6	2.7	2.7
Total.....................	47.5	48.2	48.5

TABLE 18. - Variations of West Coast placer operating costs with onboard processing ($/st dredged)

Cost description	Grade		
	Low	Low-Mid	High-Mid & High
Mine to plant, 40 nmi, 2.5 Mst/a:			
Dredge......................	1.92	1.92	1.92
Dock........................	0.03	0.03	0.03
Plant--onboard..............	.21	.21	.21
onshore..............	3.72	3.89	4.00
Working capital.............	.36	.36	.37
Total.....................	6.24	6.41	6.53

It can be seen that the effect of doubling plant feed heavy minerals content, by comparing the lowest and intermediate grade plants, increases onshore plant costs by 4 pct and total capital requirements by less than 2 pct.

The variation in operating costs between these cases is similar. From this calculation can be inferred that variation in plant feed grade of plus or minus several times will have little impact on the cost estimates contained here.

East Coast Placers

The plan for exploiting the East Coast titanium placers assumes that a trailing suction head hopper dredge will be used. It operates off the coast of Virginia or Georgia and feed a plant in Virginia. The maximum dredging depth, including water and sediment, does not exceed 150 ft. The largest unknowns are tonnage available, which will be the principal determinant of plant capacity, and the distance to a suitably protected landing point where docking and processing facilities may be constructed. Earlier analysis suggests that regional cost differentials between the East and West Coast are minimal; therefore no regional adjustment of the East Coast dredge model costs has been considered.

System Description

As in the West Coast model discussed earlier, two configurations were considered for mining the heavy mineral placer deposits (HMPD's): The first included hopper dredges with onboard mineral processing facilities and the second, hopper dredges without such facilities. In both cases the dredge will operate continuously on a 24 hr/d, 7-d/wk schedule, with an average downtime of one day or less every 2 wk for fueling, provisioning, preventative maintenance, and crew changes. One month per year is required for major repairs and shipyard overhaul. Because of probable periods of unscheduled maintenance and unfavorable sea conditions, the assumed production rate is based on 80 pct dredge availability and operating costs are based on 250 operating days per year. Specific gravity of the material mined is assumed to be 1.8 and onboard mineral processing facilities will concentrate the material by 50 pct. The dredge will be completely self-contained with crew quarters, mess, and sanitary facilities sufficient to accommodate all operating personnel for a 2-wk period. Hopper dredge production is dependent on hopper volume and cycle time requirements (i.e., loading and unloading time and time in transit). For dredges with onboard mineral processing facilities, loading time is limited to throughput of the processing plant and, owing to space and weight considerations, is assumed to be twice that of a dredge without onboard processing facilities. Therefore, cycle time requirements for a dredge with processing facilities differs from cycle time requirements for a dredge without processing facilities.

The plant was designed to recover rutile, ilmenite, leucoxene, monazite, and zircon from heavy mineral sand deposits typical of those found off the coast of Virginia. Processing facilities include an initial concentration plant located onboard the dredge, and a recovery plant located onshore. This activity reduces the amount of material that must be hauled to shore, thereby reducing operating costs. Flowsheets for both plants have been included to clarify the discussion (figs. 18-19).

The onboard facilities have been designed to operate 12 h/d with the remainder of the day given to unloading, haulage to and from the port, and maintenance and provisioning. Onboard processing facilities include trommels to eliminate the larger oversize material (+10 mesh) and foreign matter, cyclones to reduce slimes (minus 200 mesh), and spirals to concentrate heavy minerals and discard lighter fractions. Spirals were chosen because they are least affected by ship motion produced by wave action. Even so, it is assumed that only 50 pct of the total material can be eliminated at the onboard plant without significantly reducing heavy mineral recovery. Concentrates from the onboard plant will be stored in the dredge hopper to be transported to the onshore site.

Material from the dredge hopper will be stockpiled at the plant site. Owing to the differing annual operating schedules of dredge and plant it will be necessary to maintain a sizable surge pile at the plant. Conveyors will transport reclaimed material to vibrating screens where +48-mesh material is removed and sent to a rod mill for further size reduction. Rod mill discharge

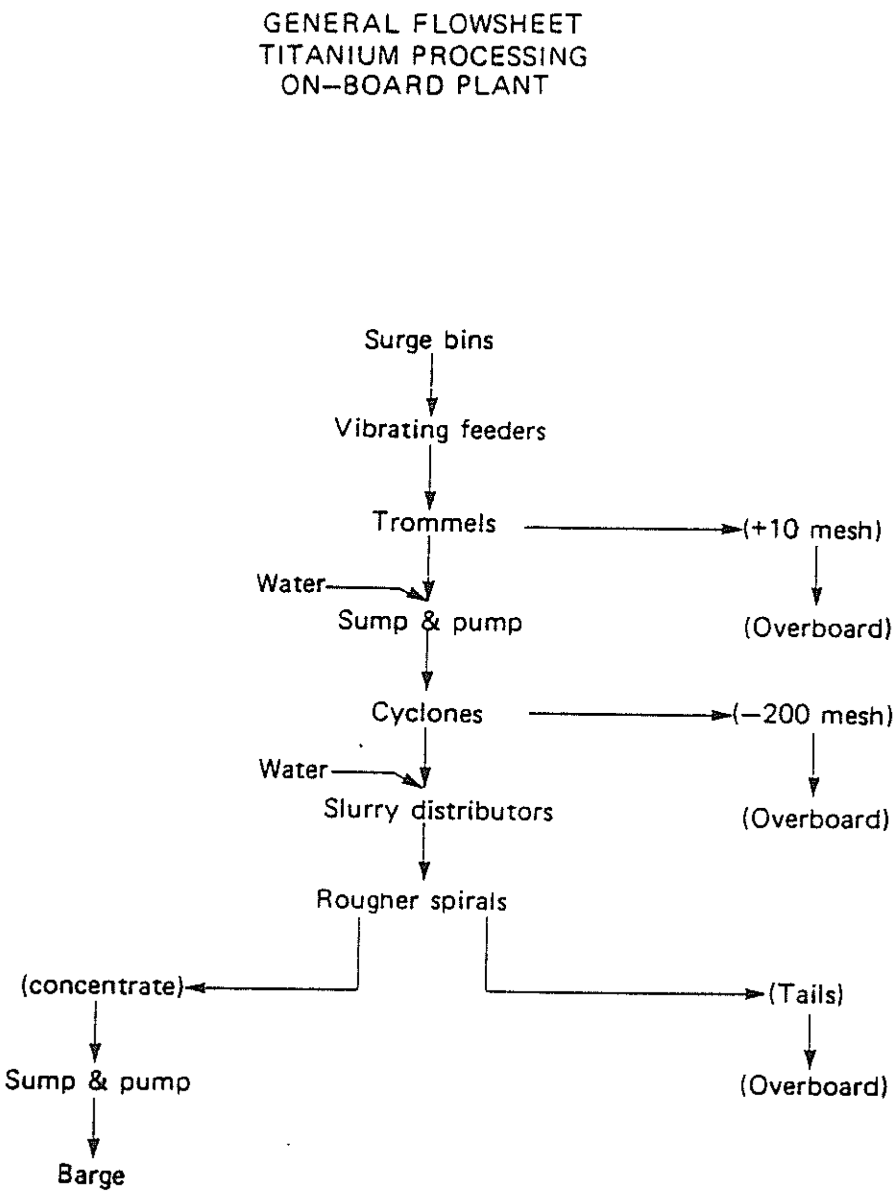

FIGURE 18. - General flowsheet, titanium processing onboard plant.

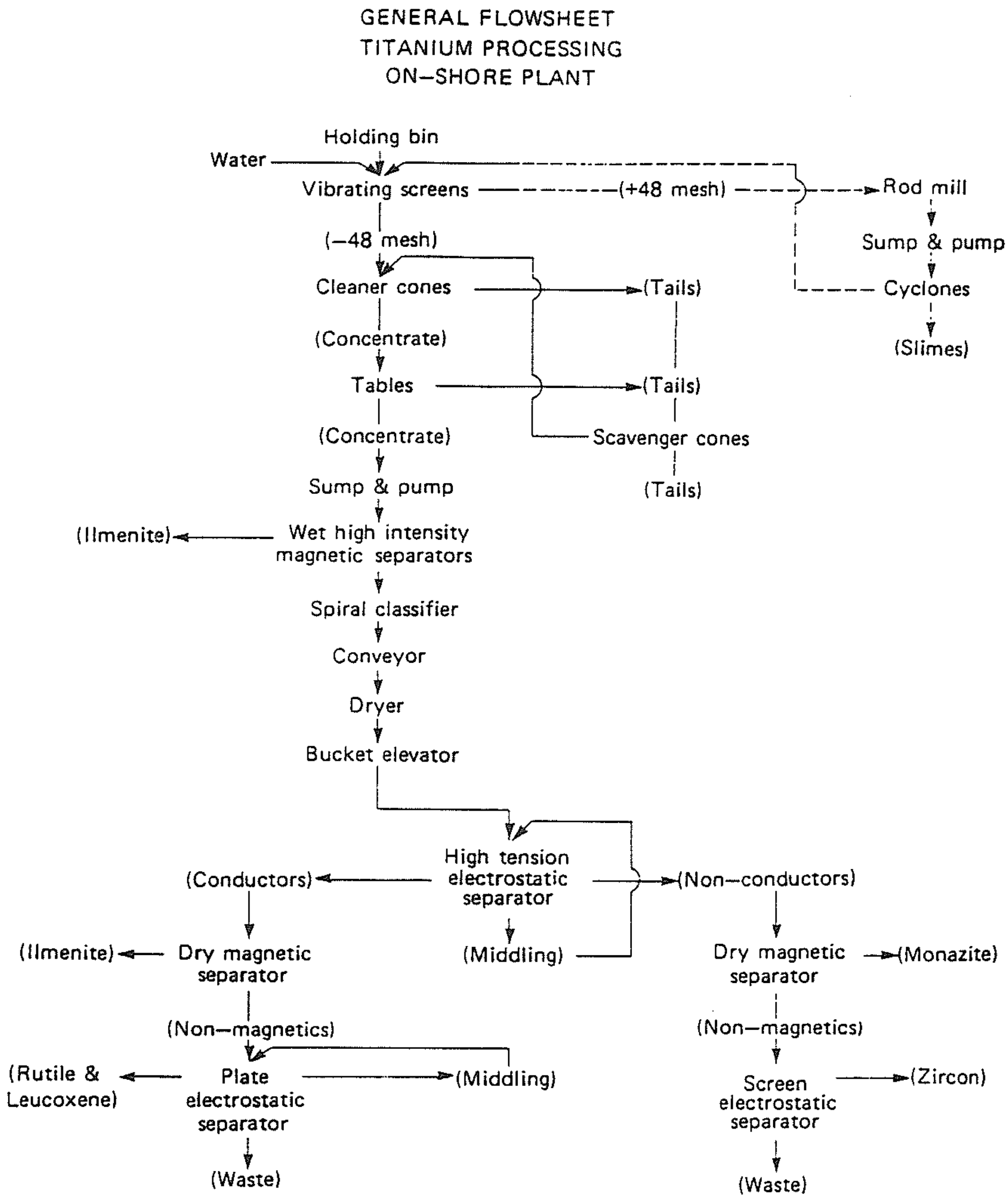

FIGURE 19. - General flowsheet, titanium processing onshore plant.

will be treated by cyclones to remove slimes, then returned to the vibrating screens. The need for this mill cannot be determined until metallurgical testing has been conducted; however, current plant facilities in the southeastern United States suggest it may be needed.

Minus 48-mesh sand from the screens is passed through a series of cleaner cones, scavenger cones, and concentrating tables to produce a concentrate containing 70 to 80 pct heavy minerals. Waste from the cleaner cones and tables is sent to scavenger cones to recover additional heavy minerals. These are then recycled to the cleaner cones.

Much of the ilmenite contained in the concentrate is then removed using a wet high-intensity magnetic separator. The remaining material is dewatered, dried, and heated prior to electrostatic separation. Using a high-tension electrostatic separator, conductors (ilmenite, rutile, and leucoxene) are separated from non-conductors (monazite and zircon). A middling fraction is recycled through the separator.

Conductors pass through a dry magnetic separator that removes ilmenite not recovered by the wet magnetic separator. The remaining conductors are concentrated into a rutile-leucoxene fraction using a plate electrostatic separator.

Non-conductors from the high-tension separator are fed to a dry magnetic separator which recovers the monazite fraction. The remaining material flows to a screen electrostatic separator where zircon is concentrated. A material balance, using the median grade values from table 4, is shown on table 19.

TABLE 19. - Material balance, East Coast concentration plant (10,000 st/d)

Product	Feed,	Recovery, %			Grade,	Product
	%	Onboard,	Onshore,	Total,	%	st/d
Rutile, % TiO_2.....	0.206	95	85	80.8	95	17.5
Ilmenite, % TiO_2...	1.39	95	88	83.6	52	223.5
Leucoxene, % TiO_2..	0.27	95	85	80.8	63	34.6
Zircon, % ZrO_2.....	0.28	95	88	83.6	64	34.6
Monazite, % REO....	0.02	95	88	83.6	50	3.3

Onboard plant recovery is assumed to be 95 pct in all instances and onshore plant recovery is assumed to be 85 pct for rutile and leucoxene, and 88 pct for the remaining products. Therefore, total recoveries are 81 pct for rutile and leucoxene, and 84 pct for ilmenite, zircon, and monazite.

Costs

Costs have been calculated for nine different cases, consisting of matrix combinations of three different production capacities and three arbitrary distances from minesite to processing facility (10, 40, and 80 nmi). Additional consideration was given to the selected processing scheme; whether the dredged material is processed initially onboard or fed directly to the onshore plant. Annual capacities and corresponding daily mine and plant capacities, in short tons, are:

Total annual capacity	1,250,000	2,500,000	5,000,000
Daily mine capacity	5,000	10,000	20,000
Daily plant capacity:			
Onboard, 250 d/year	5,000	10,000	20,000
Onshore, 350 d/year	1,800	3,600	7,100
Onshore, 350 d/year[1]	3,600	7,100	14,300

[1]Processing occurs solely onshore in this case.

Tables 20 and 21 contain estimated capital and operating costs for dredge and processing facilities for the base case. This assumes a U.S. built dredge is used and processing occurs onboard the dredge as well as onshore. Capital includes dredge, plant and dock construction, processing site acquisition, exploration, and 2 month's working capital. Operating costs include normal expenses associated with operations except taxes and debt retirement.

Examination of the capital cost estimates shows that both distance and capacity are important in determining investment requirements. The effects of capacity increases can be seen to increase the capital costs by two-thirds for dredge and plant with each doubling of capacity. The effect of variation in haulage distance is less pronounced because only dredge capital costs are affected. Total cost variations for a given capacity range between 30 and 50 pct.

Additional capital requirements with capacity increases are compensated for by lower dredge and plant operating costs This savings is not found for an increased haulage distance, when capacity is held constant. Table 21 shows that between 10- and 80-nmi haulage distances the dredge operating costs increase 40 to 60 pct and total operating costs increase 20 to 30 pct.

There is a demonstrable economy of investment at the greater capacities. Using the 40-nmi scenario, the total costs per installed annual capacity for the 1.25 Mst and 5 Mst operations are $18 and $13, respectively. Several other factors, such as markets, deposit availability, and quantity and grade, would have to be determined before an optimum capacity could be selected. In the initial cost analysis it was felt that it would be advantageous to reduce the bulk of mined material at sea to a limited degree. Therefore, in the base case, onboard processing was assumed to reduce by half

TABLE 20. - East Coast placer, dredge, and plant capital costs with onboard processing ($ million)

Cost description	Annual capacity[1] 1.25 Mst	2.5 Mst	5 Mst
Mine to plant, 10 nmi:			
Exploration..............	1.0	1.0	1.0
Acquisition..............	1.0	1.5	2.0
Dredge..................	7.6	14.6	28.1
Dock.....................	3.0	3.5	4.0
Plant--Onboard...........	1.1	2.2	4.3
--Onshore...........	3.9	6.2	10.0
Working capital[2]........	1.0	1.5	2.5
Total................	18.6	30.5	51.9
Mine to plant, 40 nmi:			
Exploration..............	1.0	1.0	1.0
Acquisition..............	1.0	1.5	2.0
Dredge..................	11.1	21.4	41.1
Dock.....................	3.0	3.5	4.0
Plant--Onboard...........	1.1	2.2	4.3
--Onshore...........	3.9	6.2	10.0
Working capital[2]........	1.1	1.8	2.9
Total................	22.2	37.6	65.3
Mine to plant, 80 nmi:			
Exploration..............	1.0	1.0	1.0
Acquisition..............	1.0	1.5	2.0
Dredge..................	13.5	25.9	49.7
Dock.....................	3.0	3.5	4.0
Plant--Onboard...........	1.1	2.2	4.3
--Onshore...........	3.9	6.2	10.0
Working capital[2].......	1.2	1.9	3.2
Total...............	24.7	42.2	74.2

[1]Annual capacities based on 250 operating days for the dredge and 350 for the plant.
[2]Working capital for 2 months.

TABLE 21. - East Coast placer operating costs with onboard processing ($/st dredged)

Cost description	Annual capacity[1] 1.25 Mst	2.5 Mst	5 Mst
Mine to plant, 10 nmi:			
Dredge..................	2.01	1.46	1.19
Dock....................	0.05	0.03	0.02
Plant--Onboard..........	.30	.21	.15
--Onshore..........	2.24	1.77	1.39
Insurance...............	.28	.23	.20
Total................	4.88	3.70	2.95
Mine to plant, 40 nmi:			
Dredge..................	2.46	1.92	1.64
Dock....................	0.05	0.03	0.02
Plant--Onboard..........	.30	.21	.15
--Onshore..........	2.24	1.77	1.39
Insurance...............	.34	.29	.25
Total................	5.39	4.22	3.45
Mine to plant, 80 nmi:			
Dredge................	2.76	2.23	1.95
Dock....................	0.05	0.03	0.02
Plant--Onboard..........	.30	.21	.15
--Onshore..........	2.24	1.77	1.39
Insurance.............	.38	.32	.28
Total..............	5.73	4.55	3.79

[1]Annual capacities based on 250 operating days for the dredge and 350 for the plant.

the amount of material hauled daily from the dredge site to the plant. To more closely quantify this apparent advantage, costs were estimated for nine cases in which all processing occurs at the onshore site. Thus, both onshore and onboard phases of processing contained in the previous examples are combined at a single onshore site. This option necessitates delivering twice the daily tonnage to the plant to achieve the same product tonnage levels. Tables 22 and 23 show the costs that result.

Comparison of tables 20-23 indicates that the on-site processing has a clear economic advantage when the haul distance is greater than 10 nmi. For shorter haul distances the costs appear comparable and no clear-cut advantage is demonstrated.

Both capital and operating cost differences derive solely from dredge size requirements. Plant costs are assumed equivalent as no processing modification other than venue will occur.

TABLE 22. - East Coast placer, dredge, and plant capital costs with no onboard processing ($ million)

Cost description	Annual capacity[1]		
	1.25 Mst	2.5 Mst	5 Mst
Mine to plant, 10 nmi:			
Exploration..............	1.0	1.0	1.0
Acquisition..............	1.0	1.5	2.0
Dredge...................	8.0	15.0	27.9
Dock.....................	3.0	3.5	4.0
Plant....................	5.0	8.4	14.3
Working capital[2].........	1.0	1.5	2.4
Total.................	19.0	30.9	51.6
Mine to plant, 40 nmi:			
Exploration..............	1.0	1.0	1.0
Acquisition..............	1.0	1.5	2.0
Dredge...................	14.7	27.5	51.2
Dock.....................	3.0	3.5	4.0
Plant....................	5.0	8.4	14.3
Working capital[2].........	1.2	1.9	3.1
Total.................	25.9	43.8	75.6
Mine to plant, 80 nmi:			
Exploration..............	1.0	1.0	1.0
Acquisition..............	1.0	1.5	2.0
Dredge.................	20.0	37.2	69.4
Dock.....................	3.0	3.5	4.0
Plant....................	5.0	8.4	14.3
Working capital[2].......	1.3	2.2	3.7
Total..............	31.3	53.8	94.4

[1]Annual capacities based on 250 operating days for the dredge and 350 for the plant.
[2]Working capital for 2 months.

TABLE 23. - East Coast placer operating costs with no onboard processing ($/st dredged)

Cost description	Annual capacity[1]		
	1.25 Mst	2.5 Mst	5 Mst
Mine to plant, 10 nmi:			
Dredge	1.89	1.35	1.07
Dock	0.05	0.03	0.02
Plant	2.54	1.98	1.54
Insurance	.29	.24	.20
Total	4.77	3.60	2.83
Mine to plant, 40 nmi:			
Dredge	2.66	2.12	1.85
Dock	.05	.03	.02
Plant	2.54	1.98	1.54
Insurance	.40	.33	.29
Total	5.65	4.46	3.70
Mine to plant, 80 nmi:			
Dredge	3.30	2.75	2.48
Dock	.05	.03	.02
Plant	2.54	1.98	1.54
Insurance	.48	.41	.36
Total	6.37	5.17	4.40

[1]Annual capacities based on 250 operating days for the dredge and 350 for the plant.

A comparison was also made to show how the use of a foreign dredge would affect the costs. As stated in an earlier discussion, there is considerable uncertainty whether this option is feasible because of maritime legislation which restricts dredging within U.S. waters to domestic vessels only. The results contained in tables 24 and 25 when compared to base case data show a decline in investment requirements of as much as 30 pct. Operating costs are unaffected other than by a drop in insurance charges. The resulting change is inconsequential.

TABLE 24. - East Coast placer, dredge, and plant capital costs ($ million)--foreign built dredge

Cost description	Annual capacity[1]		
	1.25 Mst	2.5 Mst	5 Mst
Mine to plant, 10 nmi:			
Exploration.............	1.0	1.0	1.0
Acquisition.............	1.0	1.5	2.0
Dredge..................	3.8	7.3	14.1
Dock....................	3.0	3.5	4.0
Plant--Onboard..........	1.1	2.2	4.3
--Onshore..........	3.9	6.2	10.0
Working capital[2]........	1.0	1.5	2.4
Total................	14.8	23.2	37.8
Mine to plant, 40 nmi:			
Exploration.............	1.0	1.0	1.0
Acquisition.............	1.0	1.5	2.0
Dredge..................	5.6	10.7	20.5
Dock....................	3.0	3.5	4.0
Plant--Onboard..........	1.1	2.2	4.3
--Onshore..........	3.9	6.2	10.0
Working capital[2]........	1.1	1.7	2.8
Total................	16.7	26.8	44.6
Mine to plant, 80 nmi:			
Exploration.............	1.0	1.0	1.0
Acquisition.............	1.0	1.5	2.0
Dredge................	6.8	13.0	24.9
Dock....................	3.0	3.5	4.0
Plant--Onboard..........	1.1	2.2	4.3
--Onshore..........	3.9	6.2	10.0
Working capital[2]......	1.2	1.9	3.1
Total..............	18.0	29.3	49.3

[1]Annual capacities based on 250 operating days for the dredge and 350 for the plant.
[2]Working capital for 2 months.

TABLE 25. - East Coast placer operating costs
($/st dredged)--foreign built dredge

Cost description	Annual capacity[1]		
	1.25 Mst	2.5 Mst	5 Mst
Mine to plant, 10 nmi:			
Dredge	2.01	1.46	1.19
Dock	0.05	0.03	0.02
Plant--Onboard	.30	.21	.15
--Onshore	2.24	1.77	1.39
Insurance	.22	.17	.14
Total	4.82	3.64	2.89
Mine to plant, 40 nmi:			
Dredge	2.46	1.92	1.64
Dock	.05	.03	.02
Plant--Onboard	.30	.21	.15
--Onshore	2.24	1.77	1.39
Insurance	.25	.20	.17
Total	5.30	4.13	3.37
Mine to plant, 80 nmi:			
Dredge	2.76	2.23	1.95
Dock	.05	.03	.02
Plant--Onboard	.30	.21	.15
--Onshore	2.24	1.77	1.39
Insurance	.27	.22	.18
Total	5.62	4.46	3.69

[1]Annual capacities based on 250 operating days for the dredge and 350 for the plant.

The preceding analysis has not considered the effect feed grade variance would have on operating costs. Calculations omitted here show the same minimal effect on costs in the East Coast cases as were shown earlier for the West Coast cases.

ECONOMIC ANALYSIS

Methodology

Discounted-cash-flow analysis is used to estimate total cost and profit or rate of return for the various deposit and mining characteristics chosen. This technique permits identification and measurement of the most significant components of total cost and sensitivity analysis for the major uncertainties in the evaluations.

Figure 20 illustrates the steps in a basic cash flow computation for each year of the simulated life of the mine. Annual revenue estimates are derived by multiplying recovered quantities by the assumed prices. For instance, production of 5 million tons a year, an ilmenite price of $41/ton, an ilmenite grade of 3 pct, mill recovery of 80 pct and a mill concentrate grade of 50 pct TiO_2, would yield revenues from ilmenite sales of just under $9.5 million annually [$41 * (5,000,000)*(0.03)*(0.8)/(0.5)]. This estimate is combined with similar calculations for the other commodities recovered to calculate total annual revenue. Engineering estimates of necessary capital and operating expenditures are distributed over the mine's life and combined with tax obligations to develop annual cost totals. Certain deductions considered for tax computation purposes (depreciation, losses in earlier years, etc.) are not actual charges against current revenue and thus are not subtracted from revenue to determine annual cash flow.

For the East and West coast evaluations, the intuitive appeal of the presentation of the results is improved by normalizing to a per ton value the aggregate estimates for cash flow and its constituents. The sum of the undiscounted cash flows as well as the constituents for an example evaluation are shown in Table 26. The first column shows the mine life totals in millions of constant dollars and the second column shows these estimates per ton of ore treated. These calculations do not accurately portray the relative significance of the operating and capital costs of this operation. The operating costs expenditures are spread out over the producing life of the mine while the capital expenditures are bunched at the beginning.

To reflect the time value of the funds invested in the operation, the cash flows are discounted at a rate deemed to represent the value of foregone alternative investments that could have been made with the capital tied up in this operation. The computed cash flow value is discounted with the following formula to find the net present value (NPV) of a mining operation.

$$NPV = \sum_{n=1}^{L} C_n \cdot \frac{e^{r}-1}{re^{rn}}$$

where
C = each year's net after-tax cash flow;
L = life of operation, in years
n = sequential number of year being discounted;
r = annual discount rate and/or rate of return (as a decimal);
e = 2.718281828....

R E V E N U E S

- Operating costs
- Depreciation
- Royalties
- Property taxes

B E F O R E T A X I N C O M E

- Depletion
- Severance Taxes
- Tax Loss Carry Forwards

T A X A B L E I N C O M E

- Federal and State Income Tax
+ Tax Adjustments

N E T I N C O M E

+ Depreciation
+ Depletion
+ Deferred Deductions
- Equity Investment

C A S H F L O W

Figure 20 - Illustration of Annual Cash Flow Calculation

TABLE 26. East Coast Placer Deposit Study
Zero NPV, Mean Grade Cash Flow Summary

20 year Total Cash Flow	$/ Units ($ millions)	Treated
REVENUES	$551	$5.51
Mine/Mill Operating Costs	$358	$3.58
Dredge		$1.64
On board Plant		$0.15
Dock		$0.02
Insurance		$0.25
Amortizations	$3	$0.03
Depreciation	$60	$0.60
Royalty & Property Tax	$0	
BEFORE TAX INCOME	$130	$1.30
Depletion	$60	$0.60
Severance Tax	$17	$0.17
(avail. tax loss carry)		
(preferential portion)		
Tax Loss Carry		
STATE TAXABLE INCOME	$53	$0.53
State tax	$0	
FEDERAL TAXABLE INCOME	$53	$0.53
Federal Taxes (old rate)	$28	$0.28
Federal Taxes (new rate)	$20	$0.20
(ITC carryforward available)		
Investment Tax Credit	$0	
Add-on Minimum Tax	$5	$0.05
Alternative Minimum Tax	$20	$0.20
Net Federal Taxes	$23	$0.23
Tax Loss Adjustments	$0	
NET INCOME	$31	$0.31
Depreciation	$60	$0.60
Depletion	$60	$0.60
Deferred Deductions	$3	$0.03
Equity Investments	$63	$0.63
Loan Principal Repayment	$0	
CASH FLOW	$91	$0.91
DCF (continuous)	($0)	($0.00)

After the engineering evaluation is completed, there are three unknowns remaining in the above formula; the price of the principal commodity(ies) assumed for generating revenue, the rate of return assumed to reflect the opportunity cost of capital, and the NPV. Fixing two of the unknowns allows the other to be solved for.

For the Nome, Alaska evaluation, where reliable data were available, the discounted cash flow or internal rate of return (r) was found by fixing the gold price (that is, C), setting NPV equal to zero and solving for r. In this case, the DCFROR is the rate of return that makes the present worth of cash flows from an investment equal to the present worth of all after-tax investments, including a return of r on those investments, and can be interpreted as what the yield of this investment over its projected life.

Under conditions where the cash flow stream does not become positive, no rate of return will produce a zero NPV. To deal with such conditions, the analysis must focus on NPVs or on necessary revenues, given a rate of return. For the East and West coast evaluations, where the range of possible conditions often resulted in negative cash flow streams, NPV and revenue analyses were used. A uniform 10 pct annual discount rate or rate of return on unrecovered capital was assumed. A negative NPV indicates that not all of the costs are recovered over the mine's life while a positive NPV indicates that profits above total costs in the amount of the NPV are anticipated.

The last row of Table 26 indicates a scenario in which revenues are just sufficient to cover all costs including the 10 pct return on unrecovered capital. The difference between the undiscounted and discounted cash flow totals ($0.91/ton and $0/ton) for this zero NPV case measures the opportunity cost of the capital tied up in this venture. Together with the depreciation and amortization totals, it provides a capital cost value comparable to the operating cost estimate developed in the engineering evaluation. Figures 22 and 29 (see pages 99 and 111) display simplified versions of Table 26 illustrating how the average revenue is split among vessel and onshore operating, capital, and tax costs for base cases of the East and West Coast dredging operations evaluated.

Changes in NPV or profit is the measure used to indicate how sensitive these cost estimates are to the most crucial assumptions embedded in the calculations. The sensitivity of NPV to geologic assumptions about the grades of the material and the size of the deposit mined and to engineering assumptions about the operating cost per ton mined, the annual capacity, and the distance to the shore plant is illustrated with a series of sensitivity graphs, Figures 23-27 and 30-36 (see pages 87-91 and 98-102). Steep curves indicate that profit (or loss) estimates are more variable or sensitive to the range of values deemed plausible for the horizontal axis variable than do shallow curves. Breakeven combinations (NPV = 0) of the key geologic and engineering conditions are illustrated with summary figures 28 and 37 (see pages 93 and 103) whose points represent values interpolated from the sensitivity graphs.

Nome Economic Analysis

To evaluate the economic potential of gold production in the Nome offshore placer area, rates of return (ROR) were calculated using the Bureau's MINSIM computer program. The mining/processing parameters used to determine the ROR are the same as those listed in table 7 (page 54). Input parameters for new and used equipment were used in more than 70 individual MINSIM runs; ore grades and gold prices were varied.

Figure 21 is a plot of ROR versus the recoverable value of a cubic yard of auriferous gravel. The dollar value of the grade is used so that both the assay grade of contained gold and gold price are captured as one variable.

Using the USGS grade estimate of 0.556 ppm (0.0219 tr oz/yd^3) and a recent gold price of $350/oz, the value of the gravel is approximately $7.67/$yd^3$, and the ROR using new dredging equipment over a 20-year period is 22.61 pct. Utilization of used dredging equipment would yield a 43.53 pct ROR over the same time frame.

USGS sampling results suggest that the average thickness of auriferous lag gravels ranges from 0.5 to 3.0 ft. Dilution of mill feed will occur depending on the thickness of the dredged horizon relative to the thickness of the lag gravel deposit. If a 5-ft thick horizon is removed the dilution factor may be approximately two- to five-fold. Assuming only a two-fold dilution factor for the same grade estimate used above, the ROR for a new dredge will be reduced to approximately 5 pct. The ROR for used equipment will be slightly less than 14 pct.

East and West Coast Economic Analysis

No specific deposits have been identified or delineated in either the East or West Coast placer areas studied. Thus, financial analysis techniques were applied to technically feasible mining and processing plans working deposits within the range of geologic characteristics deemed plausible for the type of deposit(s) which might occur in these areas. The results of these evaluations identify which of these possible scenarios project a profit, that is a positive net present value (NPV), and how sensitive that profit is to key uncertainties in the analysis. Together with the engineering evaluations these results can also indicate which elements are most significant in the kind of mining operation evaluated.

Several basic parameter values were adopted for all of the cash flow runs to focus comparisons on the major uncertainties. These parameter assumptions not subject to financial sensitivity analysis include: (1) capital and operating costs reflect partial processing of the ore on a U.S. built dredging vessel; (2) a 10 pct real discount rate or rate of return on invested capital with no inflation over the production life of an operation; (3) independent or stand alone operation paying severance taxes or royalties at a rate of 3 pct of gross revenues and federal taxes under major provisions of the new tax law (lower corporate tax rate, no investment tax credit, and depreciation at faster rates over longer periods); (4) 22 pct depletion allowance on each of the commodities recovered.

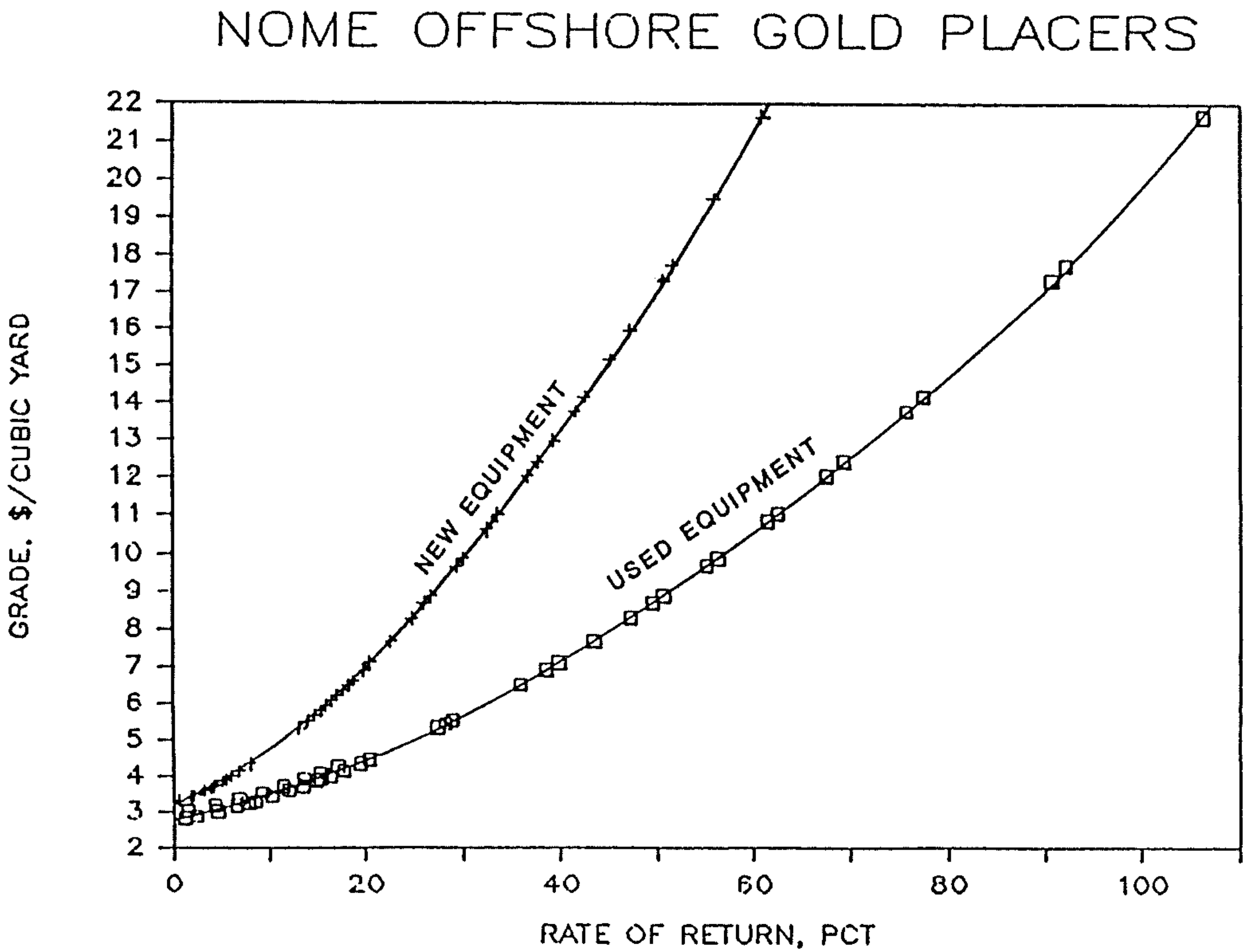

FIGURE 21. - Diagram illustrating the effects of different gold grades on rate of return.

Base product prices are specified in Table 27. All values used were current in early 1986. In general, they fall within the price range that has prevailed over the last 5 years. Over this time period, price volatility, excluding that of gold and rutile, has been limited which would suggest that the values are a reasonable representation of what can be expected.

TABLE 27. - Placer commodity prices

Commodity	Deposit type	Unit price
Chromite..................	West	$36/st[1]
Ilmenite..................	East, West	41/st
Rutile....................	East, West	495/st
Leucoxene.................	East	253/st
Zircon....................	East, West	182/st
Monazite..................	East	432/st
Gold......................	West, Alaska	350/tr oz

[1]All prices f.o.b. plant.

East Coast Placers

A 5 million ton per year operation producing for 20 years within a 40 nautical mile radius of a shore plant was used as the base case for the East coast evaluations. That situation implies that any deposit found will contain at least 100 million tons of resource. Tables 28 and 29 display the key revenue and cost assumptions used to project cash flow for the East Coast evaluations.

The top set of numbers in Table 28 reproduces the range of grades shown in Table 4 (page 43) for the five commodities expected to be produced and sold by such an operation. The top line indicates the sum of the oxides of Ti, Zr, and REE the ore treated by the mining operation and is the sum of the grades listed below for the different types of minerals. The second set of numbers indicate the annual tonnages of concentrate recovered at each grade. The last set of numbers in Table 28 reflect the average revenue per ton of ore treated that is expected to be derived from the four sets of grades evaluated. The average revenue is calculated by multiplying the annual production of concentrate by the appropriate selling price (Table 27), summing and dividing by the annual ore production (5 million tons).

The percentages opposite each mineral indicate the share it contributes to this aggregate average revenue in these cases. Any difficulty the operation might have finding a buyer for the calculated volume of each product, particularly the lesser known ones, is ignored. None of the minerals contributes a large enough share to be considered a primary product of the operation. It is important to note, at this point, that higher (lower) feed grades and lower (higher) concentrate prices or different grade combinations of these products would yield the same unit revenue. Therefore, feasibility appraisal will concentrate on the aggregate revenue figure rather than on the price necessary for a particular commodity.

Table 28. East Coast Placer Study Input Values,
New Tax Law, 10 pct DCFROR, 5 million tons per year

Input Values	First Quartile Grades	Median Grades	Mean Grades	Third Quartile Grades
Total Oxides of Heavy Minerals [a]	1.001%	2.166%	4.223%	4.723%
ilmenite (% TiO_2)	0.680%	1.390%	2.760%	3.170%
rutile (% TiO_2)	0.107%	0.206%	0.332%	0.423%
leucoxene (% TiO_2)	0.079%	0.270%	0.552%	0.480%
zircon (% ZrO_2)	0.125%	0.280%	0.398%	0.530%
monazite (% REO)	0.010%	0.020%	0.181%	0.120%
Annual Production (1000 st)				
ilmenite	54.662	111.735	221.862	254.819
rutile	4.550	8.760	14.119	17.989
leucoxene	5.066	17.314	35.398	30.781
zircon	8.164	18.287	25.994	34.616
monazite	0.836	1.672	6.772	10.032
Average Revenue ($/st)	$1.52	$3.47	$6.54	$7.55
ilmenite	29.4%	26.4%	27.8%	27.7%
rutile	29.6%	25.0%	21.4%	23.6%
leucoxene	16.8%	25.2%	27.4%	20.6%
zircon	19.5%	19.2%	14.5%	16.7%
monazite	4.7%	4.2%	8.9%	11.5%

[a] Sum not weighted by sample sizes.

Presently, some land based mines do recover all of the commodities in this set, so the technology to separate all of these commodities has been proven. The mining and processing costs for the hypothetical placer operation are based on recovery of all five commodities. Table 29 characterizes the different options (also referred to cases or scenarios in this report) and the associated capital and operating cost estimates used as inputs for the financial evaluations.

The pie diagram in Figure 22 displays the relative sizes of five basic groups of costs (vessel operating costs, onshore operating costs, vessel and plant capital costs, insurance costs, and taxes) involved in the generalized East Coast placer operation. These costs sum to a total of $5.51/ton of ore, which is the revenue per ton of ore required for this operation to breakeven or generate a zero NPV with a 10 pct return on unrecovered investment. At different unit revenues, the tax share would be different and a profit or loss share would occur. The roughly uniform distribution of almost all the costs among three categories suggests that cost saving efforts directed either at vessel or plant operations or at initial capital expenditure requirements will be equally successful in making a marginal operation viable.

Figure 23 shows the relation between NPV and the percentage of heavy minerals for each of the four sets of grade scenarios evaluated. The mining plan for each scenario assumes the operation is working a resource at an average distance of 40 nautical miles from the onshore plant for 20 years. The NPV ranges from a -$1.22/ton to a +$0.56/ton of feed for the sample grades found.

These calculations suggest that an East coast offshore operation can be viable under certain conditions. A single or closely bunched set of deposits containing a total (above 3.5 pct oxides of Ti, Zr, REE by weight) and a distribution of grades close to values for the mean shown in Table 28 must occur within a 40 mile radius of a shore plant with all five products marketable at about current prices. The next several figures indicate how robust this finding is under plausible variations in selling price, operating cost, annual capacity, and distance, each treated separately. As a point of reference, an existing operation in Florida recovering titanium minerals from beach sands projects an NPV of $0.87/ton under similar financial assumptions. The feed grade in currently worked beach sand deposits along the Florida coast is about 1.6 pct heavy mineral oxides by weight.

Figure 24 shows the relation between NPV and small changes in the long run selling prices shown in Table 27. The price variation range is chosen arbitrarily small because the base values are treated in the cash flow as average prices over the mining period. Substantial price increases should lead to more intensive exploitation of traditional land based deposits of these minerals, moderating any increase in the long term price trend. The volumes of these minerals derived from "Greenfield" ocean mining ventures are not expected to be large enough to affect market prices for these internationally tradeable minerals.

At the mean grade, the NPV ranges from a +$0.28/ton to a +$0.68/ton of feed for the sample prices or average revenues used. This narrower NPV range and the corresponding flatness of the curves in this reasonable price range suggests that viability of placer mining is less sensitive to expected market price fluctuations than to the possible variance in grades shown in Figure 23. The vertical scales in this sets of figures is held constant, so the sensitivity over the expected range of variation can be compared.

The discussion hereafter will focus on the mean grade, largely because that provides a base grade yielding positive NPVs. A positive NPV base is necessary to make the sensitivity analysis presentation visually meaningful, since discounting moves the NPV relations closer to the horizontal axis, both in the positive and the negative quadrants.

Figure 25 shows the relation between NPV and a plus or minus 25 pct change in the operating costs applied to the range of deposit qualities ($3.35/ton for low grade case, $3.45/ton for the median grade case, and $3.58/ton for the mean and high grade cases). The lack of experience with ocean placer mining prevents placing a narrower confidence interval around the

Table 29 - Cost Summary East Coast Offshore Placers Scenarios Used in Economic Analysis.

	Low Grade Case	Median Grade Case	Median Grade Case	Median Grade Case	Median Grade Case	Median Grade Case	Mean Grade Case	High Grade Case
OPTIONS								
Distance (nautical miles)	40	40	10	80	40	40	40	40
Capacity (1,000 st per year)	5,000	5,000	5,000	5,000	1,250	2,500	5,000	5,000
CAPITAL COSTS (1,000 $)								
Exploration	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000
Acquisition	$2,000	$2,000	$2,000	$2,000	$1,000	$1,000	$2,000	$2,000
Dredge	$41,100	$41,100	$28,100	$49,735	$11,132	$21,387	$41,100	$41,100
Dock	$4,000	$4,000	$4,000	$4,000	$3,000	$3,500	$4,000	$4,000
Onboard Plant	$4,300	$4,300	$4,300	$4,300	$1,134	$2,207	$4,300	$4,300
Onshore Plant	$9,309	$9,995	$9,995	$9,995	$3,859	$6,208	$10,581	$10,581
Fixed Capital Costs	61,709	$62,395	$49,395	$71,030	$21,122	$35,802	$62,981	$62,981
Working Capital	2,790	$2,870	$2,455	$3,160	$1,124	$1,755	$2,983	$2,983
Total Capital	64,500	$65,265	$51,850	$74,191	$22,246	$37,558	$65,964	$65,964
OPERATING COSTS ($/st of ore)								
Dredge	$1.64	$1.64	$1.19	$1.95	$2.46	$1.92	$1.64	$1.64
Onboard Plant	$0.15	$0.15	$0.15	$0.15	$0.30	$0.21	$0.15	$0.15
Onshore Plant	$1.29	$1.39	$1.39	$1.39	$2.24	$1.77	$1.52	$1.52
Dock	$0.02	$0.02	$0.02	$0.02	$0.05	$0.03	$0.02	$0.02
Insurance	$0.25	$0.25	$0.20	$0.28	$0.34	$0.29	$0.25	$0.25
Total Operating Cost	$3.35	$3.45	$2.95	$3.79	$5.40	$4.21	$3.58	$3.58

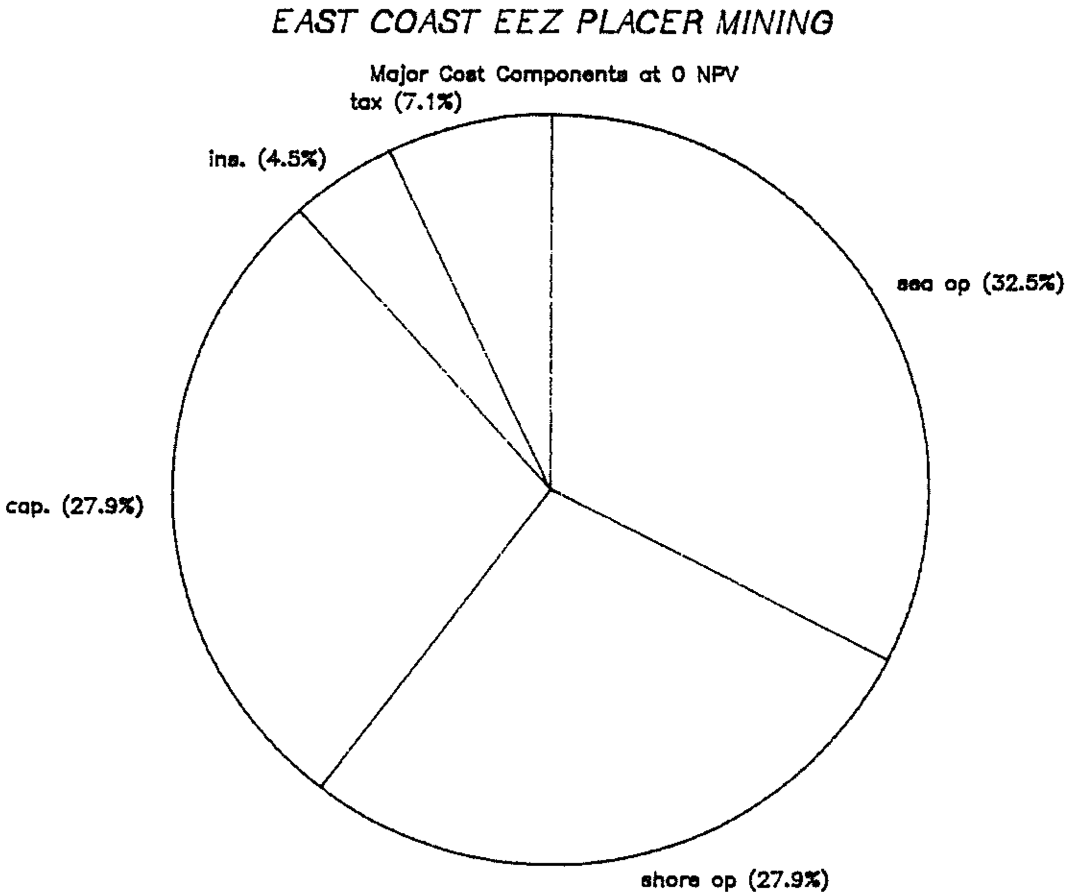

FIGURE 22. - Major Cost Components of East Coast Placer Mining.

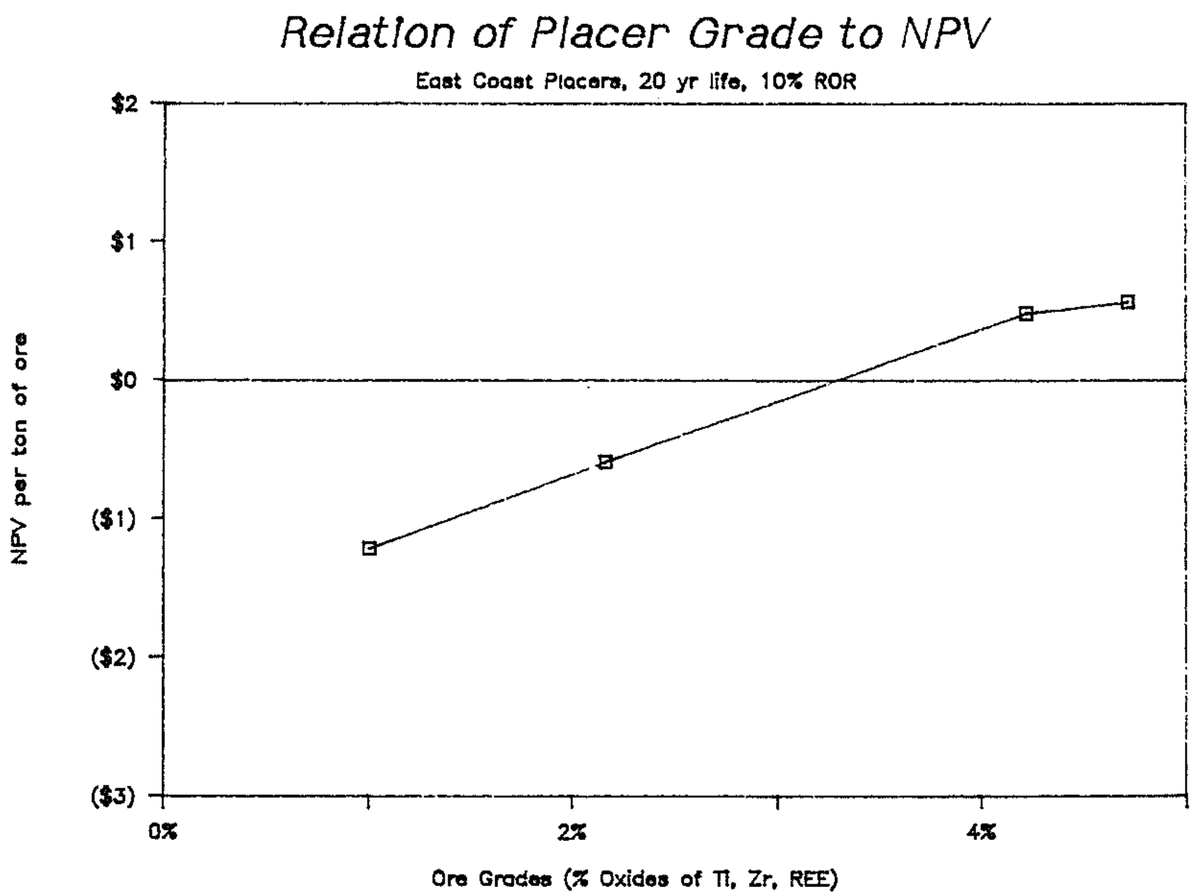

FIGURE 23. - Relation of Placer Grade on East Coast Placer Deposits.

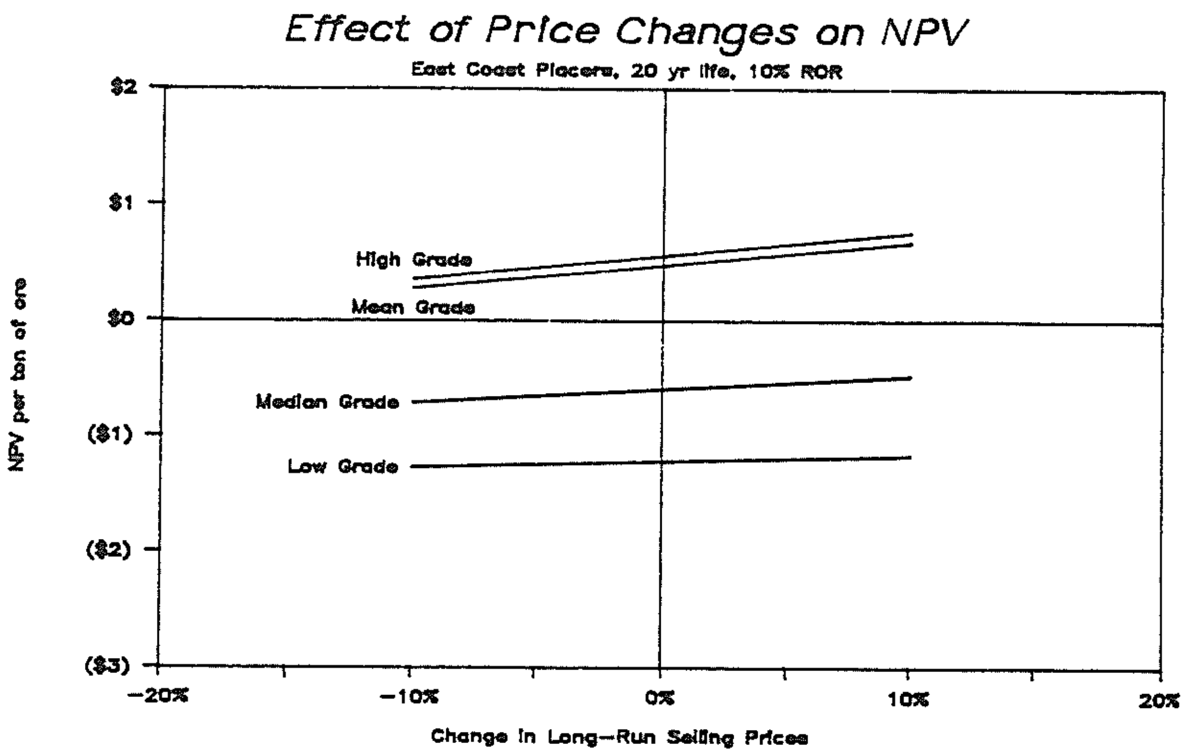

FIGURE 24. - Effect of Price Changes on East Coast Placer Deposits.

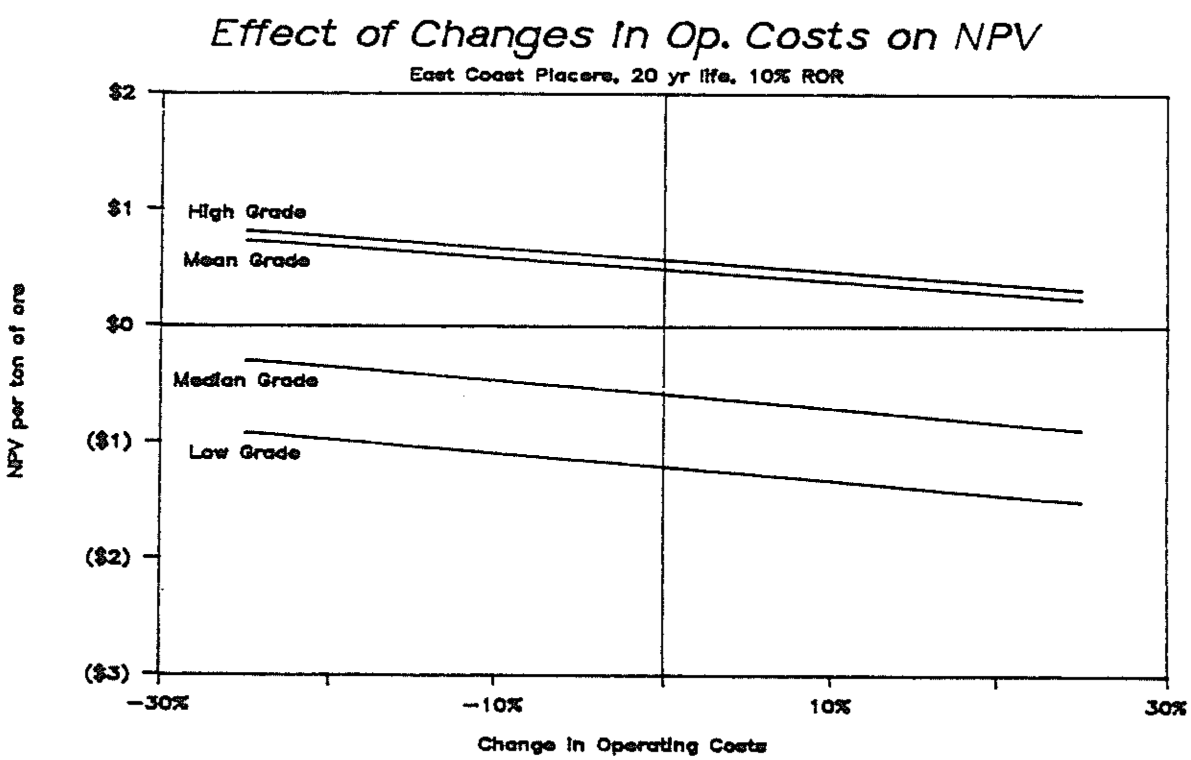

FIGURE 25. - Effect of Changes in Operating Costs on East Coast Placer Deposits.

operating costs estimated for the simplified operations designed for this study. Operations at specific deposits might develop significant efficiencies, for instance multiple dredges feeding large scale onshore processing plants. On the other hand discontinuities in grades or ocean currents and weather conditions may interfere more than expected with repetitive dredging operations.

At the mean grade, the NPV varies from a +$0.23/ton to a +$0.73/ton of feed for the range of operating costs possible. As with selling price, the conceivable variation in operating cost appears to have less affect on profitability than the possible variation in deposit grades.

Figure 26 shows the relation between NPV and annual dredge capacities ranging from 1.25 million tons to 5 million tons of ore. This set of capacities covers the range judged feasible with current vessel and equipment sizes and reasonable operating schedules. At the mean grade, the NPV ranges from a -$0.22/ton to a +$0.48/ton of feed for the sample prices or average revenues used. The increase in NPV with size indicates the existence of significant changes in economies of scale at the smaller end of the capacity range and moderate changes in economies at the upper end. Indeed, the smallest capacity evaluated appears uneconomic even at the highest grades.

Figure 27 shows the relation between NPV and distance of the deposit from the onshore plant. The 10 to 80 nautical mile distance covers the operating area judged feasible when current vessel and equipment sizes and reasonable operating schedules are adjusted to maintain a fixed annual mining rate. At the mean grade, the NPV ranges from a +$0.36/ton to a +$0.77/ton of feed for the sample prices or average revenues used. The decrease in NPV with distance indicates that increasing vessel sizes cannot compensate for the reduced trips possible over the greater distances. As expected, the 10 mile operating area produces the most favorable or profitable of the parameter ranges investigated in this set of graphs.

Table 30 summarizes the findings of these broad sensitivity analyses. Of the parameters investigated, plausible variation in the grade of the ore that might be found has by far the largest impact on viability of offshore placer operations on the East coast. The large difference between the mean and median grades of known occurrences (Table 4) suggests a population of placer titanium deposits that is asymmetrically distributed with only about one in four deposits with grades as good as the mean.

TABLE 30. - Summary of East Coast Scenario Sensitivity Analyses

Parameter	Feasible Variation	NPV Variation $/st	Range of NPV/st
Feed Grade[a,c,d] (% total oxides of Ti, Zr, REE)......	1% to 4.7%	-$1.22 to +$0.56	$1.78
Selling Price[a,b,c,d] (% of base price) ...	-10% to +10%	+$0.28 to +$0.68	$0.40
Operating Cost[a,b,c,d] (% of base op cost) .	-25% to +25%	+$0.73 to +$0.23	$0.50
Capacity[a,b,d] (million st/year) ...	1.25 to 5	-$0.22 to +$0.48	$0.70
Distance[a,b,c] (miles to plant)	10 to 80	+$0.77 to +$0.36	$0.41

[a]Twenty year operating life.
[b]At the mean grade.
[c]Five Mtpy
[d]Within 40 miles.

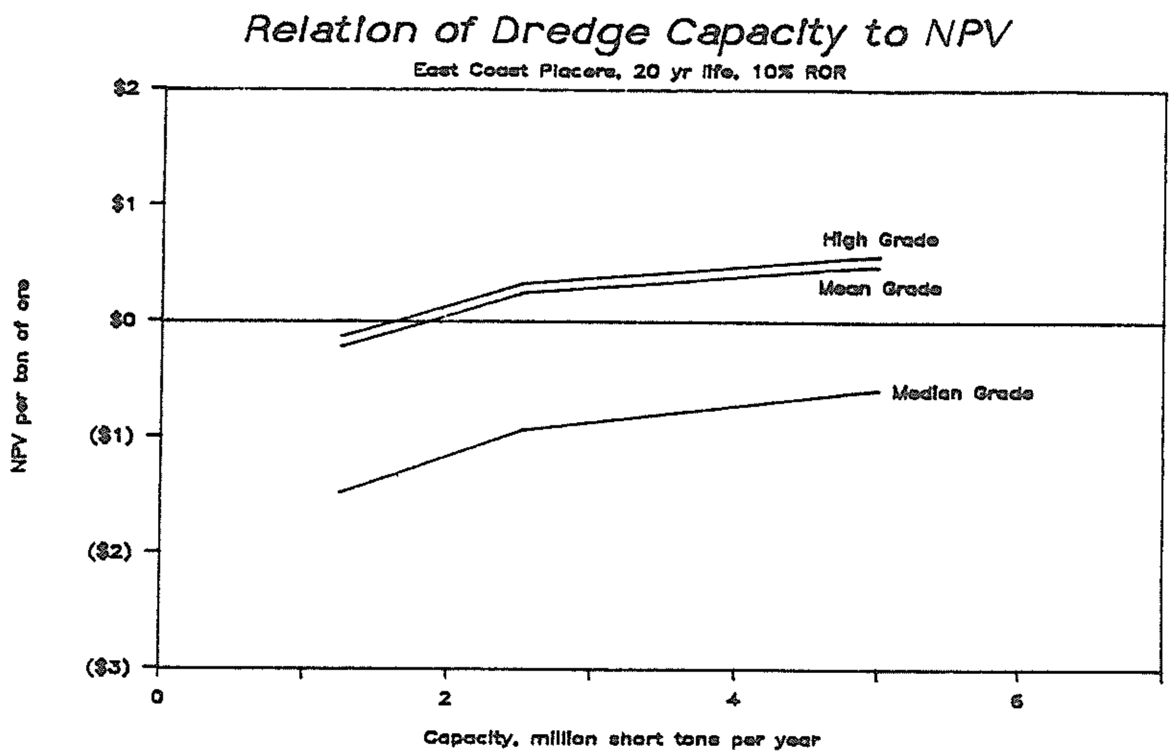

FIGURE 26. - Relation of Dredge Capacity to East Coast Placer Deposits.

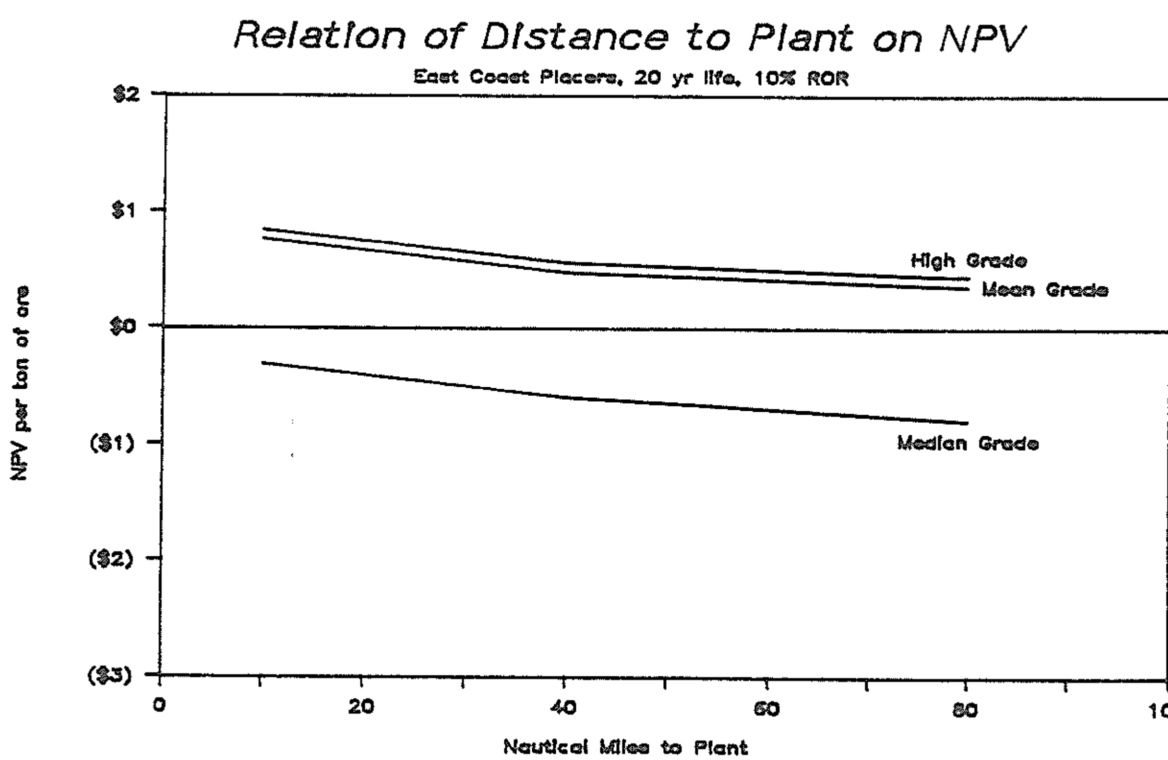

FIGURE 27. - Relation of Distance to Plant on East Coast Placer Deposits.

After grade ranges considered for the East coast, NPV or viability of the general operation is most sensitive to the ranges of capacity and operating costs evaluated. Figure 28 identifies the minimum combinations of values for the three most significant variables which separate the positive from the negative NPV results. The relations combine the interpolated values of heavy mineral oxide percentages and operating cost (or efficiency) from Figures 23 and 25 at which NPV equals zero. The area above the upper curve, labeled "PROFIT" (NPV greater than zero), indicates the set of grades and costs at which a 20 year, 2.5 million metric ton per year operation appears viable. The locus of points associated with a 20 year, 5 million metric ton per year operation indicates it can be viable with a less favorable combination of grades and efficiency.

West Coast Placers

A 2.5 million ton per year operation producing for 20 years was used as the base case for the West coast evaluations. That situation implies that any deposit found will contain at least 50 million tons of resource. Tables 31 and 32 display the key revenue and cost assumptions used to project cash flow for the West Coast evaluations. These tables are set up the same way as were Tables 29 and 30 for the East Coast evaluations, so only the differences will be mentioned here.

The top line of Table 33 indicates the aggregate share of total oxides of Cr, Ti, and Zr in heavy sands that geologic judgment suggests might be available to an operation in the Oregon area. While no single operation is recovering all of the commodities in this set, the technology to separate all of these commodities exists. Thus, the estimated costs shown in Table 32 are judged reasonable for recovery of all five commodities, and revenue calculations assume all five can be sold.

The average revenue for each grade set chosen is again calculated by multiplying the annual production of concentrate by the appropriate selling price, summing and dividing by an annual ore production (2.5 million tons). A smaller annual capacity for the base case West Coast operation than for the East Coast was used to reflect the smaller reserve size of terrace deposits historically mined onshore in this area. The percentages opposite each mineral indicate that chromite is responsible for about half of the revenue, so it can be considered the primary product of the operation. Again, as with the East Coast case, higher (lower) feed grades and lower (higher) concentrate prices or different grade combinations of these products would yield the same unit revenue, so feasibility appraisals will concentrate on the aggregate revenue figure rather than on the price necessary for a particular commodity.

ECONOMIC CRITERIA FOR EAST COAST PLACER

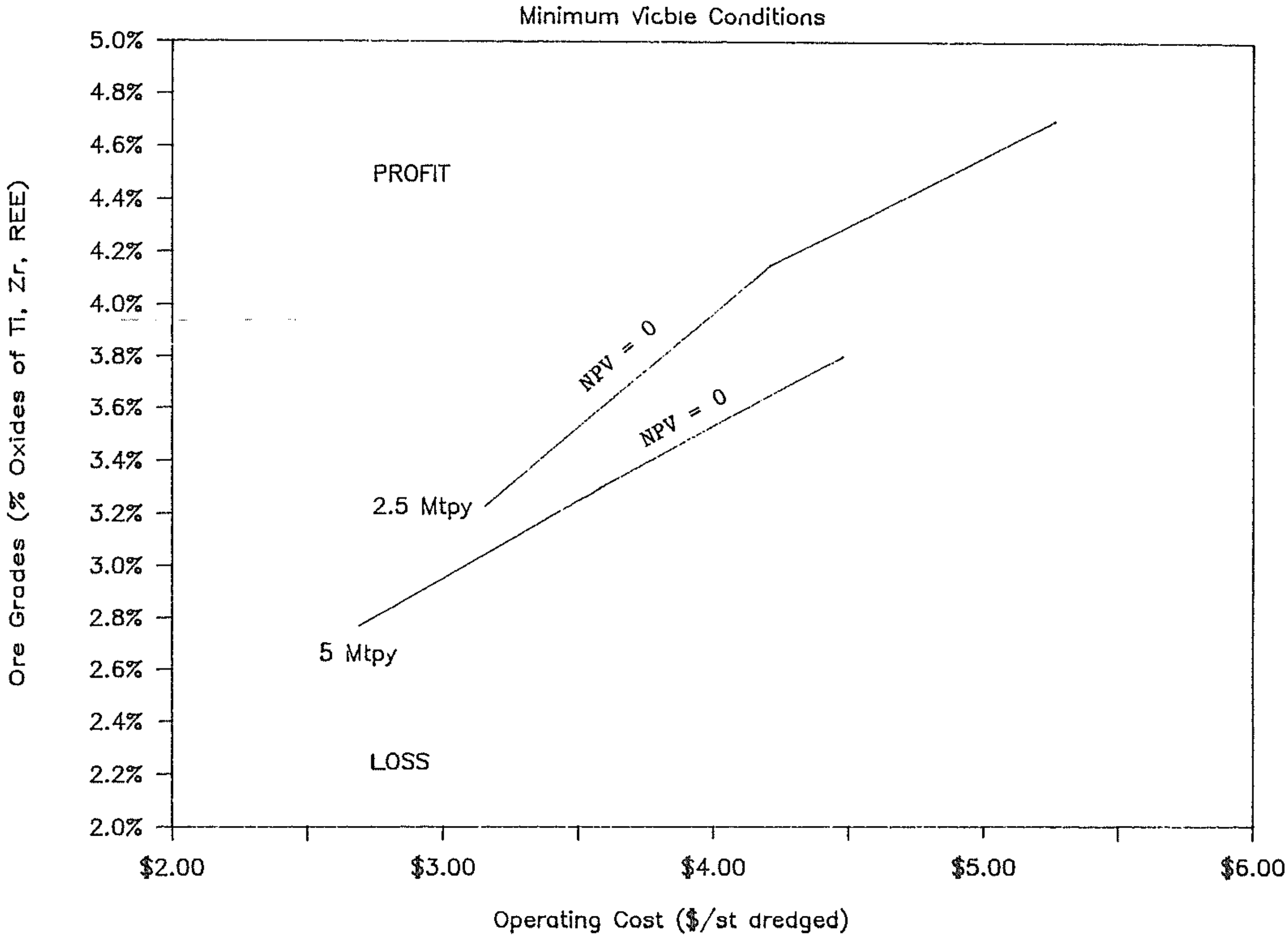

FIGURE 28

Table 31. West Coast Placer Study Input Values, New Tax Law, 10 pct DCFROR, 2.5 million tons per year

Input Values	Low Grades	Low-Mid Grades	High-Mid Grades	High Grades
Total Oxides of Cr, Ti and Zr in Heavy Sand	3.37%	6.75%	8.20%	12.30%
chromite (% Cr_2O_3)	2.60%	5.20%	6.30%	9.50%
ilmenite (% TiO_2)	0.40%	0.80%	1.00%	1.50%
rutile (% TiO_2)	0.08%	0.17%	0.20%	0.30%
zircon (% ZrO_2)	0.29%	0.58%	0.70%	1.00%
gold (tr oz/st)	0.002	0.004	0.005	0.01
Annual Production (1000 stpy)				
chromite	130.93	261.86	317.25	478.39
ilmenite	15.75	31.49	39.37	59.05
rutile	1.69	3.58	4.22	6.32
zircon	8.56	17.13	20.67	29.53
gold	4.09	8.19	10.24	20.47
Average Revenue ($/st)	$3.674	$7.390	$8.987	$14.125
chromite (@ $36/st)	51.31%	51.03%	50.84%	48.77%
ilmenite (@ $41/st)	7.03%	6.99%	7.18%	6.86%
rutile (@ $495/st)	9.09%	9.60%	9.29%	8.86%
zircon (@ $182/st)	16.97%	16.87%	16.75%	15.22%
gold (@ $350/oz)	15.60%	15.51%	15.94%	20.29%

Table 32 - Cost Summary West Coast Offshore Placers Scenarios Used in Economic Analysis.

	Low Grade Case	Low-Mid Grade Case	High-Mid Grade Case	High-Mid Grade Case	High-Mid Grade Case	High-Mid Grade Case	High Grade Case
OPTIONS							
Distance (nautical miles)	40	40	40	40	40	10	40
Capacity (1,000 st per year)	2,500	2,500	2,500	1,250	5,000	2,500	2,500
CAPITAL COSTS (1,000 $)							
Exploration	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000
Acquisition	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500
Dredge	$21,500	$21,500	$21,500	$11,200	$41,400	$14,600	$21,500
Dock	$3,500	$3,500	$3,500	$3,000	$4,000	$3,500	$3,500
Onboard Plant	$2,041	$2,041	$2,041	$1,049	$3,970	$2,041	$2,041
Onshore Plant	$15,379	$16,019	$16,341	$8,944	$28,795	$16,019	$16,341
Fixed Capital	$45,560	$44,920	$45,882	$26,293	$80,665	$38,660	$45,882
Working Capital	$2,600	$2,673	$2,720	$1,639	$4,519	$2,454	$2,720
Total Capital	$47,520	$48,233	$48,602	$28,332	$85,184	$41,114	$48,602
OPERATING COSTS ($/st of ore)							
Dredge	$1.92	$1.92	$1.92	$2.47	$1.65	$1.45	$1.92
Onboard Plant	$0.21	$0.21	$0.21	$0.30	$0.15	$0.21	$0.21
Onshore Plant	$3.72	$3.89	$4.00	$4.62	$3.28	$3.89	$4.00
Dock	$0.03	$0.03	$0.03	$0.05	$0.02	$0.03	$0.03
Insurance	$0.36	$0.36	$0.37	$0.43	$0.32	$0.31	$0.37
Total Operating Cost	$6.24	$6.41	$6.53	$7.87	$5.42	$5.89	$6.53

TABLE 33. - Summary of West Coast Scenario Sensitivity Analyses

Parameter	Feasible Variation	NPV Variation $/st	Range of NPV/st
Feed Grade[a,c,d] (% total oxide of Cr, Ti, and Zr in heavy sands)	3.37% to 12.3%	-$1.76 to +$1.30	$3.06
Gold Grade[a,b,c,d] (tr oz per ton)	-50% to +50%	-$0.34 to +$0.08	$0.42
Deposit Size[b,c,d] (million tons of ore at most efficient annual capacity)	25 to 100	-$0.57 to +$0.06	$0.63
Selling Price[a,b,c,d] (% of base price) ...	-10% to +10%	-$0.39 to +$0.13	$0.52
Operating Cost[a,b,c,d] (% of base op cost) .	-25% to +25%	+$0.35 to -$0.64	$0.99
Capacity[a,b,d] (million st/year)	1.25 to 5	-$0.69 to +$0.29	$0.98
Distance[a,b,c] (miles to plant)	10 to 40	+$0.18 to -$0.12	$0.30

[a]Twenty year operating life.
[b]At the high-mid grade.
[c]Two and a half Mtpy
[d]Within 40 miles.

The pie diagram in Figure 29 displays the relative sizes of five basic groups of costs (vessel operating costs, onshore operating costs, capital costs, insurance costs, and taxes) involved in the generalized West Coast placer operation. These costs sum to a total of $9.42/ton of ore, which is the revenue per ton of ore required for this operation to break even or generate a zero NPV with a 10 pct return. At different unit revenues, the tax share would be different and a profit or loss share would occur. The larger total cost than estimated for the East Coast placer operation and the disproportionate share attributed to onshore processing largely reflects the difficulty of processing the chromium content in ore, the mineral not expected to be found in the East Coast operation.

Figure 30 shows the relation between NPV and the percentage of total oxides of Cr, Ti, and Zr in the heavy sands for each of the four West coast grade scenarios evaluated. The mining plan for each scenario assumes a 2.5 million ton per year operation working a deposit 40 nautical miles from the onshore plant for 20 years. The NPV ranges from a -$1.76/ton to a +$1.30/ton of feed for the grades evaluated.

These calculations suggest that a West coast offshore placer operation can be viable under special conditions. A single or closely bunched set of deposits containing a total (above 8.5 pct total oxides of Cr, Ti, and Zr in heavy sands by weight) and a distribution of grades close to values of the high-mid grade case must occur within about 40 miles of a shore plant at water depths less than 150 ft. also must be all five products marketable at about current prices. As demonstrated for the East coast, the possible range of grades is very significant. The next several figures indicate how robust this finding is under different circumstances.

In the high grade case selected for the West coast, the revenue increase is largely attributable to the increase in the gold grade. Figure 31 indicates how significant variation in gold grade can be. Holding the grades of the other four commodities fixed at their high-mid grade values (Table 31), a gold grade increase from 0.005 tr oz/st to 0.0075 tr oz/st (50 pct) increases NPV from -$0.12/ton to +$0.08/ton, while a 50 pct decrease in gold grade (to 0.0025 tr oz/st) reduces NPV to -$0.34/ton from -$0.12/ton.

The heavy mineral sand grade is composed of a different, less valuable combination of minerals (specifically chromite instead of monazite), so it can not be compared with the aggregate grade scenarios used for the East coast cases. There are no chromite placer operations in the world, so an existing gold placer operation will be used to provide a point of reference. One such gold operation is estimated to break even (it projects an NPV of -$0.01/ton of ore) under similar financial assumptions. The gold grades in currently worked dredge operations run between about 0.0017 to 1.005 tr oz/st. (IC 9070, p. 78) The requirement for gold grades in the upper end of this range plus revenue from four other minerals for the offshore placer operation to approximate that NPV indicates the marginal viability of the base case West coast scenario.

Figure 32 shows the relation between NPV and a range of deposits sizes that may occur off the West coast. Three different annual capacity operations; small (1.25 million tons/year), medium (2.5 million tons/year),

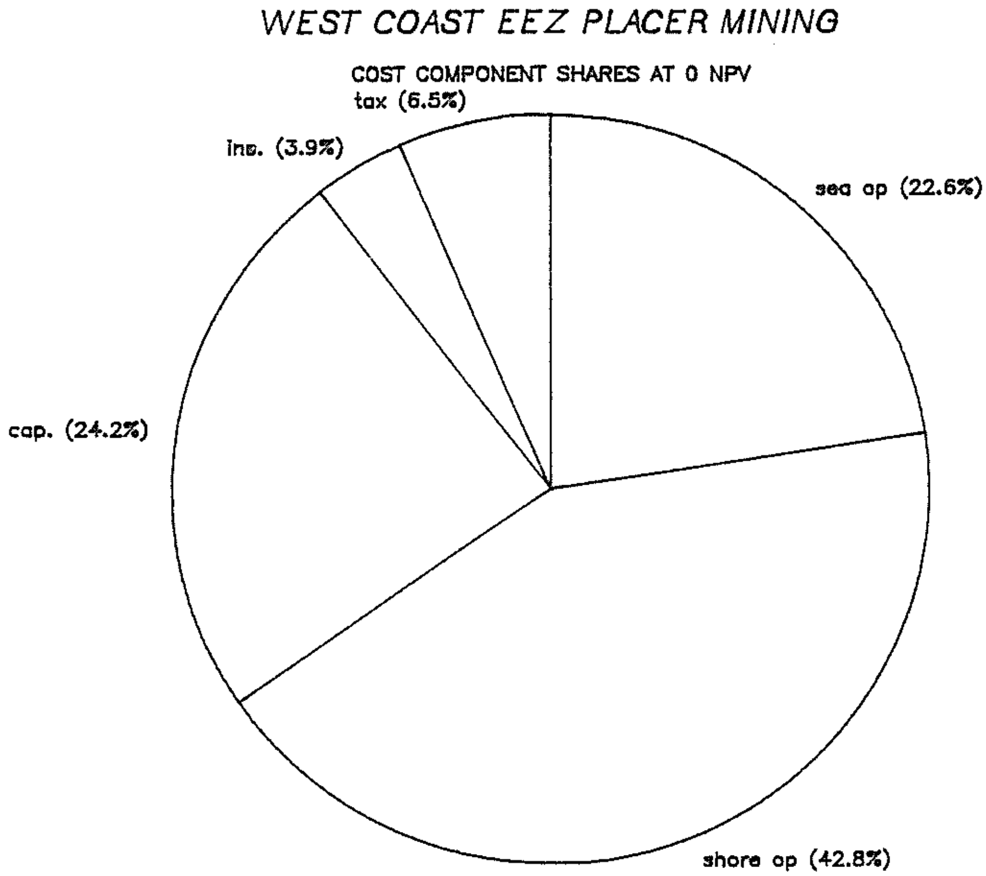

FIGURE 29. - Major Cost Components of West Coast EEZ Placer Mining.

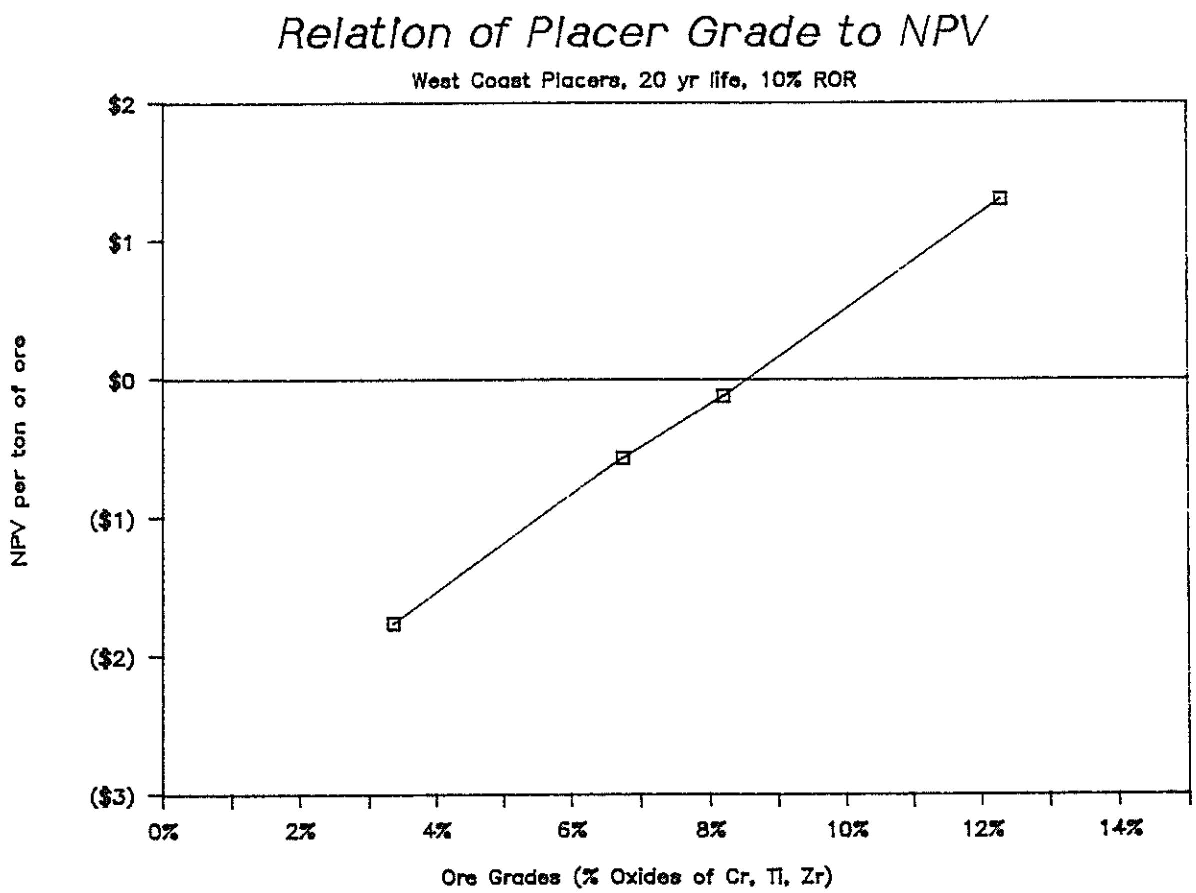

FIGURE 30. - Relation of Placer Grade to West Coast Placer Deposits.

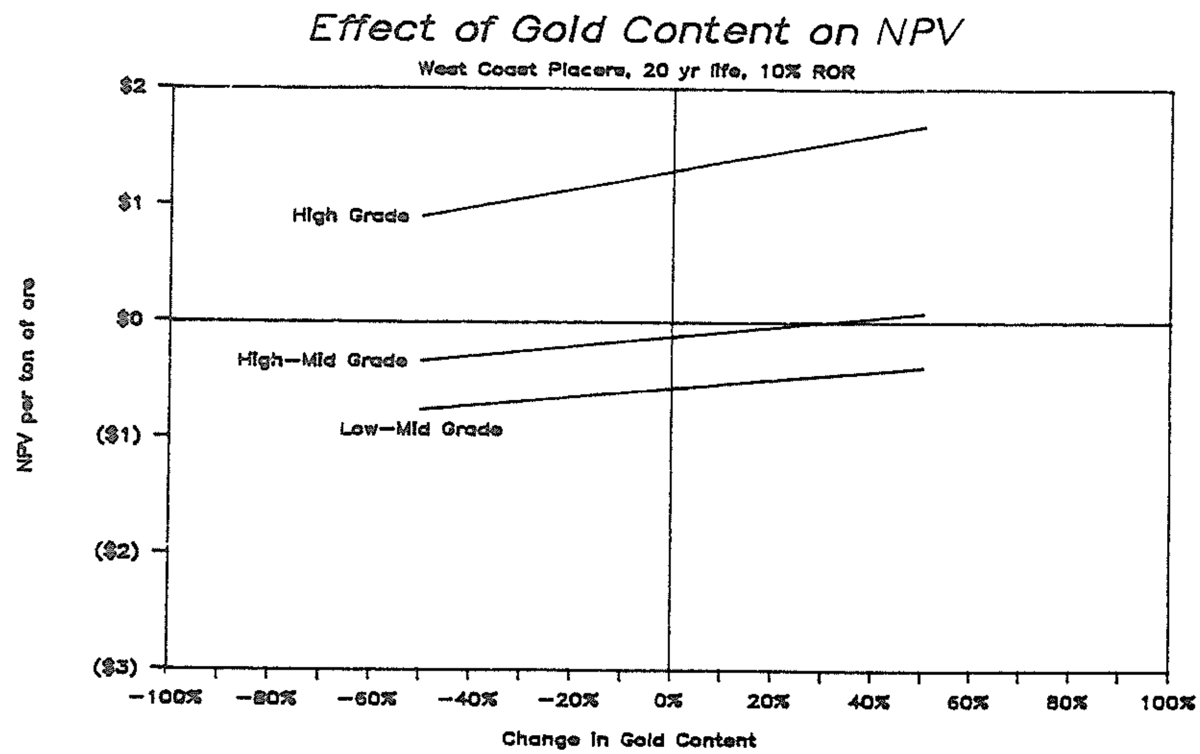

FIGURE 31. - Effect of Gold Content on West Coast Placer Deposits.

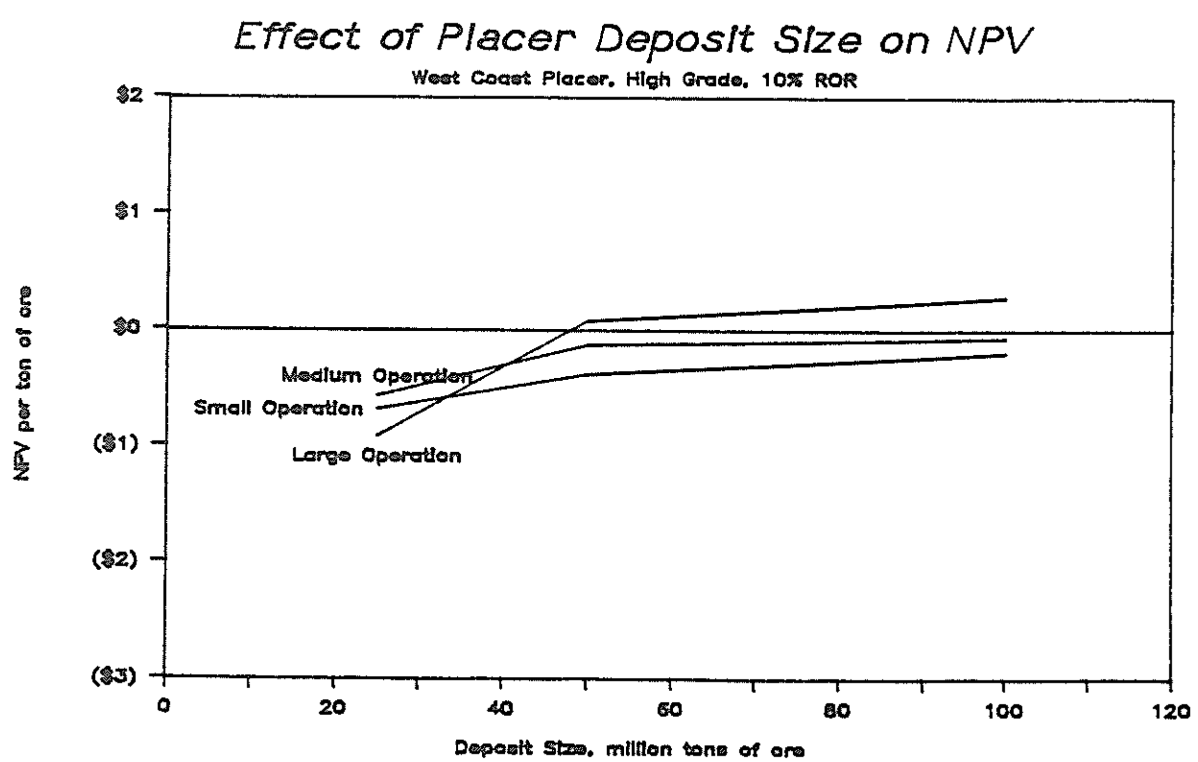

FIGURE 32. - Effect of Placer Deposit Size on West Coast Placer Deposits.

and large (5 million tons/year) are shown. Each is assumed to be working a high-mid grade case deposit 40 nautical miles from the onshore plant for the number of years that capacity requires to deplete the assumed deposit sizes (25, 50, and 100, million tons). For operations with only 5 and 10 year lives, no salvage value for undepreciated plant and equipment was assumed in the NPV calculations. At the 2.5 million ton per year rate, the NPV ranges from a -$0.57/ton (for the 25 million tons deposit worked for 10 years) to a +$0.06/ton of feed (for the 100 million ton deposit worked for 40 years). Doubling the capacity to 5 Mtpy provides only a small increase in NPVs beyond the 50 million ton deposit size.

Figures 33 through 36 compare NPVs for the West coast operation to the same variables (selling price, operating cost, annual capacity, and distance to shore plant) as used for the East coast sensitivity analyses. Table 33 summarizes the ranges of NPV estimated for the same variation in the selling price, operating cost, annual capacity, and distance to shore plant.

Given the plausible range of uncertainty about the parameter assumptions listed in Table 31, the NPV sensitivities appear to fall into three groups; (1) feed grade, (2) operating cost and capacity, and (3) deposit size, price, gold grade and distance. As was indicated in the East coast evaluation, the most crucial variable, of those evaluated, is the resource grade. Viable Figures 28 and 37 summarize the combination of grade and efficiency conditions found necessary for feasible mining of offshore heavy mineral placers. Given the speculative nature of the geologic information on the characteristics of actual offshore placer resources and the preliminary engineering scenarios used, the values estimated should only be viewed as approximations for these necessary conditions. Better delineation of actual deposits and more comprehensive evaluation of alternative mining plans is required to determine how sound these findings are.

Offshore placer operation appears to depend more on finding a large, quality deposit than on engineering and economic conditions such as price and efficiency.

Figure 37 identifies the minimum combinations of values for the three most significant variables which separate the positive from the negative NPV results for the West Coast scenarios evaluated. The relations combine the interpolated values of ore grade and operating cost (or efficiency) from Figures 30 and 34 at which NPV equals zero. The area above the upper curve, labeled "PROFIT" (NPV greater than zero), indicates the set of grades and costs at which a 25 million metric ton resource would be viable. The locus of points associated with a 100 million metric resource (and with the 50 million metric ton resource which is not shown) indicates it can be viable with a less favorable combination of grades and efficiency.

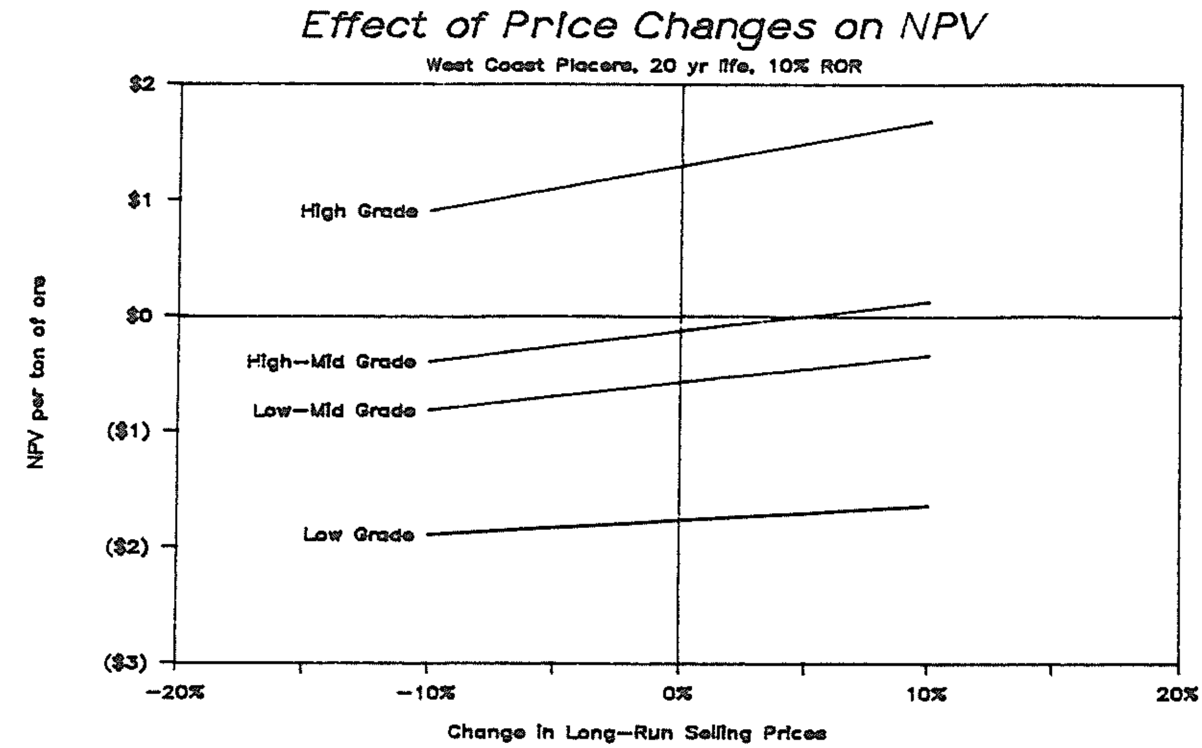

FIGURE 33. - Effect of Price Changes on West Coast Placer Deposits.

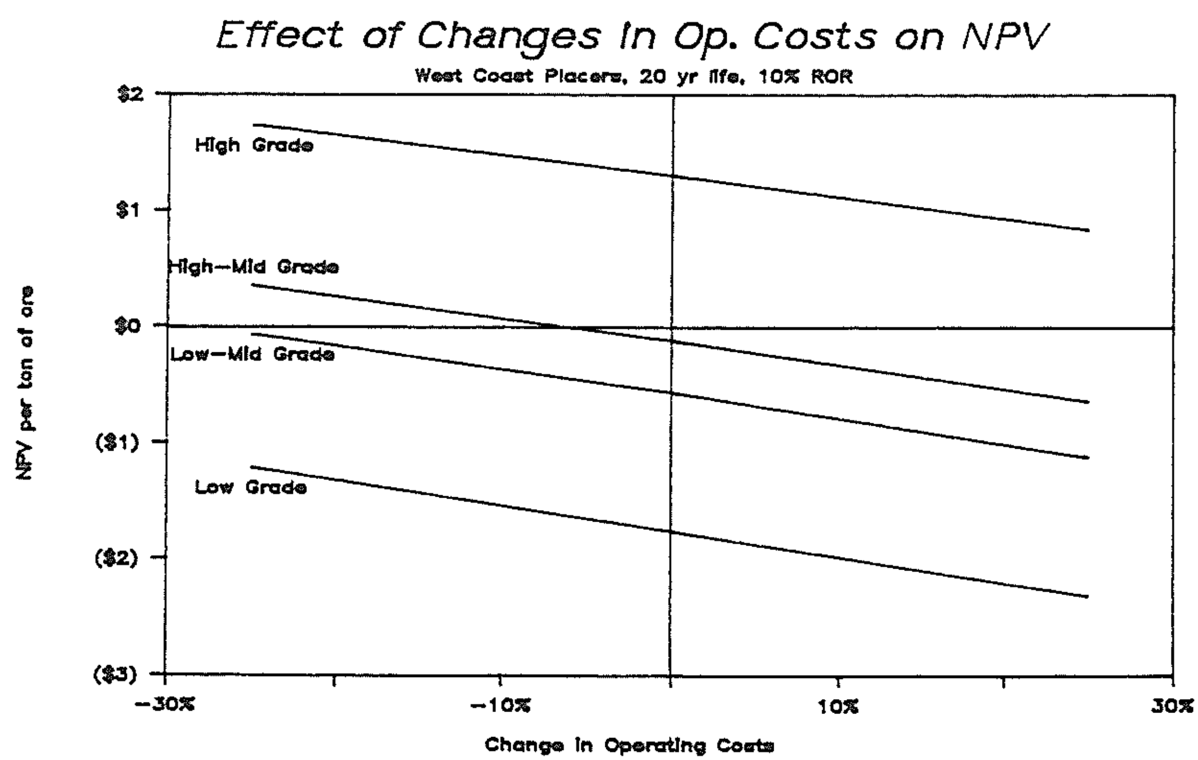

FIGURE 34. - Effect of Changes in Operating Costs on West Coast Placer Deposits.

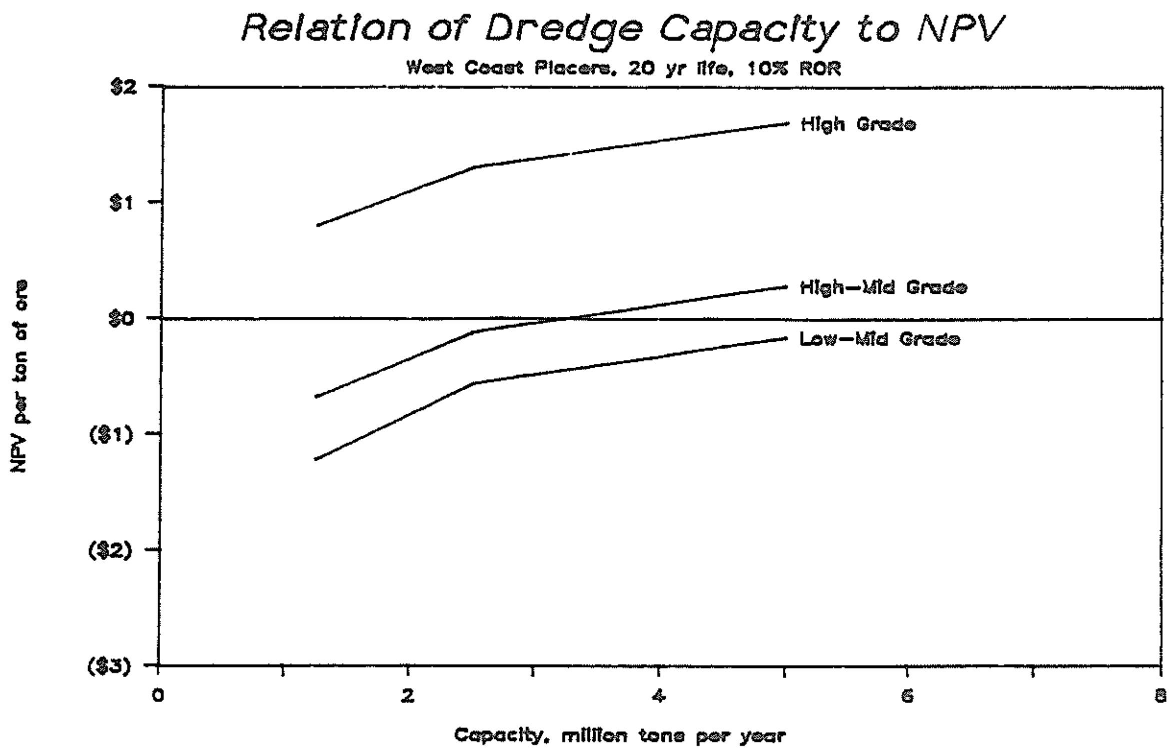

FIGURE 35. - Relation of Dredge Capacity to West Coast Placer Deposits.

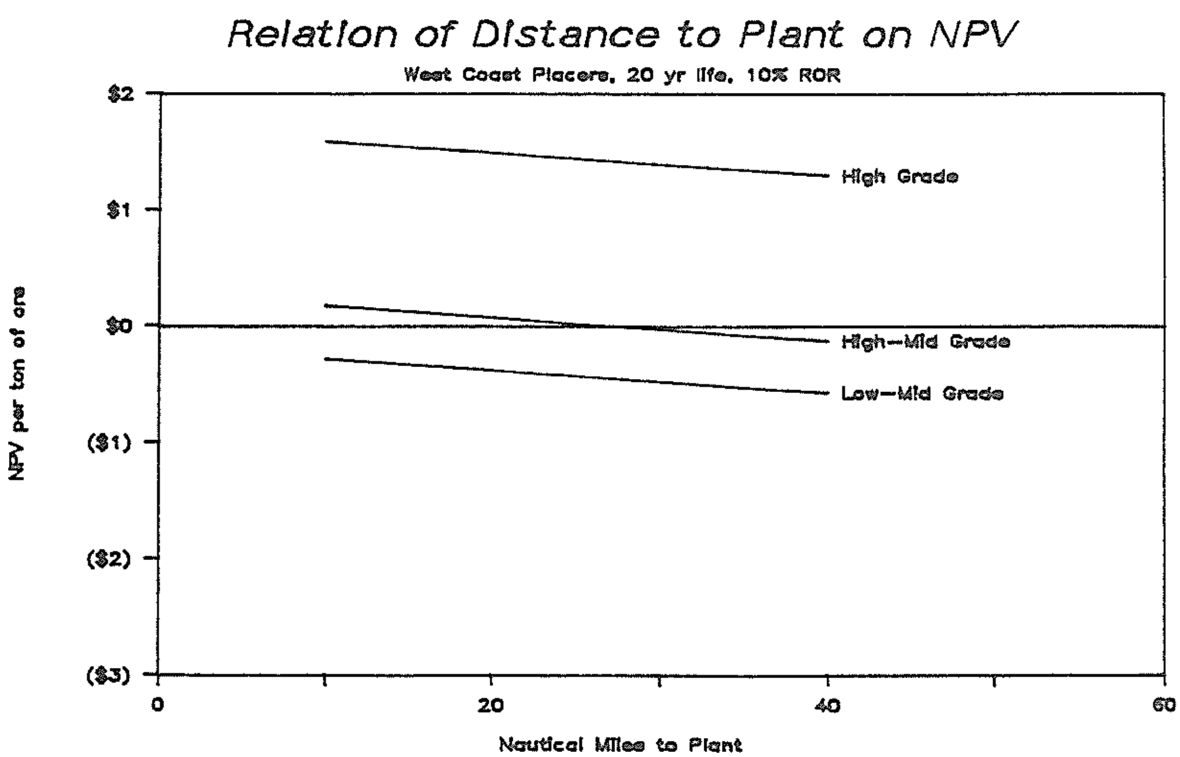

FIGURE 36. - Relation of Distance to Plant on West Coast Placer Deposits.

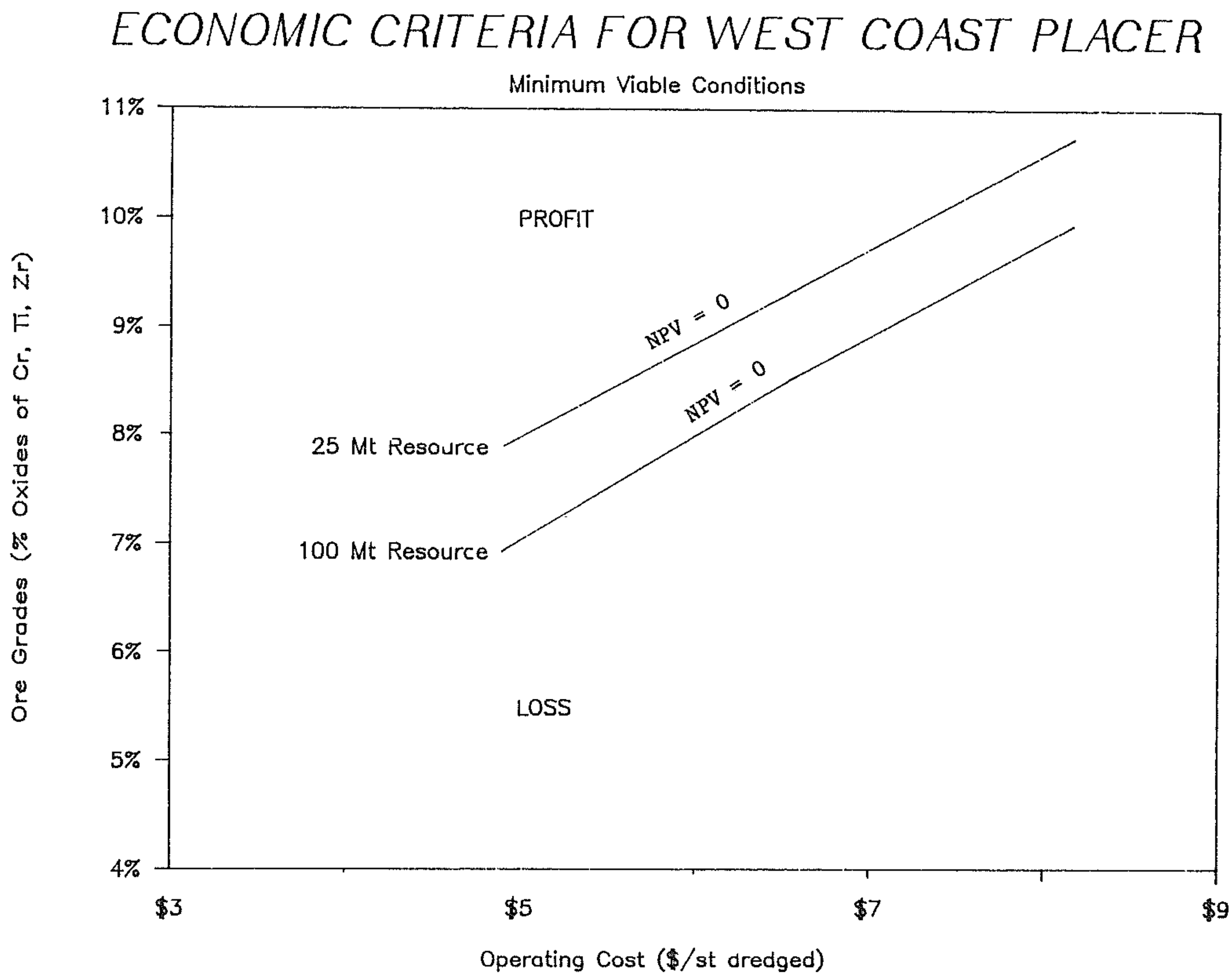
ECONOMIC CRITERIA FOR WEST COAST PLACER
Minimum Viable Conditions
11%
10%
9%
8%
7%
6%
5%
4%
Ore Grades (% Oxides of Cr, Ti, Zr)
PROFIT
NPV = 0
NPV = 0
25 Mt Resource
100 Mt Resource
LOSS
$3
$5
$7
$9
Operating Cost ($/st dredged)

FIGURE 37

CONCLUSIONS AND RECOMMENDATIONS

The following tentative conclusions are based on the limited resource data available and an economic analyses of estimated production costs for the three offshore placer areas addressed in this study.

Alaskan Gold Placers: Based on estimated grade of auriferous lag gravels and given the estimated costs of dredging and onboard processing, rates of return on investment of between 5 and 44 percent can be expected from mining of nearshore placers in Alaskan waters off Nome. However, interpretation of geological data available suggest that glacial till is the principal source of the gold in the offshore placer area, and that the areal distribution of the glacial sediments does not extend beyond about 3 miles seaward of the present coastline.

Oregon Chromium Placers: Resource parameters for offshore placers were based upon known data of onshore terrace deposits and to some degree, based upon past production of chomite and gold from that area. A range of grades and reserves were selected. While some may dispute selection of values for these parameters, given the uncertainty of what may indeed exist, examination of these values in the context of plausible engineering and economic parameters indicate the approximate minimum conditions for viable offshore mining.

Comparative engineering analysis suggests that partial processing of the feed material on the vessel saves significant capital and operating costs when haulage distances are more than 10 miles. Data received from foreign dredge owners suggests that purchase costs for a vessel built overseas would be approximately one half of a comparable U.S. built dredge. The combination of a smaller, stationary dredge with an oceangoing barge apparently does not offer any reduction in total costs over a large dredge vessel hauling the concentrate to shore itself.

Total heavy mineral grade proved to be the most significant factor affecting the value of potential offshore resources in this study. Cash flow evaluation indicates that these operations can be viable at the following grades.

Total Oxides of Cr, Ti, and Zr in Heavy Sand	8.20%
chromite (% $Cr2O_3$)	6.30%
ilmenite (% TiO_2)	1.00%
rutile (% TiO_2)	0.20%
zircon (% ZrO_2)	0.70%
gold (tr oz/st)	0.005

In addition, the resource size must be at least 50 million tons, located within 40 miles of the shore plant, and an annual mining capacity of at least 2.5 million tons is required. The steep continental shelf gradient off Oregon restricts exploitable areas to a narrow band paralleling the coast. At larger resource sizes and or with increased operating efficiency, slighltly lower total grades can be economical. Increasing annual capacity to 5 million short tons only slightly improves profit prospects.

Chromite provides half of the revenues from the grades given above, and it is likely that in any material to be found offshore, its share would be even greater. Recent investigations (from Peterson, 1986) suggest heavy mineral sands with oxide concentrations equal to or greater than the above, but it is unknown whether gold grades as high as 0.005 tr oz/st would be associated.

All of the above minerals have been identified in the onshore Oregon beach sands, and some have been mined in the past. Chromite has been mined on several occasions for strategic purposes. Zircon and other minerals have also been recovered from the resultant stockpiled material. The titanium minerals, while present in recovered concentrates, have never been commercially exploited. Gold mining has also occurred in the past, and current market conditions have stimulated renewed interest for this metal in this area. For there to be a profitable mining venture off the West coast all of the minerals identified above would have to be marketable.

Virginia-Georgia Titanium Placers: At the present time, resource estimates of placers on the Atlantic continental Shelf are speculative. A range of grades adopted from a statistical sample of worldwide strandline titanium placer deposit was used. As with the West coast evaluation, examination of these values in the context of plausible engineering and economic parameters indicates the approximate minimum conditions for viable offshore mining.

Similar engineering analysis suggests the same findings about general mining methods reported above for the West coast analyses. The cash flow evaluations for the East coast showed that operations could be viable if deposits can be found that contain about twice the grade of heavy sand minerals as are now being mined in Florida. In addition a distribution of grades like the world average for strandline titanium placer deposits must be found within about 40 miles of a shore plant. Under these conditions, the following heavy mineral grade combinations were found to be viable.

Total Oxides of Ti, Zr, REE in Heavy Sand	4.123%
ilmenite (% TiO_2)	2.76%
rutile (% TiO_2)	0.33%
leucoxene (% TiO_2)	0.55%
zircon (% ZrO_2)	0.40%
monazite (% REO)	0.18%

Geologic interpretations suggest that titanium placers comparable to those currently being mined onshore and others mined in the past could exist offshore. Recent samplings indicate possible concentrations equivalent to or higher than those above (Grosz, 1986); however the data is preliminary and no tonnages are associated. While all of the minerals in the above assemblages are currently being mined onshore, the concentration of total heavy minerals, especially the titanium minerals, are significantly lower. In addition, the required grades listed above represent values found in only about one in four strandline placer titanium deposits delineated in the world.

Recommendations

Based on the studies conducted, the following recommendations are made:

Alaska: Current mining activities in State waters near Nome indicate private sector interest in offshore development of precious metal deposits. It is recommended that this activity be monitored to stay appraised of its success and of any possible innovative technology which may develop. Economic reconnaissance should be performed on several other areas offshore Alaska (see Table 1 and Appendix A) which show promise as potential resources of gold, platinum, and other minerals. For example, the Cape Prince of Wales area may contain significant offshore placer deposits of tin.

West Coast: The potential economic viability of chromium-rich offshore placers points to the need for increased effort in evaluation of the continental shelf in the vicinity of Coos Bay, Oregon and for further investigation into costs for dredging at water depths greater than 150 ft. Before considering leasing in that area, the likelihood of resources with chromite contents at or above 6.3% Cr_2O_3 associated with high levels of gold (0.005 tr oz per short ton), titanium, and zircon in deposit sizes above 50 million metric tons should be established. It is also suggested that black sand deposits off the coast of northern Oregon and southern Washington be investigated as potential West Coast sources of titanium.

East Coast: Private sector interest in potential placer deposits off the Virginia-Georgia coast has been shown by two large corporations. It is recommended that geological reconnaissance focus on defining areas having titanium mineral constituent relationships comparable to average world strandline titanium placers and heavy sands with a minimum content of 3.5% total oxides of titanium, zirconium, and rare earth elements. Concurrently, site-specific costing should be performed to define specific location costs and constraints for offshore mining operations. For instance, consideration could be given to the efficiency of jointly mining sand and gravel with heavy mineral or of multiple mining/dredging operations feeding a common beneficiation facility.

General Recommendations: While the techniques applied in this study have provided insight into the general conditions necessary for viable mining of offshore mineral resources, certain elements need refinement. Specifically, engineering estimating capability for systems which include onboard processing, dredging, and shoresite facilities should be more completely examined and variables such as overburden and dilution should be further investigated. It is recommended that these refinements be incorporated in economic reconnaissances of additional commodities and areas within the EEZ.

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APPENDIX A

DISTRIBUTION OF OFFSHORE AND COASTAL PLACER MINERALIZATION OF POTENTIAL ECONOMIC SIGNIFICANCE IN ALASKA

Alaska Field Operation Center
United States Bureau of Mines
Anchorage, Alaska

December 1986

INTRODUCTION

This summary provides a compilation of major and most minor placer mineral occurrences which are associated with offshore placer mineral deposits of potential economic significance. This report is not complete and many smaller coastal deposits have not been included due to research time constraints. Mineralization of economic value in Alaskan waters consists of near-shore placer deposits on the coutinental shelf. High water energy requirements for placer formation generally limits the distribution of these deposits to shallow water near-shore environments. The formation of offshore marine placers is dependent upon the submarine topography, transgressive-regressive marine history, local marine processes, proximity of the mineralized source area, and in many cases, the local glacial history. Significant placer mineralization in the EEZ (Exclusive Economic Zone) will only be found in those areas with shallow marine waters extending offshore beyond the three mile limit (e.g. Cape Prince of Wales in the Bering Sea).

ORGANIZATION AND METHOD OF PRESENTATION

This report is intended to be used as a supplement to the included marine placer locality map of Alaska. Each of the 14 potentially economic mineral localities indicated on the map are listed in the enclosed report. When available, a brief summary of the locality, and production history is provided. If sampling progams have taken place in the region there reference is indicated. General references suggesting the economic potential of the areas are also included.

(1) Cape Prince of Wales — Tin, Gold, Tungsten(?) Placer

Consists of high energy placers along a north trending shallow water reef (16)[1] and coastal beach placers. Tin is the major commodity, with minor gold values. Mineralization probably extends offshore into the EEZ.

Tin production: Restricted to onshore lode and placer production near coast between Wales and Teller Mission. Total production between 1902 and 1967 is approximately 4,166,000 lbs (14).

Sampling: (32)

References: (14,16)

(2) Grantley Harbor — Gold, Tungsten Placer

High energy, shallow water placer (16)

Production: Offshore-nil. Onshore, east of Grantley Harbor-minor placer production (11).

References: (11,16)

(3) Nome Offshore Placer Region — Gold Placer

Onshore, the Nome district is the second largest producer of gold in Alaska. Most gold has been produced by dredging paleobeaches along the Nome coastal plain. Eight beach placers are recognized onshore, and at least three paleobeach strands are recognized offshore at water depths of 35 to 42 ft, 65 to 72 ft, and 80 ft. Favorable offshore deposits are hosted by reworked glacial morainal material which extends up to 3.1 mi offshore (32). The -65 to -72 ft and -80 ft beach strands are located in the EEZ. The paleobeach at -65 to -72 ft probably consists of reworked glacial debris and may be economically significant.

Gold Production: Onshore total production from 1898 to 1985 of at least 4,348,000 oz (2). Most gold produced since 1930 from dredging ancient beaches. Offshore dredging of surfacial reworked glacial gravel initiated by Inspiration Mining, Incorporated during August, 1986.

Sampling: (32)

References: (7,14,32)

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[1]Underlined numbers in parentheses refer to items in the lists of references at the end of this report.

(4) Bluff-Solomon Offshore Area   Gold Placer

Coarse gold in high energy beach and near-shore placers (16)

Gold Production: Refer to (11)

Sampling: (32)

References: (14,16)

(5) Golovin Lagoon   Gold, Tungsten(?) Placer

Low energy surficial gold, and buried gold in high energy environments (16). Surficial gold as lag deposits in high energy environment seems more likely.

Gold Production: None reported.

Sampling: (32)

References: (14,16)

(6) Goodnews Bay   Platinum, Gold, Chromite Placer

Onshore fluvial platinum-gold placers worked from 1926 to 1981. Platinum extraction restricted to fluvial channels draining from Red Mountain. Numerous researchers have reported trace to possibly economic concentrations of platinum and gold in beach and offshore sands around Goodnews Bay (1,17,23,24). Significant concentrations of chromium, with lesser amounts of gold are locally associated with platinum placers and may represent economically recoverable co-products or by-products to platinum recovery.

Favorable environments for platinum, gold and chromite enrichment include: 1) covered paleofluvial channels; 2) younger paleofluvial channels with less marine sediment overburden; 3) beach deposits, particularly in the upper swash zone and near back beach; 4) paleostrand lines; 5) inside the mouths of Goodnews and Chagvan Bays; and 6) the base of far offshore tidal ridges. Hypothetical resources of recoverable or subeconomic grade include 0.5 million oz from beach deposits and 5.0 million oz from offshore placers (25). Beach and offshore sampling programs being conducted by the Bureau in 1986 will contribute significant information aiding in the verification of specific deposit classes.

Platinum Production: Total production of PGM (platinum group metals) from the entire Goodnews Bay district between 1927-1981 is approximately 647,500 oz (25). Beach deposits in the Goodnews Bay area have not been developed.

Sampling: (26,27,28,29)

Refernces: (1,17,23,24,25)

(7) Hagemeister Strait Gold Placer

Minor beach placers reported.

Gold Production: Uncertain.

Sampling: U.S.G.S. (?)

References: (3,6,21)

(8) Kodiak Island West Coast Beaches Gold, Chromite, Platinum Placer

No recent production reported, nearshore environment unknown.

Production History: A few thousand ounces (4). Between 2,500 and 7,500 oz at $20.67/oz (15).

References: (3,4,5,6,13,15)

(9) Middleton Island Gold Placer

Gold Production: A few thousand ounces (4).

References: (4,16,33).

(10) Yakataga District Gold Placer

High and low energy placers (16).

Production History: Beach placer gold production of 15,000 to 16,000 oz (4, 33).

Sampling: (33,34)

References: (4,12,18,19)

(11,12) Lituya and Yakutat District Gold Placer

Production History: Up to 3,700 oz gold produced (4).

Sampling: (33,34,35)

References: (4,12,18,20)

(13) Kutchuma Islands Gold Placer

Coarse gold reportedly buried in high energy deposits beneath recent mud (16).

Reference: (16)

(14) Cape Fox (U.S.)-Dundas Islands (Canada) Gold Placer

High and low energy placers reported (16).

Reference: (16)

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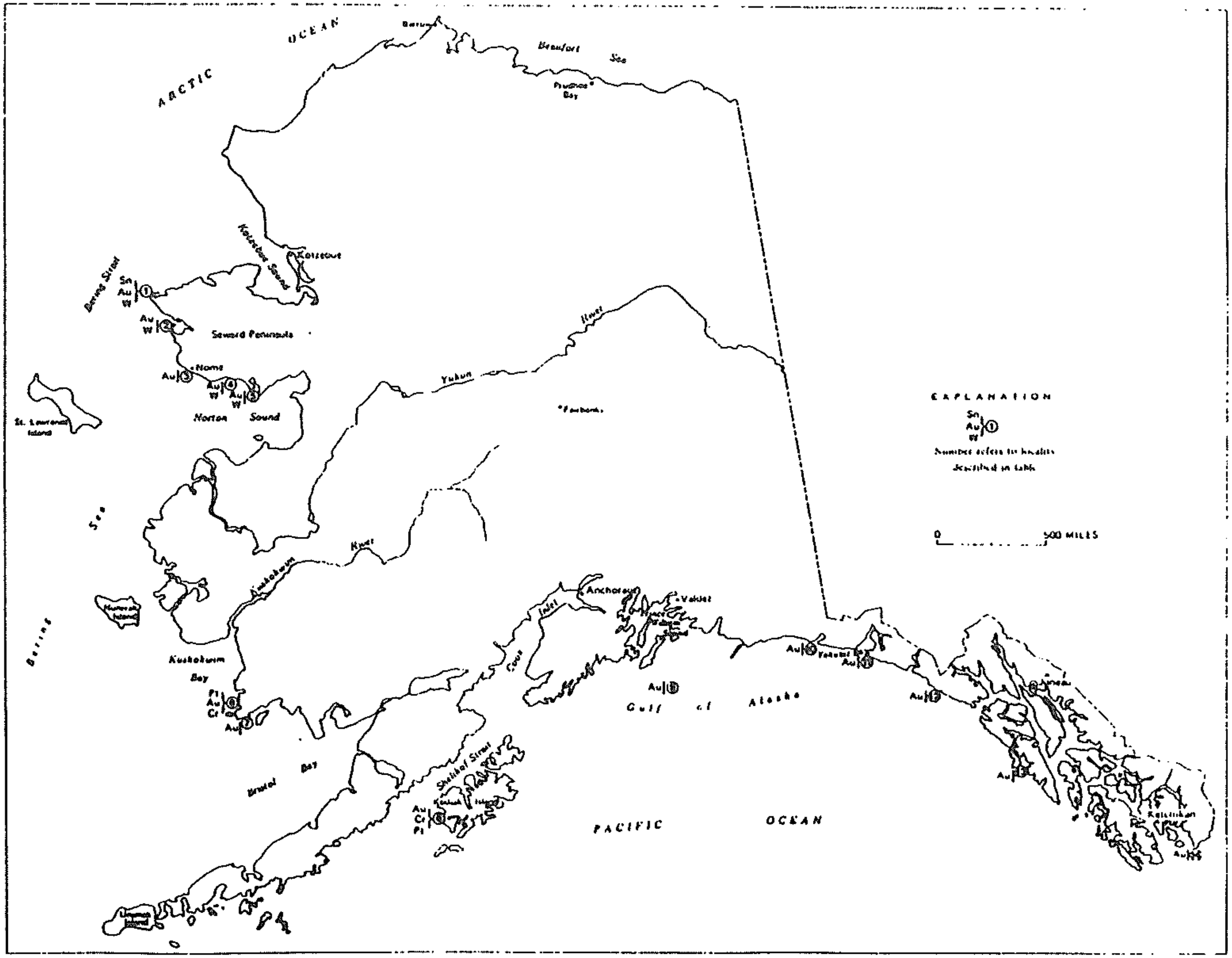

FIGURE A1. - Location map of reported placers offshore Alaska.

TABLE A1. - Distribution of known offshore placer areas, Alaska

(see figure 1 for deposit locations)

Map no.	Locality	Minerals present	Description	References
1	Cape Prince of Wales	Sn, Au, W(?)	High energy tin placers along a north-trending reef and on beaches. Mineral concentrations probably extend further offshore. Total tin production (1902-67) from nearby onshore placers is about 4 million lb.	Lu, 1968; Moore, 1979; Nelson, 1969.
2	Grantley Harbor	Au, W	High energy, shallow water placer. Minor onshore past production.	Cobb, 1981; Moore, 1979.
3	Nome Offshore Region	Au	At least three favorable paleobeach strands are offshore at water depths of 35-42 ft, 65-72 ft, and 80 ft. Deposits consist of reworked morainal material. Onshore gold production (1898-1985) is at least 5 million oz. Offshore dredging initiated by IMI in August 1986.	Bundtzen 1972; Lu, 1969; Harris, 1968; Nelson, 1969.
4	Bluff-Solomon Offshore	Au	Coarse-grained gold in high energy beach and near-shore placers.	Cobb, 1981; Lu, 1968; Moore, 1979; Nelson, 1969.
5	Golovin Lagoon	Au, W(?)	Surficial gold in lag deposits overlying high energy placers. No reported production.	Lu, 1968; Moore, 1979; Nelson, 1969.
6	Goodnews Bay	Pt, Au, Cr	Possibly economic concentrations of platinum and gold in offshore sands. Significant concentrations of chromium associated with platinum placers. Favorable environments include paleofluvial channels, paleo-strand lines, and tidal ridges. Hypothetical sub-economic resources in offshore placers are estimated to be 5 million oz. Offshore sampling by the Bureau is in progress. Total onshore production of PGM (1927-81) from Goodnews Bay District is about 650,000 oz.	Bond, 1982; Owen, 1975; Ulrich, 1984; Welkie, 1976; Zelenka, 1986; Barker, 1986; Berryhill, 1963; Cook, 1969; Coonrad, 1978.
7	Hagemeister Strait	Au	Reported minor beach placers. Production unknown.	Capps, 1937; Cobb, 1973; Smith, ____.
8	Kodiak Island Beaches	Au, Cr, Pt	Reported past production of less than 8,000 oz Au from west coast beaches.	Capps, 1937, Cobb, 1972, 197 Gassaway, 1935; Maddren, 191
9	Middleton Island	Au	Reported production of a few thousand ounces of gold.	Cobb, 1972; Moore, 1979; Nelson, 1969.
10	Yakataga District	Au	High and low energy placers. Production of about 15,000 oz Au from beaches.	Cobb, 1972, 1984; Reimnitz, 1970; Renshaw, 1978; Reimnitz, 1976; Thomas, ____.
11,12	Lituya and Yakutat District	Au	Past production of less than 4,000 oz Au.	Cobb, 1972, 1984; Reimnitz, 1970; Rossman, 1957; Reimnitz, 1976; Thomas, ____; Wright, 1969.
13	Kutchuma Islands	Au	Reported coarse-grained gold in high energy placers overlain by fine-grained sediments.	Moore, 1979.
14	Cape Fox	Au	Reported high and low energy placers.	Moore, 1979.