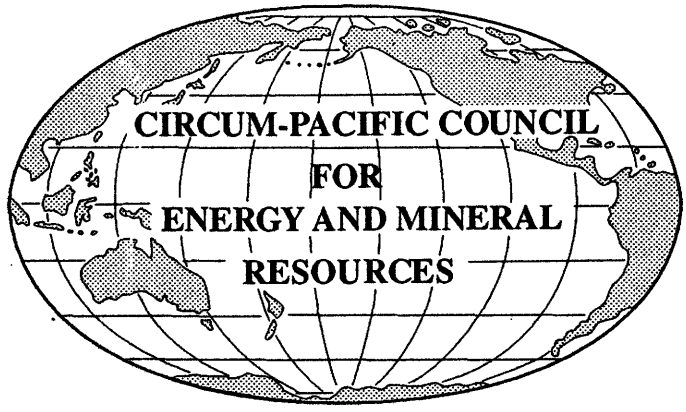
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

TO ACCOMPANY MAP CP-47

EXPLANATORY NOTES FOR THE MINERAL-RESOURCES MAP OF THE CIRCUM-PACIFIC REGION ANTARCTIC SHEET

1:10,000,000



1998

CIRCUM-PACIFIC COUNCIL FOR ENERGY AND MINERAL RESOURCES
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CIRCUM-PACIFIC MAP PROJECT
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EXPLANATORY NOTES FOR THE MINERAL-RESOURCES MAP OF THE CIRCUM-PACIFIC REGION ANTARCTIC SHEET

1:10,000,000

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1998

Explanatory Notes to Supplement the

MINERAL-RESOURCES MAP OF THE CIRCUM-PACIFIC REGION ANTARCTIC SHEET

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INTRODUCTION

By
George Gryc

CIRCUM-PACIFIC MAP PROJECT

The Circum-Pacific Map Project is a cooperative international effort designed to show the relation of known energy and mineral resources to the major geologic features of the Pacific Basin and surrounding continental areas. Available geologic, mineral-resource, and energy-resource data are being integrated with new project-developed data sets such as magnetic lineations, seafloor mineral deposits, and seafloor sediment. Earth scientists representing some 180 organizations from more than 40 Pacific-region countries are involved in this work.

Six overlapping equal-area regional maps at a scale of 1:10,000,000 form the cartographic base for the project: the four Circum-Pacific quadrants (northwest, southwest, southeast, and northeast), and the Antarctic and Arctic regions. There is also a Pacific Basin sheet at a scale of 1:17,000,000. Published map series include the base (published from 1977 to 1989), the geographic (published from 1977 to 1990), the plate-tectonic (published from 1981 to 1992), and the geodynamic (published from 1984 to 1990); all of them include seven map sheets. Thematic map series in the process of completing publication include geologic (publication initiated in 1983), tectonic (publication initiated in 1991), energy-resources (publication initiated in 1986), and mineral-resources (publication initiated in 1984). Altogether, 57 map sheets are planned. The maps are prepared cooperatively by the Circum-Pacific Council for Energy and Mineral Resources and the U.S. Geological Survey. Maps published prior to mid-1990 are available from Dr. H. Gary Greene, Circum-Pacific Council for Energy and Mineral Resources, Moss Landing Marine Laboratory, MLML, Box 450, Moss Landing, CA 95039–0450, U.S.A.; maps published from mid-1990 onward are available from the U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225, U.S.A.

The Circum-Pacific Map Project is organized under six panels of geoscientists representing national earth-science organizations, universities, and natural-resource companies. The regional panels correspond to the basic map areas. Current panel chairs are Tomoyuki Moritani (northwest quadrant), R. W. Johnson (southwest quadrant), Ian W. D. Dalziel (Antarctic region), vacant (southeast quadrant), Kenneth J. Drummond (northeast quadrant), and George W. Moore (Arctic region). Jose Corvalán D., chaired the Southeast Quadrant Panel from its inception in 1974 and the Panel completed compilations of all of the eight topical maps of that quadrant before his death in 1996.

Project coordination and final cartography are being carried out through the cooperation of the U.S. Geological Survey under the direction of Map Project General Chair George Gryc of Menlo Park, California. Project headquarters are located at 345 Middlefield Road, MS 952, Menlo Park, California 94025, U.S.A. The project has been overseen from its inception by John A. Reinemund, director of the project since 1982.

The framework for the Circum-Pacific Map Project was developed in 1973 by a specially convened group of 12 North American geoscientists meeting in California. Philip W. Guild, deceased, was one of the original group of scientists who developed the framework of the Circum-Pacific maps and was largely responsible for the format and explanatory symbols for the mineral resource series. The project was officially launched at the First Circum-Pacific Conference on Energy and Mineral Resources, held in Honolulu, Hawaii, in August 1974. Sponsors of the conference were the American Association of Petroleum Geologists (AAPG), Pacific Science Association (PSA), and the Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP). The Circum-Pacific Map Project operates as an activity of the Circum-Pacific Council for Energy and Mineral Resources, a nonprofit organization that promotes cooperation among Circum-Pacific countries in the study of energy and mineral resources of the Pacific basin. Founded by Michel T. Halbouty in 1972, the Council also sponsors quadrennial conferences, topical symposia, scientific training seminars, and the Earth Science Series of publications.

Published thematic maps of the Antarctic sheet include the plate-tectonic map (Craddock, 1981), the geodynamic map (Craddock, 1985), and the geologic map (Craddock, 1989). The tectonic map is now in cartographic preparation at CPMP headquarters in Menlo Park, California.

MINERAL-RESOURCES MAP SERIES

The mineral-resources map series is designed to be as factual as possible, with a minimum of interpretation. The small scale, 100 km/cm or 10,000 km^2/cm^2 (about 160 miles per inch or 25,000 square miles per square inch), requires an enormous simplification of both the background information and the mineral-deposit data; hence, the maps can only give a general impression of the distribution, character, and geologic environment of these resources. Nevertheless, this map series provides a unified overview of the mineral resources of a region encompassing more than half the globe. It should identify areas broadly favorable for the occurrence of specific minerals and thus assist both in resource assessment and, with additional data from more detailed sources, in exploration planning. The maps also serve to show the relation of deposits to major earth features, such as divergent and convergent plate margins, hotspots, and accreted terranes, and thus should stimulate

analysis of the role of geologic processes in the genesis of ores.

The maps show both land and seafloor deposits of most metallic and nonmetallic minerals, except for construction materials. Uranium and thorium are included, although their principal use is for energy production. Deposits on land are shown regardless of their status of exploration, and some deposits may have been totally exhausted. The maps do not, therefore, necessarily represent the present resource picture. In general, only deposits of economic size and grade are shown, but some small or low-grade occurrences have been included, where space permits, in order to indicate a resource potential. Deposits on land are shown by colored symbols outlined in black that are explained in detail on the maps.

Because most seafloor deposits have not been evaluated for their economic potential, the criterion for their inclusion on the maps is simply knowledge of their existence. Reported occurrences of nearshore heavy minerals (placer deposits) are indicated by chemical symbols (letters) in blue.

Offshore mineral resources depicted are: (1) manganese-iron oxide nodules that contain varying amounts of nickel, copper, and cobalt, and trace amounts of other metals; (2) sulfide deposits; and (3) phosphatic deposits. No attempt has been made to show the distribution of metalliferous sediments which are known to be widespread but are so low in grade that they are not considered to be resources at the present time (Field and others, 1981).

Mineral-resource information for the land and nearshore areas is assembled by members of the individual quadrant panels; compilers, contributors, and data sources are cited on the maps themselves. Information on the offshore resources has been assembled for the entire ocean area of the project principally by geologists of the U.S. Geological Survey.

The geologic features on the mineral-resources maps are taken from the corresponding geologic maps, but are in general simplified and in part modified to emphasize features that may be significant in explaining the distribution of the mineral deposits. Although the project aims at a uniform presentation throughout the Circum-Pacific region, differences among the compilers in interpretation of its geologic evolution may result in some variation in the representation of the background information of land areas from map to map. Similarly, the method of representing land-based mineral deposits varies somewhat to reflect the views of the compilers.

The only exception is Antarctica, where no economically minable deposits are known; the criteria for inclusion on that map have been relaxed to show mineral occurrences without regard to their size (shown on the map as small) or grade.

Bathymetry and the nature of surficial sediment constitute the background for the oceanic areas. The 4 types of surficial sediment shown are simplified from the 13 categories shown in the geologic map series. Active plate boundaries are taken from the plate-tectonic maps, but spreading axes are depicted as lines of uniform width rather than by varying widths reflecting spreading rates.

MINERAL-RESOURCES MAP OF THE ANTARCTIC SHEET

The Mineral-Resources Map of the Circum-Pacific Region Antarctic Sheet is the fourth published in a series of six overlapping 1:10,000,000-scale mineral resources maps. The Mineral-Resources Map of the Circum-Pacific Region Northeast Quadrant (Drummond) was published in 1985, the Mineral-Resources Map of the Circum-Pacific Region Southwest Quadrant (Palfreyman) in 1996, and the Mineral-Resources Map of the Circum-Pacific Region Southeast Quadrant (Corvalán) also in 1996.

Data depicted on this map include a generalized geologic background and minerals distribution according to the main metal or mineral content, type, age, and size of each individual deposit. Compilation was made from many published and unpublished national geologic and metallogenic maps at various scales. The data were first plotted at 1:1,000,000 scale, then transferred to 1:5,000,000 scale, and finally to 1:10,000,000 scale.

Compilation of this map involved work and contributions from many individuals and organizations. Philip W. Guild, as adviser to the mineral-resources map series since the inception of the project, took the lead in the selection of map elements, units, and symbology, especially for land resources. David Z. Piper and Theresa R. Swint-Iki were responsible for most of the compilation and analysis of seafloor mineral data; Philip W. Guild and Michael P. Lee for compilation of land mineral data in Antarctica.

RESOURCE SYMBOLS

Because mineral resources vary widely in their characteristics, the symbols that represent the deposits have been designed to impart as much information as possible at the map scale. Although the map explanations give the details, a brief discussion of the system may be helpful to the reader.

LAND RESOURCES

The legend for the land mineral resources has been modified and simplified from that used for the Preliminary Metallogenic Map of North America (North American Metallogenic Map Committee, 1981) and described by Guild (1981), with later revisions to deposit symbology for the Mineral-Resources Map of the Circum-Pacific Region Southwest Quadrant (Guild, 1988). The map symbols show the metal or mineral content of the deposits by colored geomet-

ric shapes. The colors, insofar as possible, show metals or minerals of similar type or geologic occurrence: precious metals or gems are yellow, copper and associated metals are orange, chromium, nickel, cobalt, platinum, and asbestos, all commonly found in mafic or ultramafic rocks, are green, and so forth. The 5 shapes and 10 colors indicated on the legend of the map provide for 50 combinations. Not all symbols are used on every map.

Three sizes of symbols denote the relative importance of the deposits. Limits between the size categories for each commodity are, for the most part, in terms of metric tons of the substance(s) contained before exploitation. These limits are obviously arbitrary; they have been selected on the basis of the worldwide abundance of the commodity concerned in deposits that are exploitable under current economic and technological conditions.

One or more ticks on the symbol indicate the general nature of the deposit. Two schemes have been used here, since the southeast quadrant uses eight types of deposit, and the Antarctic and southwest quadrant regions use eleven types. Most of the eight deposit types are distinctive, but the category designated "stockworks, including 'porphyry' deposits" encompasses such disparate types as sulfur in the cap rock of salt domes, manto deposits, and porphyry deposits, so that judgement must be used in interpreting this symbol. The ticks have been omitted on many of the small symbols either because of ignorance of deposit type or because it was felt unnecessary to identify all of them where they occur in clusters of deposits of the same kind. Some deposits shown as "small" on this map correspond only to occurrences; they have been included because they may help to identify areas broadly favorable for exploration planning of specific minerals.

A description of the eleven-deposit-type scheme used for the Antarctic sheet and the overlap area (26° to 60°S) of the southwest quadrant map is as follows:

Stratiform. Deposits more or less rigorously confined to one or more layers in stratified (sedimentary or volcanic) rocks. Some are of great lateral extent in relation to thickness. May be layered (banded). Usually syngenetic with enclosing rocks. Examples: evaporites, phosphorites, iron formations. Most "massive sulfide" deposits belong here.

Stratabound. Deposits, generally of limited horizontal extent, that occur at more or less the same horizon in stratified rocks. May be partly concordant, partly discordant with enclosing rocks. Usually considered to be epigenetic. Examples: carbonate-hosted (Mississippi Valley) base-metal deposits, sandstone ("red bed") copper deposits, uranium deposits of Colorado Plateau, Wyoming Basin, and so forth.

Vein or shear-zone filling. Crosscutting, epigenetic deposits in any type of host rock. The major dimensions are transverse to stratification in sedimentary or volcanic hosts. Most stockworks fit here; some in igneous hosts are better equated with the irregular disseminated deposits.

Manto. Deposits that combine stratabound and crosscutting features. Characteristically, one or several ore horizons (of replacement origin?) are underlain and/or joined by vein or stockwork ore shoots. Examples: Leadville and Gilman, Colorado, lead-zinc-silver; Santa Eulalia, and Chihuahua, Mexico, lead-zinc-silver; La Encantada, and others in Mexico;

Skarn. Contact-metamorphic (tactite) deposits. Stratified, usually carbonate, rocks intruded by intermediate to acid igneous rock.

"Porphyry" deposits. Irregular disseminated deposits, in or associated with intrusive igneous rocks. Parts of some have been described as stockworks. Hydrothermal alteration, including greisenization,common.

Magmatic (irregular massive) deposits; includes pegmatites. Examples: podiform chromite, some magnetite and magnetite-ilmenite deposits.

Magmatic cumulate deposits. Concordant in layered, generally mafic or ultramafic igneous rocks. Examples: stratiform chromite, ilmenite, platinum-group metals of Bushveld type; certain nickel-sulfide (komatiite-hosted) deposits.

Pipe. includes breccia pipe. Essentially a two-dimensional deposit with long axis vertical (crosscutting) Examples: diamondiferous kimberlite, diapir-related (salt dome) sulfur.

Surficial chemical concentration. Includes laterite, bauxite, uraniferous calcrete, and some manganese oxide deposits. The criterion is that supergene processes were responsible for producing ore-grade material.

Surficial mechanical concentration (placer) deposits. Includes "fossil" black sands.

A description of the eight-deposit-type scheme used for the southeast quadrant map (map overlap region of South America from 26°to 60°S on this map) is as follows:

Veins and shear-zone fillings. Crosscutting, epigenetic deposits in any type of host rock. The major dimensions are transverse to stratification in sedimentary or volcanic hosts. Most stockworks fit here; some in igneous hosts are better equated with the irregular disseminated deposits.

Stratabound, including magmatic cumulates. Deposits, generally of limited horizontal extent, that occur at more or less the same horizon in stratified rocks. May be partly concordant, partly discordant with enclosing rocks. Usually considered to be epigenetic. Examples: carbonate-hosted (Mississippi Valley) base-metal deposits, sandstone ("red bed") copper deposits, uranium deposits of Colorado Plateau, Wyoming Basin, and so forth. Magmatic cumulates are concordant in layered, generally mafic or ultramafic igneous rocks. Examples: stratiform chromite, ilmenite, platinum-group metals of Bushveld type; certain nickel-sulfide (komatiite-hosted) deposits.

Stockworks, including "porphyry" deposits. Irregular disseminated deposits, in or associated with intrusive igneous rocks. Parts of some have been described as stockworks. Hydrothermal alteration, including greisenization, common.

Magmatic and irregular massive deposits; includes pegmatites. Examples: podiform chromite, some magnetite and magnetite-ilmenite deposits.

Skarn or greisen deposits. Contact-metamorphic (tactite) deposits. Stratified, usually carbonate, rocks intruded by intermediate to acid igneous rock.

Sandstone (red bed) deposits

Laterite deposits (surficial chemical concentrations). Includes laterite, bauxite, uraniferous calcrete, and some manganese oxide deposits. The criterion is that supergene processes were responsible for producing ore-grade material.

Placer deposits (surficial mechanical concentrations). Includes "fossil" black sands.

Mineralization ages for most deposits are indicated by double ticks placed according to a clockwise order from older to younger. Where a tick to indicate the deposit type already occurs in the required position, a single tick for age is added and the two must be read together. Different age categories have been used for the southwest quadrant overlap, as compared to the categories used for the Antarctic sheet and the southeast quadrant overlap. These categories are shown on the map explanation.

Space limitations on the map do not permit identifying by name all the deposits shown, but many of the larger ones are named, especially in relatively open areas.

SEAFLOOR RESOURCES

The potential value of manganese nodules depends on their abundance and composition. Abundance data have been derived principally from seafloor photographs, typical examples of which are reproduced in the explanation of the map. Nodule coverage of the sea floor ranges from 0 to nearly 100 percent. On the map, squares 2 mm on a side, empty to totally filled in black, indicate graphically where bottom photographs have been taken and the abundance of nodules at these points. Additional information on the occurrence of nodules was gained from core sampling; small black x's and o's indicate where nodules have been recovered or not recovered, respectively, in cores. Details of the methods used in studying these data sources and in deriving abundance contours are described later.

The composition of analyzed nodules is indicated within certain limits by different colored +'s for ranges of nickel plus copper content and by brown +'s for those with high manganese. Composition of analyzed manganese crusts is indicated by colored asterisk for range of cobalt content (Manheim and Lane-Bostwick, 1989).

The polymetallic sulfide deposits thus far discovered on the spreading ridges are shown by black semicircles.

Seafloor phosphorite occurrences are depicted by brown horizontal lozenges without an outline. Although this symbol is approximately as large as that used for the medium-sized land deposit, it has no size or grade significance. The many "guano-type" phosphate deposits on oceanic islands so small that the symbol obscures them entirely are distinguished by having a black outline and the tick indicating a surficial chemical concentration.

LAND RESOURCES

By
Michael P. Lee

The geologic background shown on the mineral-resources map has been simplified from the Geologic Map of the Circum-Pacific Region Antarctic Sheet (Craddock, 1989). A chief difference from the geologic map is the use of color and pattern to denote structural state (unfolded, deformed, or strongly metamorphosed) and depositional environment of the stratified rocks rather than geologic age; igneous rocks are differentiated by color and pattern. However, letter symbols from the geologic map keyed to the correlation diagram indicate ages in most areas, and time divisions are used for older and younger Precambrian rocks and, by implication, for surficial deposits (late Cenozoic). The description of map units from the Geologic Map of the Circum-Pacific Region Antarctic Sheet (Craddock, 1989) for Antarctica, adjacent islands, and Scotia arc, is listed below.

Quaternary (Q)

Glacigenic sedimentary deposits and undifferentiated volcanic rocks. Occur in Transantarctic Mountains, under Ross Ice Shelf, and in South Shetland Islands off northern Antarctic Peninsula. Glacigenic sedimentary deposits lie along some valley walls in the Dominion Range, and they were recovered from a borehole in the southern Ross Ice Shelf. Quaternary volcanic rocks make up a part of southeastern King George Island and Deception Island (an active volcano) off the coast of Graham Land, in the Bransfield Strait south of Livingston Island.

Cenozoic (Cz)

Undifferentiated volcanic rocks, mainly basaltic, locally with interbedded volcanigenic sedimentary rocks. Occur in East Antarctica, Balleny Islands, Transantarctic Mountains, coastal West Antarctica,

Antarctic Peninsula, and Scotia arc. Active volcanoes known in northern Victoria Land, Ross Island, Marie Byrd Land, northern Antarctic Peninsula, and South Sandwich Islands.

Neogene (Tn)

Glacigenic sedimentary deposits in Transantarctic Mountains, and undifferentiated volcanic rocks of coastal West Antarctica area. The sedimentary deposits lie along some valley walls in the Dominion Range. The volcanic rocks make up Peter I Island, north of the Eights Coast.

Tertiary (T)

Undifferentiated volcanic rocks of the Antarctic Peninsula area. Found on Alexander Island and Brabant Island.

Tertiary-Jurassic (TJ)

Intrusive igneous rocks of the Antarctic Peninsula and adjacent islands. These gabbroic-granitic plutons make up the Andean Intrusive Suite.

Paleogene (Tp)

Mainly marine sedimentary rocks of the northern Antarctic Peninsula area. Found on Seymour Island, south of Snow Hill Island off Graham Land, as abundantly fossiliferous Paleocene and Eocene strata.

Tertiary-Cretaceous (TK)

Undifferentiated volcanic rocks of the northern Antarctic Peninsula area. Mafic extrusive volcanic rocks occur on King George Island in the South Shetland Islands.

Mesozoic (Mz)

Intrusive and extrusive igneous rocks in West Antarctica. Felsic plutons in the Whitmore Mountains and small ranges and nunataks to the east; probably Jurassic in age. Undifferentiated plutons of Pine Island Bay and the Eights Coast. Undifferentiated volcanic rocks of the Jones Mountains and Thurston Island.

Mesozoic-Paleozoic (MzPz)

Sedimentary rocks of Transantarctic Mountains and adjacent East Antarctica; volcanic rocks of West Antarctica; sedimentary, metasedimentary, and mafic extrusive rocks of Antarctic Peninsula area; and metasedimentary rocks of Scotia arc. Includes widespread continental and marine, Devonian-Triassic, subhorizontal, locally fossiliferous, sedimentary rocks (Gondwana sequence) of Transantarctic Mountains and western Queen Maud Land; calc-alkaline metavolcanic rocks of Ruppert Coast; diverse sedimentary, metasedimentary, and mafic extrusive rocks which form a deformed basement complex in much of the Antarctic Peninsula, Alexander Island, and the South Shetland Islands; and metasedimentary rocks of South Orkney Islands.

Cretaceous (K)

Intrusive and extrusive igneous rocks of Marie Byrd Land, and intrusive igneous and sedimentary rocks of the Antarctic Peninsula area. Includes felsic plutons in western Marie Byrd Land; undifferentiated volcanic rocks of the Hobbs Coast; undifferentiated plutons in the Executive Committee Range, on the Bakutis Coast, in eastern Ellsworth Land, and in Palmer Land; and marine sedimentary rocks on islands near the northeast end of the Antarctic Peninsula.

Cretaceous-Jurassic (KJ)

Volcanic and sedimentary rocks of the Antarctic Peninsula area and the Scotia arc. Calc-alkaline rocks of the Antarctic Peninsula Volcanic Group occur on the peninsula, adjacent islands, and the South Shetland Islands; some extrusive rocks now known to be Paleogene in age. Sedimentary rocks of Alexander Island and the South Orkney Islands. Felsic to intermediate volcaniclastic strata and basaltic volcanic rocks with mafic intrusions of South Georgia Island.

Jurassic (J)

Mafic extrusive and intrusive igneous rocks of Transantarctic Mountains and adjacent East Antarctica; sedimentary and extrusive igneous rocks of the southern Antarctic Peninsula area. Includes basaltic volcanic rocks, with dikes and sills, at many localities between Thiel Mountains and northern Victoria Land, and on George V Coast; Dufek Massif (layered gabbro complex) in Pensacola Mountains; basaltic volcanic rocks and mafic dikes in western Queen Maud Land; undifferentiated volcanic rocks and marine and continental sedimentary rocks of eastern Ellsworth Land and Palmer Land.

Triassic (Ŕ)

Sedimentary and intrusive and extrusive igneous rocks of East Antarctica, and sedimentary rocks of south Livingston Island, Antarctic Peninsula area. Includes intrusive igneous and sedimentary rocks of George V Coast; Triassic(?) mafic volcanic rocks of western Queen Maud Land; sedimentary rocks with plant fossils on Livingston Island, South Shetland Islands.

Late Paleozoic (Pz_2)

Sedimentary rocks in East Antarctica; intrusive igneous rocks in Transantarctic Mountains; sedimentary

rocks in interior and coastal West Antarctica; and intrusive igneous rocks in coastal West Antarctica. Includes clastic sedimentary rocks near Amery Ice Shelf and in western Queen Maud Land; generally felsic intrusive igneous rocks of Admiralty Mountains (Devonian) of northern Victoria Land; marine sedimentary rocks of Ellsworth Mountains, and one outcrop of plant-bearing sedimentary rocks in eastern Ellsworth Land; felsic igneous plutons of western Marie Byrd Land, and undifferentiated igneous plutons of the Hobbs Coast.

Early Paleozoic (Pz_1)

Intrusive and extrusive igneous rocks, sedimentary rocks, and metamorphic rocks of Transantarctic Mountains; sedimentary and volcanic rocks of Ellsworth Mountains; and meta-igneous rocks of coastal West Antarctica. Includes many plutons, mostly felsic, undifferentiated volcanic rocks, and diverse sedimentary rocks, locally metamorphosed—widely distributed in the Transantarctic Mountains between northern Victoria Land and the Shackleton Range; undifferentiated volcanic rocks and continental(?) and marine sedimentary rocks, slightly metamorphosed, in the southern Ellsworth Mountains; and metamorphosed gabbroic rocks of the Hobbs Coast.

Paleozoic (Pz)

Intrusive igneous rocks of East Antarctica; metamorphic rocks of coastal West Antarctica, and sedimentary and intrusive igneous rocks of interior West Antarctica. Includes many igneous plutons, mainly felsic, along Ingrid Christensen Coast, in Prince Charles Mountains, and in Queen Maud Land; metamorphic rocks in the Amundsen Sea area, and metamorphic and undifferentiated intrusive igneous rocks of Thurston Island; sedimentary rocks, mainly clastic and locally slightly metamorphosed, in the Whitmore Mountains and ranges and nunataks to the north and east (in the Hart Hills, sedimentary rocks are intruded by a body of metagabbro).

Early Paleozoic-Proterozoic (Pz_1P_3)

Metasedimentary rocks of East Antarctica; sedimentary rocks, intrusive and extrusive igneous rocks, and metamorphic rocks of Transantarctic Mountains; and sedimentary and metamorphic rocks of West Antarctica. Includes low-grade metasedimentary rocks of western and eastern Wilkes Land, locally with possible microfossils; felsic plutons and diverse sedimentary and volcanic rocks, locally metamorphosed, from northern Victoria Land to Ohio Range; clastic sedimentary rocks and metamorphic complex of western Marie Byrd Land; and sedimentary rocks cut by small Cretaceous pluton in eastern Marie Byrd Land.

Proterozoic (P)

Sedimentary rocks, intrusive and extrusive igneous rocks, and metamorphic rocks of East Antarctica; sedimentary, extrusive igneous, and metamorphic rocks of the Transantarctic Mountains; metasedimentary and metamorphic rocks of interior West Antarctica; and metamorphic rocks of coastal west Antarctica. Includes sedimentary and mafic volcanic rocks of western Queen Maud Land, felsic plutons of Ingrid Christensen Coast and Queen Maud Land, mafic plutons of Queen Maud Land, and widely distributed metamorphic rocks of coastal East Antarctica; undifferentiated extrusive igneous rocks, diverse sedimentary rocks, and metamorphic rocks from Churchill Mountains to Horlick Mountains; sedimentary and metasedimentary rocks from Thiel Mountains to Shackleton Range; felsic extrusive igneous rocks of Luitpold Coast; metasedimentary rocks of interior West Antarctica; metamorphic rocks of southern Ellsworth Land; and gneiss of central Marie Byrd Land.

Archean (A)

Metamorphic and intrusive igneous rocks of East Antarctica. Includes medium- to high-grade metamorphic complexes of Ingrid Christensen Coast, Prince Charles Mountains, and Enderby Land; felsic intrusions of Napier Mountains, Tange Promontory, and possibly of western Queen Maud Land.

These explanatory notes have been designed to be used in conjunction with and as a complement to the Mineral-Resources Map of the Circum-Pacific region, Antarctic Sheet. Its chief purpose is to identify the mineral occurrences in Antarctica and to give certain information on their commodities and geographic locations. None of the mineral occurrences reported is currently considered economically exploitable now or in the foreseeable future.

The Antarctic mineral-resources map depicts 67 mineral occurrences in Antarctica, representing 21 metallic and non-metallic mineral commodities (see table 1). This information was first compiled for the Circum-Pacific Map Project in 1983 and was based on a review of other Antarctic mineral resource compilations available at the time. In subsequent years, the 1983 compilation was examined periodically, and some additions and revisions were made. As noted in table 1, the principal sources used to prepare this map were earlier compilations made by Wright and Williams (1974), Rowley and Pride (1982), Vieira and others (1982), and Farrar and others (1982), and Rowley and others (1991). Although there have been modest increases in information about the economic geology of Antarctic mineral resources, the actual number of reported mineral occurrences on the continent has remained relatively fixed.

Finally, to aid in the use of the map, it would be helpful to provide some general background on the geology of Antarctica. Geologically, Antarctica consists of two major provinces. East Antarctica is a Precambrian shield of igneous and metamorphic rocks and overlain in part by relatively undeformed sedimentary strata. West Antarctica is for the most part characterized by younger, locally highly deformed and metamorphosed strata that are intruded by igneous rocks; the Ellsworth Mountains are, however, a displaced terrane of the East Antarctic margin within West Antarctica. Association of the geology with reported mineral occurrences has lead to the identification of three Antarctic metallogenic provinces (see figure 1), each with a different geologic history, tectonic framework, and mineral resource potential: the East Antarctic iron metallogenic province; the Transantarctic metallogenic province; and the Andean metallogenic province.

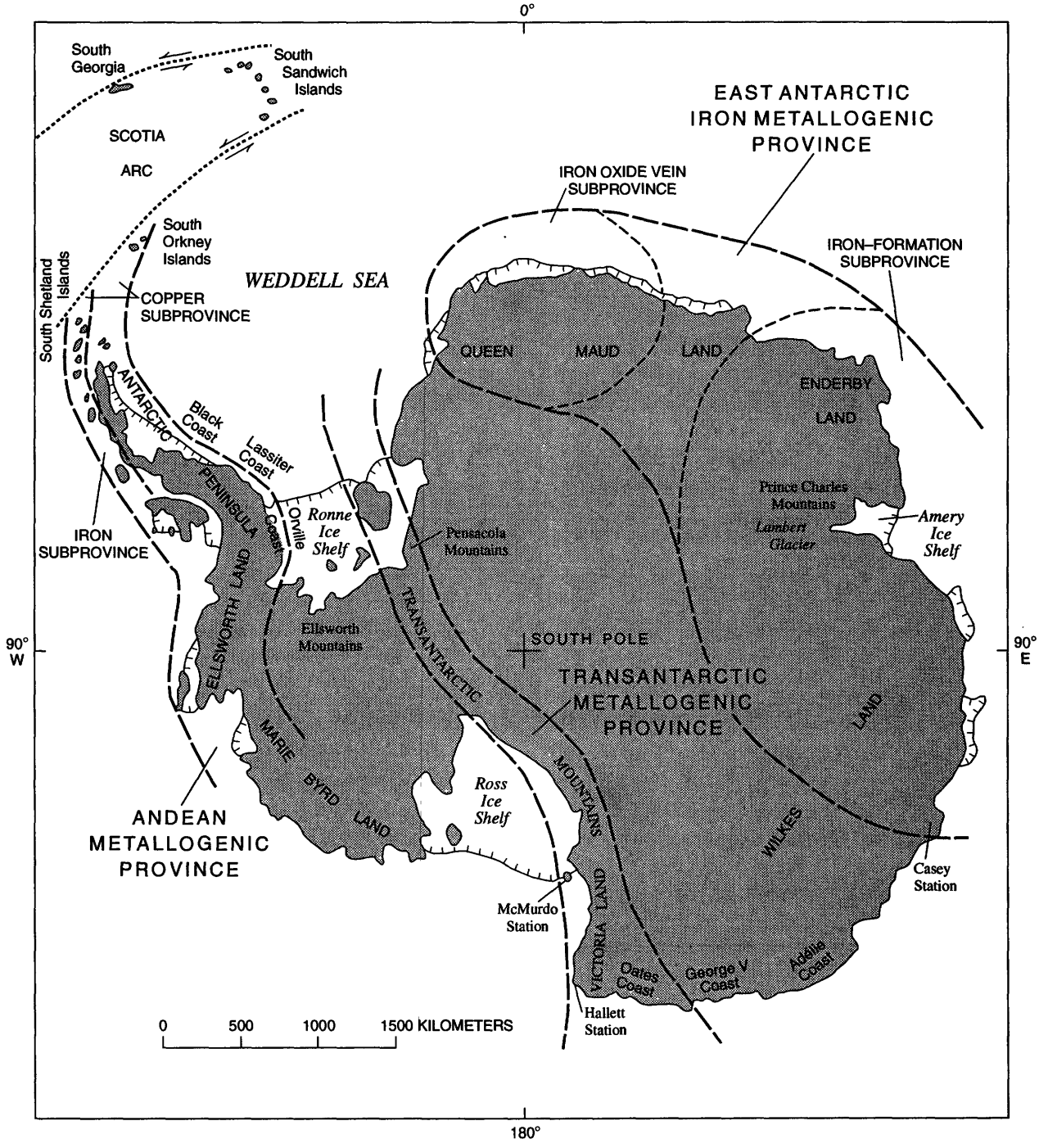

Figure 1. Metallogenic provinces of Antarctica.

EAST ANTARCTIC IRON METALLOGENIC PROVINCE

The Precambrian shield complex of East Antarctica is a fragment of Gondwanaland that broke up during the Jurassic period, about 250 million years ago. In other parts of the world, the Precambrian shield has proven to be a major source of minerals such as iron ore, gold, chromite, nickel, and copper. In Antarctica, reported mineral occurrences include principally iron ore as well as molybdenum, copper, gold, silver, and uranium. The iron formations occur as magnetite (banded iron formation), disseminated to nearly pure, in a number of localities from Enderby Land to Wilkes Land and in Queen Maud Land around igneous intrusions. Most of the other reported mineral occurrences are associated with pegmatite dikes.

TRANSANTARCTIC METALLOGENIC PROVINCE

The Transantarctic metallogenic province is coincident with the Transantarctic Mountains. This province is the raised Pacific edge of the Precambrian shield complex containing a thick layer of later marine and continental sediments and igneous rocks of Proterozoic to Paleozoic age. The principal reported mineral occurrence is the Dufek intrusion, a stratiform mafic body of Middle Jurassic age containing platinum-group elements, chromite, nickel, and cobalt. Other reported mineral occurrences include base and precious metals associated with silicic intrusions.

ANDEAN METALLOGENIC PROVINCE

The rocks of the Antarctic Peninsula are generally regarded as part of the circum-Pacific Andean orogenic belt. Most of the rocks in the region are stocks and batholiths of Mesozoic and Tertiary age. Reported mineral occurrences include ferrous, base, and precious metals in hydrothermal and porphyry-type deposits.

LIMITATIONS TO THE COMPILATION

Unlike the other maps in the Circum-Pacific mineral-resources map series, the Antarctic sheet depicts principally *mineral occurrences* as opposed to *mineral deposits (or districts)*. Despite decades of geologic inquiry, knowledge of Antarctica geology, including economic geology, is limited in comparison to similar areas of the world. Only about 2 percent (260,000 km^2) of Antarctica's 13.5 million km^2 has exposed geology. The paucity of mineral exploration data have thus made it difficult to characterize and estimate the mineral resource potential (see Singer and Mosier (1981) for additional discussion of mineral-resource assessment techniques) of Antarctica. Notable exceptions might be the Dufek intrusion (No. 31), the banded iron formations in East Antarctica (No. 40), and some Andean-type base metal porphyry deposits (No. 10). However, economic and engineering considerations at the present time diminish the value of these potential resources. Accordingly, the mineral occurrences that have been identified on the Antarctic continent should be regarded as geologic resources in the broadest of terms and not potential sources of supply (for additional information on mineral resource classification systems, refer to Brobst and Pratt (1973) or Schanz (1980)). It should be noted, though, that the wide distribution of mineral resources across the known pieces of Gond-wanaland implies their probable existence, by analogy, within the least known piece–Antarctica (Craddock, 1990).

MINERAL OCCURRENCE LISTINGS

The numbers shown on the map in Antarctica are keyed to mineral occurrence/deposit names listed in Table 1 to permit cross-referencing between the map and the table. Table 1 also identifies the approximate latitude and longitude of the mineral occurrence, expressed in degrees and minutes. Finally, the table identifies the commodities reported to be present; however, no distinctions should be drawn about the relative abundance of a particular commodity in a deposit based on the order in which it is reported.

Five classes of metals and minerals have been identified in the Antarctic region on the Antarctic mineral resources map, as listed in the following tables.

SEAFLOOR RESOURCES

Seafloor deposits shown on the map include ferromanganese nodules, hydrothermal sulfide deposits, phosphorites, and the occurrence of heavy-mineral sand. The information available on sulfide deposits, phosphorites, and heavy-mineral sands is so limited as to preclude estimating abundance; we have merely denoted their locations. Greatest attention has been devoted to the abundance of and metal content of nodules.

Nodule abundance (seafloor coverage) at discrete locations has been ascertained from seafloor photographs and sediment cores. The nickel, copper, cobalt, and manganese contents of nodules in many of the core samples and in dredge samples have also been shown, rather than their iron content or other minor element composition. The aim of this section is to explain the procedures used to display these data.

Ferromanganese crust, recovered by dredging, are also shown on the map. No attempt is made to show all dredge sites. They are divided into groups, based their elemental contents (Lane and others, 1986; Manheim and Lane-Bostwick, 1989). Infor-

mation on the occurrence of ferromanganese crust in the region of the Antarctic sheet is still extremely sparse.

SEAFLOOR SEDIMENT

By
Floyd W. McCoy

Seafloor sediment is classified in four categories by its dominant component: (1) calcareous debris (calcareous ooze/clay or marl), (2) biosiliceous material (biosiliceous ooze/mud/clay), (3) terrigenous clastics (gravel/sand/silt), and (4) clays (including pelagic clay). These four sediment types are generalized from the 13-category classification scheme used to depict surficial deposits on the various Circum-Pacific geologic quadrant maps, a scheme defining 30-60 percent boundaries for sediment nomenclature following that devised by Murray and Renard (1891). On the Antarctic region mineral-resources map, a stippled pattern is superimposed where coarse-grained particles (gravel, sand or coarse-silt sizes) form greater than 15 percent of the sediment (for example, silty or sandy clay, volcanic gravel/sand/silt; calcareous gravel/sand/silt, or biosiliceous silt).

Sedimentary components were identified and abundances estimated via smear-slide analyses of core-top deposits in piston and gravity cores archived at the Lamont-Doherty Earth Observatory. Quantitative control came from analyses of $CaCO_3$ on selected samples. Additional smear-slide and $CaCO_3$ data came from published and unpublished sources. These data formed a primary data base for plotting sediment distributions. A secondary data base was constructed from general sediment descriptions in the literature that lacked quantitative component and $CaCO_3$ information; this information was used to estimate the geographic extent of distribution patterns. Information from Deep Sea Drilling Project (DSDP) samples were not incorporated because rotary drilling techniques do not recover undisturbed seafloor sediment. Data available at the time of map compilation from Ocean Drilling Program (ODP) sampling by hydraulic piston corers were incorporated. For clastic debris, the Wentworth grade scale was used. Constraints, problems, and assumptions in establishing these data bases and using them for mapping are discussed in the various explanatory notes booklets that accompany each Geologic quadrant map.

For simplification on the Antarctic mineral-resources map, stations where surficial sediment was sampled or identification of sediment criteria derived from primary/secondary data bases are not shown; refer to the Antarctic geologic map for this information (Craddock, 1989).

Mapping boundaries of sediment types were controlled by bathymetry, regional water depth of the calcite compensation depth, proximity to land (including knowledge of local geology), documented seafloor sedimentation processes, and the deposits left by this activity, as well as oceanographic/biologic phenomena.

This map depicts unconsolidated sediment recovered primarily by coring and presumably exposed on the ocean floor at the sediment/water interface. This sediment is not necessarily of Holocene age, nor is it necessarily the result of Holocene sedimentary processes.

FERROMANGANESE NODULES

By
David Z. Piper and Theresa R. Swint-Iki

Nodules, consisting mainly of manganese and iron oxides, were first recovered from the Pacific Ocean by HMS *Challenger* during its voyage from 1872 to 1876 (Murray and Renard, 1891). They were most frequently recovered from abyssal depths where the bottom sediment is composed of red clay. Analyses of samples collected during that cruise, as well as of many samples collected subsequently, showed contents of nickel, copper, and cobalt in the range of a few tenths of one percent to about three percent. Interest in mining these deposits developed following a series of papers by Mero (1959, 1965) who called attention to the feasibility of their commercial recovery. McKelvey and others (1983) suggested that molybdenum, vanadium, and several of the rare earth elements might also be recoverable as by-products of possible future extractions of nickel, copper, and cobalt. These elements, as well as titanium, zinc, barium, lead, strontium, and yttrium, are present in the nodules in the range of ≤ 0.01 to nearly 0.1 percent (McKelvey and others, 1983).

Mero (1965) outlined the features of the geographic distribution of nodules in the Pacific Ocean and the regional variations in their composition. More recent studies include those by Cronan and Tooms (1969), Piper and Williamson (1977), and Calvert (1978), and still others are reported in the compendia of Glasby(1976), Bischoff and Piper (1979), and Sorem and Fewkes (1979). Other efforts to delineate the distribution of nodules on maps include those of Ewing and others (1971), Frazer and others (1972), Cronan (1977; 1980), Rawson and Ryan (1978), and McKelvey and others (1979, 1983).

These maps suggest that nodule occurrence and composition in the Pacific Ocean exhibit a rather uniform distribution over areas as great as several thousand square kilometers. Both parameters, however, show uneven variations on the scale of a few tens of square meters. For example, nodule coverage at individual stations in the northeast quadrant, at which we had as many as 550 bottom photographs, in the area at lat 10°N and long 150°W, ranges from 0 to greater than 75 percent. Photographs were taken at this station as the ship drifted at a distance of only about 1.5 km. Such variability (patchiness) makes it

extremely difficult to estimate seafloor coverage on any scale, and particularly at the scale of this map. All maps showing the distribution of abundance and metal content at such scales have, therefore, a significant degree of uncertainty. Individual data points of nodule abundance and metal content are shown on the map by sets of symbols in order to permit evaluation of the procedures used in the contouring, which are explained below.

Ideally, nodule abundance should be expressed in mass per unit area; for example, kilograms per square meter. Such data, however, are sparse and the abundance is therefore shown in terms of percentage of the sea floor covered. No attempt is made to convert seafloor coverage to mass per unit area for three reasons. (1) Photographs may underestimate the seafloor coverage by as much as 25 percent, because nodules often are partially covered by a layer of "fluffy" sediment 5 to 15 mm thick (Felix, 1980). The degree to which they are covered is likely to vary between areas with different seafloor environments and with different nodule morphologies; it varies considerably even between box cores from a single relatively small area. (2) No simple relation exists between nodule cross-sectional area and nodule volume; nodule shapes vary from roughly spherical to strongly discoidal (Sorem and Fewkes, 1979). (3) Photographs are taken with the camera nearly on the bottom to as much as several meters above the bottom, thus making it impossible to ascertain accurately from the photographs the nodule size.

Nodules are identified on the bottom photographs as dark and roughly equidimensional objects, with the entire population having a distribution strongly peaked in the size range of 1 to 12 cm in diameter. Angular objects and sub-rounded objects, often several tens of centimeters across, are identified as rock debris. In most cases, the difference between nodules and rocks is clear. Three people examined all photographs; still, some errors in identification may have occurred.

Seafloor coverage of nodules was determined by comparing each photograph with templates showing a light background covered to varying degrees by black objects. The upper limit of 100 percent represents an arrangement of closest packing. The average coverage for all photographs at any one station was plotted as a single point. The number of photographs at a single station ranges from 1 to 850, although for most stations it is between 5 and 15.

Data from sediment cores (including box, gravity, and piston cores) supplement the photographic data. Core stations are plotted merely as recovering or not recovering nodules. Although the core sizes vary from a half meter on a side (box cores) to 2.5-cm diameter (gravity cores), integrating these measurements with the photographic data was achieved in the following way.

Areas of varying seafloor coverage of nodules were delineated initially by using only the data obtained from the seafloor photography. A contour of one percent was drawn to exclude areas in which photo stations recorded zero coverage. Several sediment cores recovered nodules in these areas, but the coverage outside this contour is certainly less than 1 percent and probably less than 0.1 percent. The position of the one-percent contour was further defined by using the core data in two ways: (1) a nodule-bearing core was allowed in the <1-percent area only when its five nearest neighboring cores did not recover nodules, and (2) the contour was drawn to exclude all areas having at least 20 cores, of which 10 percent or fewer recovered nodules. In most areas as large as 12,000 km^2, cores recovering nodules average less than 1 percent of the total number of cores.

The second step was to draw the 50-percent contours to include both photographic stations of greater than 50 percent coverage and areas where recovery of nodules was greater than 75 percent.

The 10-percent contours were then drawn. This contour enclosed photographic stations that showed the complete range of coverage. Emphasis was placed, however, on photographic stations that showed greater than 25 percent coverage. Some photographic stations that recorded greater than 25 percent coverage lie outside the 10-percent contour line if their nearest neighbor recorded zero percent coverage or if 4 of 5 nearest cores failed to recover a nodule.

The 25-percent contours were drawn lastly to enclose areas of high coverage, as supported by either core or photographic data.

The percentage of cores recovering nodules between the 1-percent and 10-percent contours is surprisingly high: within the northeast quadrant of the Pacific Ocean, nodule recovery varied from 8 to 70 percent and averaged 40 percent in areas containing more than 10 cores and these percentages held for the southeast quadrant. In the Antarctic, in the areas where contours define nodule coverage at 10-25 percent, nodule recovery by cores averaged 55 percent and ranged from 25 to 62 percent. For the area of 25-50 percent coverage, nodule recovery by cores averaged 64 percent and ranged from 30 to 92 percent. In the area where coverage exceeded 50 percent, nodule recovery by cores averaged 83 percent. One possible explanation for such high recoveries by cores is that we have not distinguished between box cores, which sample a relatively large surface area of the seafloor, and gravity and piston cores. Alternatively, seafloor coverage based on bottom photographs may be biased on the low side owing to sediment cover.

Dredge hauls were not used as a supplement to the photographic and core data because the area sampled by dredging generally is not accurately known.

Nodules were divided according to their chemical composition into four partly overlapping categories: (1) greater than 1.8 percent nickel plus copper, (2) 1.0 to 1.79 percent nickel plus copper, (3) greater than 35 percent manganese, and (4) less than 1.0 percent nickel plus copper (McKelvey and others, 1983). These categories are shown on the map for stations for which data were available in the Scripps Sediment Data Bank. Two areas of high seafloor coverage are delineated by the contours. One area is located in the Southwest Pacific Basin.The second area extends along the south flank

of the Pacific-Antarctic Ridge, Southeast Pacific Basin, and Drake Passage.

Nodules and crusts with high cobalt content (these include dredge material) occur in areas of elevated relief, such as the seamounts and ridges. In many areas where cobalt-rich nodules are present, encrustations of the same composition can exceed 2 cm in thickness (Manheim and Halbach, 1982). Nodules with high manganese content (>35 percent Mn) are restricted within the quadrant to the east margin of the Pacific, that is, to the area of hemipelagic sediment.

The distribution of nodules is strongly related to sediment lithology, shown on the map as a background to the nodule distribution, and to sediment accumulation rates, not shown on this map but included on a 1:17,000,000-scale map of the Pacific Basin (Piper and others, 1985). The distribution of nodules shows a strong preference for siliceous sediment and pelagic clay. That is, they tend not to occur on calcareous sediment, although the west slope of the East Pacific Rise (EPR) at lat 40° to 50°S represents an exception to this generalization. In this and other areas, however, nodules are apparently further restricted to areas exhibiting sediment accumulation rates of less than approximately 5 mm per thousand years (Piper and Swint, 1984; Piper and others, 1987).

Both nodule occurrence and sedimentation rates are likely related to deep ocean currents and in no area is this more evident than in the area around Antarctica (Piper and others, 1987). Many measurements of deep-ocean bottom currents have been made, but their usually weak intensity, and the complex seafloor bathymetry have combined to thwart attempts to evaluate quantitatively their importance as a control on sediment accumulation rates and, thus indirectly on nodule distribution, except for several rather careful studies of a few small areas (Lonsdale, 1981).

Other factors influence the rather complex patterns of sea-bottom sediment lithology. These include the supply of material to the seafloor and the secondary processes in the deep ocean that alter or redistribute that supply. The supply is controlled largely by (1) proximity to a source of alumino-silicate material and (2) primary productivity in the photic zone of the ocean. The source of silicates (clay minerals as well as coarse debris) may be local (marine volcanic activity) or terrigenous (continents contribute material via both rivers and the atmosphere). Primary productivity, on the other hand, controls the rain of biogenic detritus to the seafloor. This fraction of organics consists mostly of siliceous and calcareous tests of planktonic organisms, but contains lesser amounts of phosphatic material and organic matter from the soft parts of organisms.

Secondary processes include the dissolution of organic matter at depth in the ocean and the redistribution of sediment by deep-ocean currents. The occurrence of calcareous sediment and the depth of the sea floor show a strong relation, owing to the dissolution of $CaCO_3$ in the deep ocean. This relation can be seen along the EPR (McCoy, 1985, 1989). Calcareous mud predominates along the crest of the rise and down its flanks to a depth of approximately 4,000 to 4,500 m, at which depth it gives way to pelagic clay or siliceous sediment. The exclusion of calcareous debris from the deeper sediment is controlled by the balance between the rate of supply of $CaCO_3$ to the seafloor and its rate of dissolution. The latter increases with water depth, owing to the increase in the solubility of $CaCO_3$ with decreasing water temperature and increasing pressure.

Bottom photographs used in this study are from the Bundesanstalt für Geowissenshaften und Rohstoffe, Committee for Co-ordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas, Geological Survey of Japan, Hawaii Institute of Geophysics, Institut Français de Recherches pour l'Exploitation de la Mer, Lamont-Doherty Earth Observatory, Kennecott Exploration, Inc., National Oceanic and Atmospheric Administration, Scripps Institution of Oceanography, Smithsonian Institution, U.S. Navy Electronics Laboratory, and from published literature (Zenkevich, 1970; Andrews and Meylan, 1972; Greenslate and others, 1978). The chemical data on the nodules are from the Scripps Institution of Oceanography Sediment Data Bank.

FERROMANGANESE CRUSTS

By

Frank T. Manheim and Candice M. Lane-Bostwick

The cobalt values indicated in the map represent data normalized to a hygroscopic moisture and substrate- (detrital matter) free basis. The algorithm to obtain these values is given by Co* = Co x 51.23/(Fe+Mn), as determined in Manheim and Lane-Bostwick (1989). Samples designated as being of possible hydrothermal origin are identified by Mn/Fe > 5 and Co < 0.2 percent. Some classes of samples are excluded; data of Barnes (1967) in the Scripps Institution Nodule Data Bank, samples lacking Mn and/or Fe data, (which do not permit normalization), and samples having Mn < 5 percent. Multiple samples at one location have been averaged.

The geographical distribution of samples has been largely published in Lane and others (1986). Discussion of the significance of cobalt distributions and of the development of the U.S. Geological Survey Ferromanganese Crust Database is given in Manheim (1986) and Manheim and Lane-Bostwick (1989). The majority of the ferromanganese crust analyses are from two sources; the U.S. Geological Survey World Ocean Ferromanganese Crust Database and the Scripps Institution Nodule Data Bank. Evaluation of these data are discussed in Manheim and Lane-Bostwick (1989). These and other sources are described in Manheim and Lane-Bostwick (1989).

POLYMETALLIC SULFIDES

By
Theresa R. Swint-Iki

The initial discovery of warm-water springs rising from mounds of hydrothermal sediment at the Galapagos spreading center (Corliss, 1971; Weiss and others, 1977) and sulfide deposits forming at active high-temperature discharge sites at 21°N on the East Pacific Rise (EPR) (Spiess and others, 1980) confirmed that hydrothermal circulation at seafloor-spreading axes leads to the precipitation of metal -sulfides from hydrothermal fluids strongly enriched in sulfide and metals (von Damm and others, 1985). Several types of deposits (metal oxides and sulfides) form directly or indirectly from this hydrothermal activity at divergent plate boundaries.

The thermal balance in oceanic crust along spreading axes is considered to be dominated by hydrothermal circulation and advective cooling because conductive heat-flow measurements taken along ridge crests consistently show lower than expected values (Lister, 1972; Sleep and Wolery, 1978). Models of hydrothermal processes in oceanic crust developed by Lister (1977, 1982), Sleep and Wolery (1978), Edmond and others (1979), Fehn and Cathles (1979), Bischoff (1980), and Fehn and others (1983) are largely based on investigations of seafloor-spreading axes in the northeast quadrant of the Pacific.

Since the initial observations of hydrothermal activity along the Galapagos spreading center and segments along the EPR, polymetallic sulfides have been found in back-arc basins where seafloor spreading occurs above subduction zones along convergent plate boundaries. The occurrence of metal-enriched sediment (Fe, Mn, Cu, Zn, As, Ag, and Au) is also indicative of hydrothermal activity in regions of back-arc basins (Cronan, 1989). Evidence of hydrothermal mineralization and their locations in the Antarctic region have been located in three areas and are shown on this map (Rona and Scott, 1993).

Massive sulfide chimneys occur within the axial zone of the EPR at lat 26°12.3'S, long 112°36.8' W (Marchig and Grundlach, 1987). At Macdonald Seamount, a seafloor volcano at an intraplate volcanic center, metalliferous sediment occurs in the summit crater at lat 28°59'S, long 140°15'E (Cheminee and others, 1991). Hydrothermally altered sediments are reported in the region of the Antarctic Peninsula, in the Bransfield Strait basin, at lat 63°S, long 60°W (Brault and Simmoneit, 1987).

Much further work is required to evaluate the extent and composition of known seafloor polymetallic sulfide deposits along spreading centers at divergent plate boundaries, in backarc basins, and at intraplate volcanic centers, to evaluate possible future economic potential of polymetallic sulfide deposits, and to explore for new deposits.

PHOSPHORITES AND PHOSPHATIZED ROCKS

By
David Z. Piper and Theresa R. Swint-Iki

Submarine phosphate deposits consist of rock encrustations, nodules, and pellets. Occurrences in the on the continental shelf of western Tasmania (Noakesand Jones, 1975), on the upper continental slope off northern New South Wales, Australia between lat 30° and 40°S at depths between 210 and 385 m (von der Borch, 1970), on the continental shelf of western Australia, and on Pacific seamounts at variable depths. None of the seamount deposits of the deep ocean are considered to be of commercial interest.

An area of high phosphorite coverage is located east of New Zealand along the crest of Chatham Rise at depths of 250 to 500 m. Reserves of phosphorite in a 378 km^2 area along Chatham Rise are estimated at 25 million tons. The phosphorite in this area averages 22 percent P_2O_5 (Kudrass, 1984). Estimated total reserves of phosphorite are 100 million tons for the region along the crest of Chatham Rise between long 179°E and 180° (Cullen, 1989). Guano deposits are located on many Pacific Ocean islands. They represented a major resource in the last century.

The Chatham Rise region may be of interest, as New Zealand's source of phosphorite from Nauru and Christmas Islands (not on this map sheet) are depleted.

HEAVY-MINERAL DEPOSITS

By
Gretchen Luepke

Submerged beaches and river channels are favorable sites in the marine environment for the occurrence of concentrations of heavy minerals (placers) such as gold, platinum, chromite, rutile (TiO_2) and ilmenite ($FeTiO_3$). Beginning with the formation of the great ice sheets during the Quaternary, sea level has repeatedly fallen and risen more than 200 m. As a result of sea-level fluctuation, fossil beaches are found both above and below present sea level.

The shelf of Antarctica has not been explored for offshore placer deposits. Thick prograding sediment packages were deposited on the Antarctic continental shelf during the late Oligocene to late Miocene (Anderson, 1991), and buried placers could exist within them. However, no significant concentrations of precious metals have been publicly recorded in Antarctica, but scattered occurrences of gold have been found; the Dufek layered intrusion near the base of the Antarctic Peninsula may contain significant quantities of platinum-group metals (Rowley and others, 1991). It is unknown if these deposits are extensive enough to have served as sources for placers.

In Australia, onshore placers containing high concentrations of rutile and zircon are mined in Quaternary coastal sediment of southeast Queensland. Continental shelf sediments along the coast of eastern Australia were surveyed for placers in 1980 (von Stackelberg, 1982). The shelf sediment sampled between Newcastle and Fraser Island contains lower concentrations of heavy minerals (0.1-1.6 percent) than onshore deposits (Riech and others, 1982; Jones and others, 1982). An extensive deposit of garnet in dune sands occurs at Port Gregory, Western Australia (Harben and Bates, 1990).

On the North Island of New Zealand, titaniferous magnetite has been mined from onshore marine deposits at Taharoa (Stokes and others, 1989) and Waikato North Head, providing over 2 million tons per year for making steel (Minehan, 1989). At Auckland and New Plymouth, offshore sands with greater than 15 percent titanomagnetite were identified in 1968. Other heavy-mineral deposits have been found in Whangaroa Harbour (mercury in cinnabar [HgS]; Foveaux Strait (tin in alluvial cassiterite [SnO_2]); and 10 km off Hokitika (Ag) (Utting, 1989). No offshore mining has yet occurred in New Zealand; all of the above deposits must be examined in more detail to determine the feasibility of exploiting them.

In Chile, gold placers, associated with magnetite, ilmenite, zircon, garnet, and in some places monazite, occur on the west coast of Isla de Chiloe near Pumillahue and Cucao (Fuller, 1965) and also on Isla Ipun. Gold placers of glaciofluvial origin occur on islands, including Islas Picton, Nueva, Lennox, and Navarino, south of the Beagle Canal in Tierra del Fuego (Fuller, 1965). Because of the narrow shelf along most of the west coast of South America, offshore marine placers will probably be rare.

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Table 1. Reported mineral occurrence in Antarctica

Map number	Name	Latitude	Longitude	Commodities	Reference
1	Sky-Hi Nunataks	74°55'S	71°20'W	CuPbZnFe	Rowley and Pride 1982
2	Merrick Mountains	75°05'S	72°10'W	Cu	Rowley and Vennum 1988
3	Alexander Island	71°30'S	69°45'W	FeS	Rowley and Pride 1982
4	Marquerite Bay vicinity	68°30'S	67°30'W	FeCu	Rowley and Pride 1982
5	Adelaide Island and others	67°45'S	69°15'W	FeMo	Rowley and Pride 1982
6	Terra Firma Islands	69°00'S	68°30'W	CuFe	Rowley and Pride 1982
7	Marquerite Bay Islands	69°15'S	69°30'W	AuAgMo	Rowley and Pride 1982
8	Stonington Island	68°11'S	67°00'W	AuAgMoMg	Wright and Williams 1974
9	Biscoe Island	66°30'S	67°00'W	FeS	Rowley and Pride 1982
10	Central Lassiter Coast (Moats Nunataks)	74°22'S	65°00'W	CuPbMo	Rowley and Pride 1982
11	Argentine Island	65°00'S	65°00'W	Fe	Rowley and Pride 1982
12	Eternity Range	70°34'S	62°15'W	AuAg	Wright and Williams 1974
13	Oscar II Coast	65°45'S	63°00'W	CuFe	Rowley and Pride 1982
14	Northern Graham Coast	65°00'S	64°30'W	Cu	Rowley and Pride 1982
15	LeMaire Channel-Gerlache Strait area			CuMo	Vieira and others 1982
16	Central-Southern Danco Coast	64°45'S	63°15'W	FeSZn	Rowley and Pride 1982
17	Copper Peak (Anvers Island)	64°43'S	63°21'W	Cu	Wright and Williams 1974
18	Brabant Island	64°15'S	62°20'W	FeS	Rowley and Pride 1982
19	Low Island			FeS	Rowley and others 1991
20	Eielson Peninsula (Cape Eielson-Cape Boggs)	70°35'S	61°45'W	CuMoFeAuAg	Farrar and others 1982
21	Northern Danco Coast	64°00'S	61°00'W	FeS	Rowley and Pride 1982
22	Bransfield Strait area			CuPbZn	
23	Deception Island	62°57'S	60°38'W	S	Rowley and others 1991
24	Livingston Island	62°36'S	60°30'W	CuPbZn	Rowley and Pride 1982
25	Duse Bay-Larsen Inlet			Cu	Rowley and Pride 1982
27	Coppermine Cove (Robert Island)	62°23'S	59°42'W	FeS	Rowley and Pride 1982
28	King George Island	62°10'S	58°25'W	FeS	Rowley and Pride 1982
29	Central Neptune Range	83°50'S	57°09'W	P	Wright and Williams 1974
30	ne Trinity Peninsula	64°00'S	58°30'W	Cu	Rowley and Pride 1982
31	Dufek Massif	82°36'S	52°30'W	CrNiCoPt	Wright and Williams 1974
32	Aspland and Gibbs Island	61°30'S	55°49'W	CrNiCo	Rowley and Pride 1982
33	Forrestal Range	83°00'S	49°30'W	FeTiV	Wright and Williams 1974
34	Coronation Island			PbZnAg	Rowley and Pride 1982
35	Belliggshausen Island	59°25'S	27°05'W	S[1]	Rowley and others 1991
36	Montagu Island	58°25'S	26°20'W	Cu	Rowley and others 1991
37	Zavodovski Island	56°20'S	27°35'W	S[1]	Rowley and Pride 1982
38	Ahlman Ridge			CuFePb	Rowley and others 1991
39	Gburek Peaks	72°11'S	00°15'E	FeTi	Wright and Williams 1974
40	Sverdrup Mountains			Fe	Rowley and others 1991
41	Mt. Hedden	72°05'S	01°22'E	Fe	Wright and Williams 1974
42	Marble Nunataks	71°22'S	07°35'E	SPS[2]	Wright and Williams 1974
43	Titov Mountains	71°58'S	10°52'E	SPS	Wright and Williams 1974
44	Mt. Humbolt	71°45'S	11°30'E	Fe	Wright and Williams 1974
45	Mt. Nikolaev	71°58'S	12°23'E	Fe	Wright and Williams 1974
46	Lutzow-Holm Bay area	69°38'S	38°18'E	U RE[3]	Wright and Williams 1974
47	Amundsen Bay area	66°55'S	50°00'E	Fe	Rowley and others 1991
48	Knuckey Peaks			Fe	Rowley and others 1991
49	Mt. Cook			Fe	Rowley and others 1991
50	Mt. Ruker	73°38'S	64°45'E	Fe	Wright and Williams 1974
51	Mt. Stinear			Fe	Rowley and others 1991

Table 1. Reported mineral occurrence in Antarctica–Continued

Map number	Name	Latitude	Longitude	Commodities	Reference
52	Larsemann Hills	69°23'S	70°13'E	Fe	Wright and Williams 1974
53	Vestfold Hills	68°33'S	72°15'E	Fe	Wright and Williams 1974
54	Mirnyy Station vicinity	69°20'S	72°34'E	Mo	Wright and Williams 1974
55	Bunger Hills	66°17'S	100°47'E	FeAsMo	Wright and Williams 1974
56	Clark Peninsula	66°15'S	110°33'E	MnFe	Wright and Williams 1974
57	Cape Denison	67°00'S	142°42'E	AsZnMo	Wright and Williams 1974
58	Ainsworth Bay	67°47'S	146°43'E	Mo	Wright and Williams 1974
59	Horn Bluff	68°29'S	149°46'E	Sn[4]	Wright andWilliams 1974
60	Darwin Glacier vicinity			U Th RE	Rowley and others 1991
61	Terra Nova Bay			Sn	Rowley and others 1991
62	Beardmore Glacier area	83°45'S	171°00'E	P	Barrett 1969
63	Mount Erebus			S[1]	Rowley and others 1991
64	Copper Cove		170°00'E	Cu	Rowley and others 1991
65	Rockefeller Mountains	78°00'S	155°00'W	SPS	Rowley and others 1991
66	Haines Mountains			PbFe	Rowley and others 1991
67	Scott Coast			F	Rowley and others 1991

[1]Native
[2]Semi-precious stones
[3]Rare earth minerals
[4]Placer

Ferrous Metals (Iron and its Alloying Metals)

Map number	Name	Latitude	Longitude	Commodities
3	Alexander Island	71°30'S	71°20'W	FeS
4	Marquerite Bay vicinity	68°30'S	67°30'W	FeCu
5	Adelaide Island and others	67°45'S	69°15'W	FeMo
9	Biscoe Island	66°30'S	67°00'W	FeS
11	Argentine Island	65°00'S	65°00'W	Fe
16	Central-Southern Danco Coast	64°45'S	63°15'W	FeSZn
18	Brabant Island	64°15'S	62°20'W	FeS
19	Low Island			FeS
21	Northern Danco Coast	64°00'S	61°00'W	FeS
27	Coppermine Cove	62°23'S	59°42'W	FeS
28	King George Island	62°10'S	58°25'W	FeS
31	Dufek Massif	82°36'S	52°30'W	CrNiCoPt
32	Aspland and Gibbs Island	61°30'S	55°49'W	CrNiCo
33	Forrestal Range	83°00'S	49°30'W	FeTiV
39	Gburek Peaks	72°11'S	00°15'E	FeTi
40	Sverdrup Mountains			Fe
41	Mt. Hedden	72°05'S	01°22'E	Fe
44	Mt. Humbolt	71°45'S	11°30'E	Fe
45	Mt. Nikolaev	71°58'S	12°23'E	Fe
47	Amundsen Bay area	66°55'S	50°00'E	Fe
48	Knuckey Peaks			Fe
49	Mt. Cook			Fe
50	Mt. Ruker	73°38'S	64°45'E	Fe
51	Mt. Stinear			Fe
52	Larsemann Hills	69°23'S	70°13'E	Fe
53	Vestfold Hills	68°33'S	72°15'E	Fe
54	Mirnyy Station vicinity	69°20'S	72°34'E	Mo
56	Clark Peninsula	66°15'S	110°33'E	Mn
58	Ainsworth Bay	67°47'S	146°43'E	Mo

Table 1. Reported mineral occurrence in Antarctica–Continued

Base Metals

Map number	Name	Latitude	Longitude	Commodities
1	Sky-Hi Nunataks	74°55'S	71°20'W	CuPbZnFe
2	Merrick Mountains	75°05'S	72°10'W	Cu
6	Terra Firma Islands	69°00'S	68°30'W	CuFe
10	Central Lassiter Coast	74°22'S	65°00'W	CuPbMo
13	Oscar II Coast	65°45'S	63°00'W	CuFe
14	Northern Graham Coast	65°00'S	64°30'W	Cu
15	LeMaire Channel-Gerlache Strait area			CuMo
17	Copper Peak	64°43'S	63°21'W	Cu
20	Eielson Peninsula	70°35'S	61°45'W	CuMoFe
25	Duse Bay-Larsen Inlet			Cu
26	Greenwich Island	62°31'S	59°47'W	Cu
30	ne Trinity Peninsula	64°00'S	58°30'W	Cu
34	Coronation Island			PbZnAg
36	Montagu Island	58°25'S	26°20'W	Cu
38	Ahlman Ridge			CuFePb
59	Horn Bluff	68°29'S	149°46'E	Sn
61	Terra Nova Bay			Sn
64	Copper Cove		170°00'E	Cu
66	Haines Mountains			PbFe

Precious Metals

Map number	Name	Latitude	Longitude	Commodities
7	Marquerite Bay Islands	69°15'S	69°30'W	AuAgMo
8	Stonington Island	68°11'S	67°00'W	AuAgMoMg
12	Eternity Range	70°34'S	62°15'W	AuAg
31	Dufek Massif	82°36'S	52°30'W	CrNiCoPt
55	Bunger Hills	66°17'S	100°47'E	As
57	Cape Denison	67°00'S	142°42'E	AsZn

Nuclear Fuels

Map number	Name	Latitude	Longitude	Commodities
46	Lutzow-Holm Bay area	69°38'S	38°18'E	U RE
60	Darwin Glacier vicinity			U Th RE

Non-Metallic Minerals

Map number	Name	Latitude	Longitude	Commodities
23	Deception Island	62°57'S	60°38'W	S
29	Central Neptune Range	83°50'S	57°09'W	P
35	Belliggshausen Island	59°25'S	27°05'W	S
37	Zavodovski Island	56°20'S	27°35'W	S
42	Marble Nunataks	71°22'S	07°35'E	SPS
43	Titov Mountains	71°58'S	10°52'E	SPS
62	Beardmore Glacier area	83°45'S	171°00'E	P
63	Mt. Erebus			S
65	Rockefeller Mountains	78°00'S	155°00'W	SPS

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