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ATLAS OF METAL AND NONMETAL MINERAL PROVINCES CONTERMINOUS U. S.
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TOOKER AND CORNWALL- NICKEL

Planimetric Base from National Atlas 1:7 500 000, 1970

SCALE 1:5 000 000
100 0 100 200 300 400 500 MILES
100 0 100 200 300 400 500 600 700 KILOMETRES

PRELIMINARY MAP OF NICKEL PROVINCES IN THE CONTERMINOUS UNITED STATES

BY

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Introduction

The the map shows that the United States presently has limited domestic sources of minable nickel, which is a vital component of steel and other alloys. Apparent domestic consumption of nickel in 1975, the base year used in the atlas (Tooker, 1979), was about 196,000 short tons (178,000 tonnes), an amount valued at that time at more than $750 million (U.S. Bur. Mines, 1979). Domestic deposits accounted for less than 2 percent of world mine production but supplied about 11 percent of the primary (new mined) nickel consumed in the United States. Most of the nation's industrial needs (72 percent) that year were met through imported material mined mainly in Canada; the remainder was derived largely from secondary production by recycling (U.S. Bur. Mines, 1976). Nickel is an essential strategic and industrial commodity because it provides both strength and corrosion resistance for metal alloys across a broad thermal range. Substitutes for it can be used but with consequent increased cost and a reduction in performance characteristics. Most important, however, is the fact that such substitutes are often also critical commodities. Although present and future economically available domestic supplies are limited, domestic production may be increased through the use of geologically available lower grade and presently subeconomic resources. Mining and refining such ores will be more energy intensive and undoubtedly will require additional expensive environmental land restoration following mining.

Official projections by Corrick (1976) indicate that consumption in the United States will more than double by the year 2,000. The options for achieving these added supplies are: (1) a continued reliance on imports, always subject to political and economic availability constraints; (2) the development of more effective conservation methods such as recycling and recovering now-wasted byproduct nickel from the mining of other commodities; (3) the use of deep sea resources whose availability and quantity are still uncertain (Pasho and McIntosh, 1976); and (4) a development of domestic possibilities for primary, coproduct, and (or) byproduct nickel resources. The potential of domestic nickel resources is the chief subject addressed by the nickel province map, which shows the location of known deposits and occurrences of nickel and provides a preliminary estimate of the anticipated potential resources for each province.

The map was compiled from published and unpublished reports (Albers, written commun., 1979; Beal, 1964; Bentley and Mowat, 1970; Cornwall, 1966, 1973; Cornwall and Burbank, 1952; Cornwall, Vhay, and Frendzel, 1968; Hotz, 1964, 1966, 1969; Maine Geological Survey, 1956; Moore, 1969; Neuschel and McKnight, 1948; Osterwald, Osterwald, Long, and Wilson, 1966; Pearre 1948, 1961; Pearre and Calkins, 1957; Pierce, 1944; Schwartz and Prokopovich, 1956; Vhay, 1964, 1966; Weber, 1965). We are particularly grateful for the constructive advice of M. P. Foose during the preparation of this summary. Geologic information used on the map is from the geologic map of the United States (King and Beikman, 1974). The rationale of province maps and some of the unfamiliar technical terms and geologic concepts used in the atlas of some metal and nonmetal provinces, of which this is a part, are discussed and defined in a companion background report by Tooker (1979).

Distinguishing map features

The province map summarizes current information about the location, size, and distribution of known nickel deposits and occurrences. The map is designed to help narrow the search for domestic nickel resources to regions or provinces that may be geologically favorable for nickel concentrations well above its average in rocks of the Earth's crust. A province (short dashed boundary) represents a region containing small groups or a cluster of nickel deposits and occurrences that were formed in similar geologic environments. For some areas, more than one concentration event may have occurred during geologic time, resulting in overlap of geologic environments within the province. The localities may represent either primary or byproduct sources; some currently are economic, most are subeconomic. Where possible the boundaries are drawn on the basis of geologic units, with the result that some provinces may consist of a number of detached outlying areas. For example, a boundary may enclose a region containing a group of ultramafic rock bodies or a large mafic rock complex that in due time was laterized. In the absence of prominent mappable geologic features, province boundaries are drawn about concentrations of localities. Where more than one geologic environment is associated with nickel concentrations in a region, the province is subdivided. Less well known geological territories that contain widely dispersed nickel localities have in some cases tentatively been called provinces. The dispersion of localities in such provinces may prove to be the result of a natural geologic distribution or result from an insufficient systematic assessment of nickel in an area. A number of additional solitary localities are also present on the map; they do not seem to fall into a regional geologic pattern at present and may represent only isolated occurrences of the metal.

Nickel is considered the fifth most plentiful element of the Earth, but most of it is concentrated in interior parts. The geologic environments favorable for concentrating significant amounts of nickel in crustal rocks of the Earth are those associated with the formation of intrusive mafic and ultramafic rocks, the segregation of nickel-bearing sulfide minerals within mafic rocks, and (or) much later, the weathering of nickel-rich ultramafic rocks to form nickel-rich soils or laterite. These geologic environments seem to have produced distinctive types of deposits in the two types of crustal rock--the border oceanic-island arc crust and interior old continent type crust (Tooker, 1979).

Near the surface, nickel is most abundant as a constituent in ultramafic rocks (dunite, peridotite, and pyroxenite), where it averages 0.12 percent, and in mafic rocks (diorite, gabbro, and norite), where it average 0.016 percent (Vinogradov, 1956; Cornwall, 1973). Where preserved on erosion surfaces, nickel oxides or hydrosilicates that are residual concentrations from the lateritic (tropical) surface weathering of these types of rock may be a source of nickel. Major production has come from such deposits in Russia, New Caledonia, and Cuba (Corrick, 1976). Subeconomic examples also occur in the conterminous United States.

The large production from Canada and Australia (and a large subeconomic potential in the United States) comprises nickel sulfides that were concentrated during the intrusion of mafic and ultramafic bodies as massive layered, or disseminated sheetlike (stratiform) segregations and related veins. Smaller intrusives and comparable volcanogenic (extrusive) lenticular bodies may also contain segregations of nickel sulfide minerals. The metal has been concentrated to a lesser extent by hydrothermal solutions in silicate, iron oxide, sulfide, iron sulfide, and sulfarsenide minerals (Cornwall, 1973, table 86) that are associated with mafic to intermediate igneous rocks in veins, breccia fillings, and small irregular masses. The nickel commonly is a byproduct associate of base and precious metals and cobalt.

The old continent crust seems to be the host for the few known large stratiform nickel sulfide segregations in ultramafic and mafic intrusives. These are discrete geologic bodies, widely and irregularly spaced in Precambrian terranes. The intrusives are of Precambrian age and undoubtedly were emplaced along existing zones of crustal weakness. Precambrian terranes also contain base-metal massive sulfide-type occurrences of presumed volcanogenic origin that locally were enriched in nickel. Along the outer rim of the old continent plate, and locally within it (e.g., Missouri), are scattered sites of complex hydrothermal vein and breccia-filling deposits that may or may not be visibly associated with intrusive rocks. These are limited sources of nickel that may occur both in Precambrian basement and in Phanerozoic cover rocks.

Oceanic-island arc crust, which formed gradually by the addition (accretion) of rock materials along an unstable, active, deeply faulted zone at the edge of the old continent plate, was the site where mantle-derived mafic and ultramafic rocks were emplaced during Phanerozoic time. The main nickel concentrations are contained in sulfide mineral segregations or disseminations that occur in small discontinuous podlike or lens-shaped intrusives, only some of which contain nickel concentrations, and in irregular small massive sulfide bodies of volcanogenic origin. The mafic host rocks are alined in sinuous north-trending zones parallel with the long-continuing fault structures (subduction zones). These deposits are of Phanerozoic age.

Disseminated nickel in sedimentary rocks is often associated with manganese oxides; they may occur on either crustal plates, and they probably result from remobilization and redeposition during sedimentation or by groundwater action. Laterites or saprolitic soils seem to be restricted to obducted fragments of the oceanic plate. Absence in interior areas may be the result of deep burial during weathering or complete stripping by erosion during uplift of the basement rocks.

For purposes of comparison, the deposits and occurrences shown on the map have been separated into those that are large, greater than 50,000 short tons (>45,000 tonnes) of combined production and known minable contained nickel, and those that are small or are occurrences of as yet undetermined size and quality. For reference, a large nickel deposit as defined is, at a minimum, roughly equivalent to one-fourth of one year's consumption by the United States in 1975 and was worth about $200 million. The large deposits have been subdivided into active (type A) and inactive (type B) classes in the atlas (Tooker, 1979). By definition here, type A are those nickel deposits that were significant producers in 1975, and also reported in a survey of world mining activity (Mining Mag., 1976). Type B includes mainly inactive former large productive deposits that: (1) are temporarily subeconomic but may still contain potentially minable materials, (2) are now mined out, or (3) were producing but at too low a rate to be included in this survey. A fourth type represents very large unmined, not fully appraised subeconomic, but potentially minable occurrences. All small deposits or occurrences, whether active or inactive, are grouped in type C. Many of these have not been properly assessed. Some type C deposits ultimately may be reclassified when appropriate geologic assessment studies have been completed.

Nickel provinces

The map distribution of 17 nickel provinces and the types of deposits and occurrences within them seem to be closely related to a number of geologic features in the conterminous United States, but particularly with specific parts of the oceanic and old continent crustal plates. Discussions about the nickel provinces listed in table 1 are based on their position and composition in this large scale geologic framework.

Provinces 1 through 5 in the western part of the Cordilleran belt occur mostly in oceanic crust rocks. The one domestic type A nickel deposit in the conterminous United States is located in the vicinity of Riddle, Oregon, in province 1. The province is centered on the Klamath Mountains, which span the California-Oregon boundary and contains at least the two potential type B deposits shown. The Riddle deposit is composed of nickel silicate-iron oxide laterite with nickel silicate boxworks of garnierite veins and veinlets in it and the underlying peridotite (Hotz, 1964). Other deposits and occurrences in province 1 are mostly composed of ferruginous nickeliferous lateritic soils that contain complex mineral assemblages, the result of tropical or subtropical weathering of the ultramafic rocks and serpentinites. The geologic setting in eastern Oregon, seems to resemble the Klamath Mountain province geologically in that a number of intrusive ultramafic masses occur in a somewhat comparable sedimentary sequence of rocks, however, few nickel occurrences have yet been reported, possibly because the rocks were not as intensely laterized to form residual nickel concentration. Province 2 in central California, which geologically has been considered an offset part of province 1 (W. P. Irwin, verbal commun., 1979) contains a number of small eroded remnants of a nickel silicate lateritic residuum underlain by ultramafic rocks (Hotz, 1966). Albers (1978) discusses more detailed geologic-metallogenic relationships that characterize nickel and other metals in the oceanic plate rocks in California.

Province 3, in southern California, contains disseminated and massive bodies of nickel sulfides that are associated with gabbro and peridotite intrusives (Hotz, 1966). Three main types of nickel occurrences are recognized in province 4 in northern Washington (Vhay, 1966). Subprovince 4a contains nickel in altered volcanogenic rocks associated with manganese oxides and silicates, as well as native copper. Subprovince 4b includes the iron-rich lateritic nickel occurrences that generally overlie deeply weathered mafic and ultramafic rock bodies. The occurrence of this type in the Cle Elum area is shown to have potential as a type B deposit. Subprovince 4c contains mixed occurrences types: Some seem to be closely associated with ultramafic rocks containing sulfide disseminations or segregations suggestive of an oceanic crust association; in others, nickel was concentrated along contacts of ultramafic bodies by hydrothermal solutions, or are hydrothermal occurrences that contain base metal and cobalt sulfides and sulfarsenides which generally are not associated with ultramafic rocks. This latter subgroup seems to be somewhat characteristic of nickel occurrences that occur sporadically along the transition border zone between plates and within rocks of the old continent crust. Here geologic environments of different age may overlap within a province.

In the eastern part of the Cordilleran belt, in Idaho (Province 5) and Montana (Province 6), nickel is a consistent potential byproduct of cobalt seggregations in folded metasedimentary possibly volcanogenic rocks as well as in base metal veins in a wide variety of favorable host rocks (Vhay, 1964; Bentley, and Mowat, 1967). Nickel occurs in province 7 with copper in sulfide segregations in mafic rocks and adjacent hornfels related to the stratiform Stillwater Complex of Precambrian age. It is shown potentially as of type B magnitude. In Colorado (14), Nevada (15), and Arizona (16), sulfide or sulfarsenide nickel mineral occurrences seem to occur as a byproduct of copper, lead, and zinc deposition in replacement mantos, breccia fillings, veins, and dissemination formed by hydrothermal processes (Beal, 1964; Moore, 1969, and U.S. Geol. Survey, 1968). In New Mexico and Nevada, nickel is locally also concentrated in manganese oxide deposits (Weber, 1965). Because of the wide dispersion of a sparse number of occurrences in these provinces, a dotted line boundary is shown pending more detailed assessment of the location and extent of nickel concentration in the areas.

The Precambrian shield in Minnesota (Province 8) contains pods, veinlets, and disseminations of nickel sulfides as a potential coproduct with copper sulfides in the lower parts of the Duluth complex, a composite mafic intrusive (Schwartz and Prokopovich, 1956) of Precambrian age. Two type B deposits have been explored, the Minnamax near Babbitt by Amax Inc. and the Spruce Pit near Ely by Inco Ltd. These deposits contain several hundred million tons of mineralized rock averaging about 0.4 percent Cu and 0.17 percent Ni. One occurrence of nickel in Wisconsin (Dutton and Bradley, 1970) calls attention to a part of the Precambrian shield that is incompletely assessed for nickel, and tentatively proposed as province 17, which may be a potentially important new type of occurrence and source of byproduct nickel from Precambrian base-metal massive sulfides.

Nickel concentrations are sparse in the Central Plains region, but locally are potentially important as a coproduct or byproduct resource. The main occurrences are in the southeast Missouri lead district, Province 9 (Neuschel and McKnight, 1948). Nickel minerals occur as disseminated replacements and open space fillings associated with base metal, silver, and cobalt-bearing sulfides in altered Phanerozoic carbonate sediments which flank the Precambrian rock core of the St. Francois Mountains. This district already is a major lead source, and according to R. L. Erickson (oral commun., 1979) has a potential for byproduct nickel, perhaps enough to be considered as of type B magnitude.

Several types of nickel deposits and occurrences are present in the Appalachian belt, but geologic information about them is meager. Province 11 in the southern part (Alabama, Georgia, Tennessee, and Virginia) contains potential byproduct nickel localized as fracture fillings and incrustations, replacement, and fragmental or pelletal concentrations in colluvial clays associated with cobalt-bearing sedimentary black manganese oxide concentrations. These occurrences are of very low grade (Pierce, 1944). Province 10, which includes the type B, saprolite nickel deposit at Webster, North Carolina, also includes a number of other small localities in Georgia, North Carolina, and Virginia that contain typical old continent assemblages of sulfide in veins, faults, and disseminations associated with mafic and ultramafic intrusives in metasedimentary terranes (Cornwall 1966; Cornwall, Vhay, and Frendzel, 1968; Cornwall and Burbank, 1952) in which nickel is a possible byproduct. The northern part of the Appalachian belt contains a number of small local sulfide deposits and occurrences from Maryland to Maine that also are associated with mafic intrusives (Pearre 1948, 1961; Pearre and Calkins, 1957; Maine Geological Survey, 1958). Owing to a lack of more definitive data these are here tentatively considered as dispersed parts of province 12. The province includes the mined-out Gap and Cornwall, Pennsylvania deposits (of widely different ages) at the south end, a number of old mines in Connecticut and Massachusetts, and the Moxie Lake deposit and other occurrences in central Maine. The sulfide nickel minerals in this province are associated with mafic and ultramafic rocks or their altered equivalents. Appalachian belt provinces (10, 11, and 12) thus contain a variety of deposit types formed in varied geologic environments during different parts of geologic time. Province 13 includes occurrences in coastal Maine, and possibly those in central Connecticut and eastern Massachusetts, which contain nickel as replacements in volcanogenic eugeosynclinal sedimentary sequences with associated mafic intrusives. These may represent occurrences in an accreted eastern oceanic crust plate.

Table 1.--*Location, types of deposits, estimates of resource potential, and status of geologic resource knowledge of nickel provinces in the conterminous United States*

Province			Geologic types of deposits[1]	Preliminary estimates of resource potential			Status of geologic resource information	
No.	State	Area		High	Medium	Low	Adequate	Insufficient
1	Oregon and California	Klamath Mountains	VI	X	--	--	--	X
2	California	Sierra Nevada western foothills	VI	--	X	--	--	X
3	Do	San Diego County	III	--	--	X	--	X
4a	Washington	Olympic Peninsula	IV	--	--	X	--	X
4b	Do	Cle Elum	III, VI	--	X	--	--	X
4c	Washington and Idaho	Northern counties	II, VI	--	--	X	--	X
5	Idaho	Blackbird district	VI?	--	X	--	--	X
6	Montana	Dillon	III	--	X	--	--	X
7	Do	Stillwater complex	I	X	--	--	--	X
8	Minnesota	Duluth complex	I	X	--	--	--	X
9	Missouri	Southeast lead district	III	X	--	--	X	--
10	Georgia, North Carolina and Virginia	Southern Appalachian Mountains	II, III, VI	--	--	X	--	X
11	Alabama, Georgia, and Tennessee	do	V	--	--	X	X	--
12	Maryland, Pennsylvania, New Jersey, New York, Connecticut, Vermont, Massachusetts, and Maine	Northern Appalachian and Taconic) Mountains	I, III	--	--	X	--	x
13	Maine, Connecticut, and Massachusetts	Coastal region	I, IV	--unknown--			--	X
14	Colorado	Front Range	III	--unknown--			--	X
15	Nevada	Great Basin	III, IV	--unknown--			--	X
16	Arizona	South-central	III	--unknown--			--	X
17	Wisconsin	Northern	IV	--unknown--			--	X

[1] Main geologic types of nickel deposits and occurrences, generalized, based on Cornwall (1973):

I. Magmatic seggregation (or hydrothermal introduction) of nickel-bearing sulfides in disseminated and massive elongate or sheetlike bodies, veins, and veinlets; generally at the base of intrusive mafic and ultramafic complexes.

II. Hydrothermal veins of sulfides and arsenides of nickel, cobalt, and copper; generally not related to ultramafic rocks.

III. Hydrothermal veins, breccia zones, replacement mantos (in carbonate rock), and disseminations of nickel oxides, sulfides, and (or) sulfarsonides in host rocks; commonly associated with base and precious metal and cobalt sulfides. An igneous rock source may or may not be present.

IV. Eugeosynclinal (volcanogenic?) sedimentary rock concentration of nickel and manganese oxides, silicates and (or) sulfides; often associated with mafic intrusives.

V. Black manganese oxides containing nickel in fracture fillings and incrustations in siliceous sediments, or in oxide fragments, or rounded pellets in red colluvial clay bodies.

VI. Deep weathering of ultramafic rocks under tropical conditions to form nickel-bearing lateritic soil (or saprolite).

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Background information relating to this map and others in the Atlas of Metal and Nonmetal Provinces in the Conterminous United States is published as U.S. Geological Survey Circular 792 (Tooker, 1979), available free of charge from the U.S. Geological Survey, Branch of Distribution, 1200 Eads St., Arlington, VA 22202.