

Information Circular 8813

Iron Oxide Pigments

(In Two Parts)

2. Natural Iron Oxide Pigments— Location, Production, and Geological Description

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UNITED STATES DEPARTMENT OF THE INTERIOR
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BUREAU OF MINES
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This publication has been cataloged as follows:

Jolly, Janice L W

Iron Oxide Pigments (In Two Parts) 2. Natural Iron Oxide
Pigments--Location, Production, and Geological Description.

(Information circular - Bureau of Mines ; 8813)

Bibliography: p. 67-73

I. Pigments. 2. Iron oxides. I. Collins, Cynthia T., joint author.
II. Title. III. Series: United States. Bureau of Mines. Information
circular ; 8813

TN295.U4 [TP936] 622'.08s [667'.26] 79-19994

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IRON OXIDE PIGMENTS

(In Two Parts)

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by

Janice L. W. Jolly¹ and Cynthia T. Collins²

ABSTRACT

This Bureau of Mines publication reviews the location, principal producers, and geologic occurrence of natural iron oxide pigment deposits. The most famous deposits are found in Cyprus, Iran, Spain, France, Italy, and the Federal Republic of Germany; significant deposits are also exploited in India, the Republic of South Africa, and the United States. Some other countries where iron oxide pigment deposits are, or have been, exploited include Argentina, Australia, Brazil, Burma, Canada, Chile, Egypt, Israel, Jordan, Kenya, Mexico, Morocco, Pakistan, Paraguay, Sweden, the United Kingdom, and Venezuela. Most iron oxide pigment deposits were derived by decomposition of rocks and minerals, resulting in the secondary redistribution and concentration of liberated iron into favorable sites of accumulation. Gossans, laterites, bog iron ores, karst sediments, river channel sediments, and contact metamorphic limestones are favorable sites for iron oxide pigment deposits. Large-scale sedimentary iron deposits such as the minette, Clinton, and black band ores, and Precambrian iron formations are also important pigment sources. Iron oxide pigments are both mined as a primary product and produced as a byproduct of mining other ores, such as iron ore, barite, or sulfides. Maps, tables of production and trade, and lists of producers are included where possible.

INTRODUCTION

Background

Natural iron oxide pigments and natural iron oxides used in making ferrite material are derived from any one of five mineralogical types of iron ores: hematite, limonite (a group of hydrated oxides), siderite, magnetite, and iron-bearing sulfides. Iron ores used for pigments or ferrites are most commonly classified as nonmetallic or industrial mineral ores, whereas other iron ores are classified as metallics. The Standard Industrial Codes (SIC) used by industry and Government are also distinctly grouped in one area

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(metallic minerals) for iron ore (10110, 10111, 10112, and 10113) and in another area (nonmetallic minerals) for those ores used for pigments (14794).

Despite these separate classifications, ores of the two types have a common genesis and mineralogy, and may be subject to the same economic influences. Metallic ore dominates the literature, and it is virtually impossible to find a description of an iron oxide pigment deposit in general treatises on iron ore; often no mention is made of pigment characteristics even when pigment and metallic ores are derived from the same mine.

This Bureau of Mines study treats the pigments as a variety of iron ore for the purpose of genetic classification and discussion and attempts to bridge the information gap created by the conventional classification. The study is the result of an extensive literature survey; inferences on genetic classification or mode of origin for the deposits described were taken from the literature and do not reflect the personal views of the authors. Definitions of commercial and local terms used by the pigment industry and of most of the technical terms used appear in the glossary (appendix B). All tonnages are given as metric tons. A more detailed discussion of the economics and technical application of iron oxides as pigments and ferrites is found in part 1 of the study (47).³ Production information in part 2 is as current as possible, given the different sources of the data.

Iron oxide pigment deposits occur as a wide variety of iron ore genetic types. Most commonly exploited for pigment are residual iron ores that have formed by a mechanism of redistribution and concentration. Eleven of the most common geologic types are described at the conclusion of the introduction, and a chart indicating geologic age relations appears as appendix A.

Color is of the greatest importance in deciding the value of a pigment. Other important considerations are oil absorption properties, grain size, and chemical impurities. These properties can be controlled and consistent colors can be maintained in the production of synthetic pigments. Both natural and synthetic inorganic pigments are superior in heat resistance, weatherability, and color fastness when compared with organic pigments.

The red hue of natural red pigments is derived from hematite (Fe_2O_3). Pigments containing hematite may vary in total iron oxide content as well as in color, which will range from brownish red and purplish red to red. Specular hematite gives a metallic gray luster to pigment, caused by its platy or "micaceous" form. Red colors may also be obtained from conversion of a hydrated iron oxide (limonite group of minerals) to red ferric oxide (hematite) by calcination. General characteristics of a natural hematite pigment are essentially the same as those attributed to the equivalent synthetic material. Differences in detail for the natural ores, such as color, impurities, and other specific properties, are peculiar to the particular source of the material. Impurities such as calcite, gypsum, clays, manganese, and carbon often impart special qualities and color to the pigment that are difficult, if not impossible, to duplicate artificially.

³Underlined numbers in parentheses refer to items in the bibliography preceding the appendixes.

Ochers, siennas, and umbers are yellow to brown iron oxide pigments that are basically a form of limonite (a collective group of hydrated iron oxides that includes goethite, lepidocrocite, etc.), combined with varying percentages of silica, alumina, and, in the case of umber and sienna, manganese. Burnt siennas and umbers are derived through heat treatment of the raw ore, driving off the contained water to form hematitic pigment of red or brownish hue.

Popularity and local acceptance of a particular pigment also help to determine its value. Micaceous iron oxide, a naturally occurring ore known also as flake or specular hematite, is mined in Europe, where it is used in corrosion-resistant paints for exposed steel parts (60). It has not been widely accepted for use in the United States, although a small amount is imported. Specular hematite is a fairly common mineral in mines of the Lake Superior region, as well as other areas, but it is not mined for pigment use. The most acceptable grades come from Austria where the quality of the ore lies in its high Fe_2O_3 content, extremely low soluble salts, and surface area of the flakes. Most specular hematite ores are comparable in softness and hiding power.

Micaceous iron oxide imparts unique properties to coatings (75). The flaky particles align with planes parallel to the surface being coated in overlapping layers, thereby forming a tight, laminated seal. This structure makes the penetration of moisture and gases extremely difficult and can effectively prevent corrosion and rusting of metals. The coatings also resist blistering, flaking, peeling, and cracking for extended periods of time.

Types of Iron Ore Important as Iron Oxide Pigment Deposits

Gossan Type

Gossan ores are residual deposits of iron oxides that are formed by the decomposition by weathering of iron-bearing sulfides, and they form a capping on sulfide deposits. "Filled-sink" ores are gossans that developed on weathered masses of sulfides occurring in large sinkholes (karst topography) in carbonate rocks. Examples: Spain, United Kingdom, California, Morocco, Chile.

Enriched Iron Formations

These are oxidized iron minerals usually formed from cherty Lake Superior-type iron formations by leaching of silica and oxidation of magnetite, carbonate, and ferrous silicates, leaving residual deposits of iron oxide. Considerable redistribution, introduction, and enrichment of iron has taken place. Examples: U.S. Lake Superior deposits, India, Brazil.

Laterites

Laterites are deposits of iron oxides resulting from deep tropical and subtropical weathering with residual accumulation of the oxidized and relatively insoluble rock constituents. Iron-rich blankets of laterite form over ultrabasic rocks with high primary iron content. Examples: South Africa, Pakistan, United Kingdom, India, Australia, Brazil.

Bog Iron Ores

Bog ores are chemically precipitated iron oxides that have accumulated in lakes or around discharge areas of springs and seepage water, either in low ground or on slopes. Organic debris is commonly replaced by ferric oxide or siderite. Manganese oxides may be abundant. Examples: Eastern United States, California, Colorado, Australia, Germany, Denmark.

Redistributed Ores

Residual and Transported Residual Ores

These deposits typically occur in weathered limestone or dolomite, or in ferruginous sandstones and shales, and they may be concentrated along structural weaknesses. Meteoric waters serve as a concentrating agent, dissolving the iron from carbonate and reprecipitating it at select places along main watercourses in the same or associated rocks. Examples: Eastern United States (brown iron ores); South Africa; Devon and Cornwall, United Kingdom; Pakistan; India; Germany (brown iron ores).

Shallow Marine Deposits

Iron derived from deep-rock weathering is transported as colloidal or fine particles and deposited by marine waters in beds, bars, or pockets. In the case of volcanic or other igneous source rocks, the iron oxide may be associated with jarosite, bentonitic clays, siltstones, radiolarian cherts, and reworked tuffaceous materials. Marine chalks, marls, and cherts are commonly associated. Examples: Cyprus, France, Australia.

Ferruginous Sands and Sandstones

Iron sands are concentrations of minerals liberated from source rock by weathering and decomposition, and concentrated by river, marine, or wind (eluvial) action. Examples: India, California.

River Bed or Erosional Distribution

Iron derived from rock weathering and erosion is transported as particulate material or in solution, and deposited on other erosional surfaces, or in beds or bars in river channels. Examples: Coastal plain ores, Virginia.

Massive Iron Oxide Deposits--Bilbao Type

Bilbao deposits are massive replacements in limestone, composed of goethite or hematite in near-surface zones with siderite below. Ore above the water table is composed of iron oxides that formed by oxidation of massive siderite bodies in a karst environment. Examples: Bilbao, Spain; Cumberland, United Kingdom; northern Italy; southern France; Erzberg, Austria.

Minette Type

Minettes are oolitic, noncherty, iron-rich sediments that are usually brownish to dark greenish brown, composed mainly of siderite, iron silicates such as chamosite or iron chlorites, goethite-siderite, and chamosite. They are closely associated with black carbonaceous shale and sandy shales that apparently formed in brackish or marine water in shallow basins. Minette deposits frequently have enriched surface zones of brown and red oxide as decomposition products of the primary iron minerals (ore). Examples: Northern United Kingdom, Germany, France, Pennsylvania, northern Sardinia.

Clinton Type

Clinton deposits are typically deep red to purple massive beds with oolitic textures composed of mixtures of hematite, chamosite, and siderite. The oolites are formed around fossil fragments or clastic grains of quartz. Silica is present mainly as iron silicates in some ores, but others consist of quartz sand cemented by hematite. Clinton ores contain more hematite than chamosite or carbonate compared with the minette types; phosphorus is greater than in the Lake Superior type. These ores are associated with carbonaceous shale, sand shales, dolomite, and limestone, and they apparently formed along margins of continents, on continental shelves or in shallow basins. Examples: Eastern United States, South Africa.

Nonoolitic Iron Carbonate and Iron Silicate Ores (Black Band Ores)

These are poorly bedded siderites, sideritic mudstones, siderite-hematites, or massive hematite and goethite that may be the product of volcanic exhalations of iron and silica. In some beds, the iron oxide may be derived from the alteration of glauconite or iron carbonates; it may be less than 25% iron, siliceous, and high in alumina, lime, and manganese. The ore may be associated with coal and is considered syngenetic when it occurs as sediments associated with coal measures. Examples: India, Federal Republic of Germany, France, Pennsylvania, Ohio, Kentucky, Alabama.

Evaporite Basin Sediments

Iron-enriched sediments are associated with salt plugs, sandstones, grits, shales, volcanic tuffs, agglomerates, and dolomitic limestones. Sediments are typically deposited in an evaporite basin. Examples: Iran, India, Pakistan.

Contact Metasomatic Iron Oxides

Massive magnetite and/or hematite, sometimes with pyrite and skarn minerals, occur mainly in limestone associated with igneous masses. Examples: Eastern United States (Pennsylvania, New York, New Jersey, Missouri, North Carolina), Austria.

ACKNOWLEDGMENTS

In the course of this investigation, the cooperation of several Government agencies was especially helpful. A special note of thanks is extended to the Bundestahl für Geowissenschaften und Rohstoffe of the Federal Republic of Germany; the Bureau de Recherches Géologiques et Minières of France; the Department of Mines, Republic of South Africa; and the Office of the Ambassador of Australia for providing details and references. Universal Milling Co. Pty. Ltd. of Australia was very helpful in their replies. Cooperation of the U.S. Embassy in Italy is also gratefully acknowledged.

We would also like to acknowledge the assistance of many domestic producers and colleagues at the U.S. Bureau of Mines and the U.S. Geological Survey whose suggestions contributed materially to this effort.

DOMESTIC ORES

General Discussion

In 1978, the known crude iron ore resources of the world were estimated at more than 800 billion tons. In the United States, crude iron ore reserves were estimated at 17 billion tons (50). Iron ore deposits in the United States are seldom mined solely for pigment or ferrite use, and, historically, much of the iron oxide pigment production in the United States was a byproduct of mining done primarily for iron ore used for production of iron and steel. Iron oxide pigments have also frequently been a coproduct of operations that recover ores such as manganese, barite, or sulfides.

Locations and detailed descriptions of many iron ore deposits in the United States as they pertain to pigment use are given in an early (1933), but still very useful, report by the Federal Bureau of Mines (103). Figures 1 and 2 show the broad distribution of limonite, brown iron ore, ocher, magnetite, and hematite. It might appear to be an enigma, in view of the relative abundance of iron oxide deposits in the United States, that only a few deposits are being exploited for their coloring and magnetic properties. This is readily understood, however, once the characteristics of the industry become clear.

At one time, natural iron oxide pigments dominated the U.S. pigment industry, however, in recent years, the emphasis of the pigment industry has shifted with the advent of new and often superior synthetic materials. In the United States, this trend was also a reflection of changes in the iron and steel industry, in the needs of the pigment industry, and in mining practices.

In the mid-1800's, production of iron ore began in the Lake Superior region. The development of this region was to have a continuing effect on the economics of iron ore and the associated pigment production in the rest of the United States as larger scale mining became possible. The importance to the iron ore industry of these large, more efficient mines was shown by the facts that, by 1938, 75% of the iron ore came from mines with 500,000 ton-annual production or more and 13 mines were producing more than half the U.S. production.

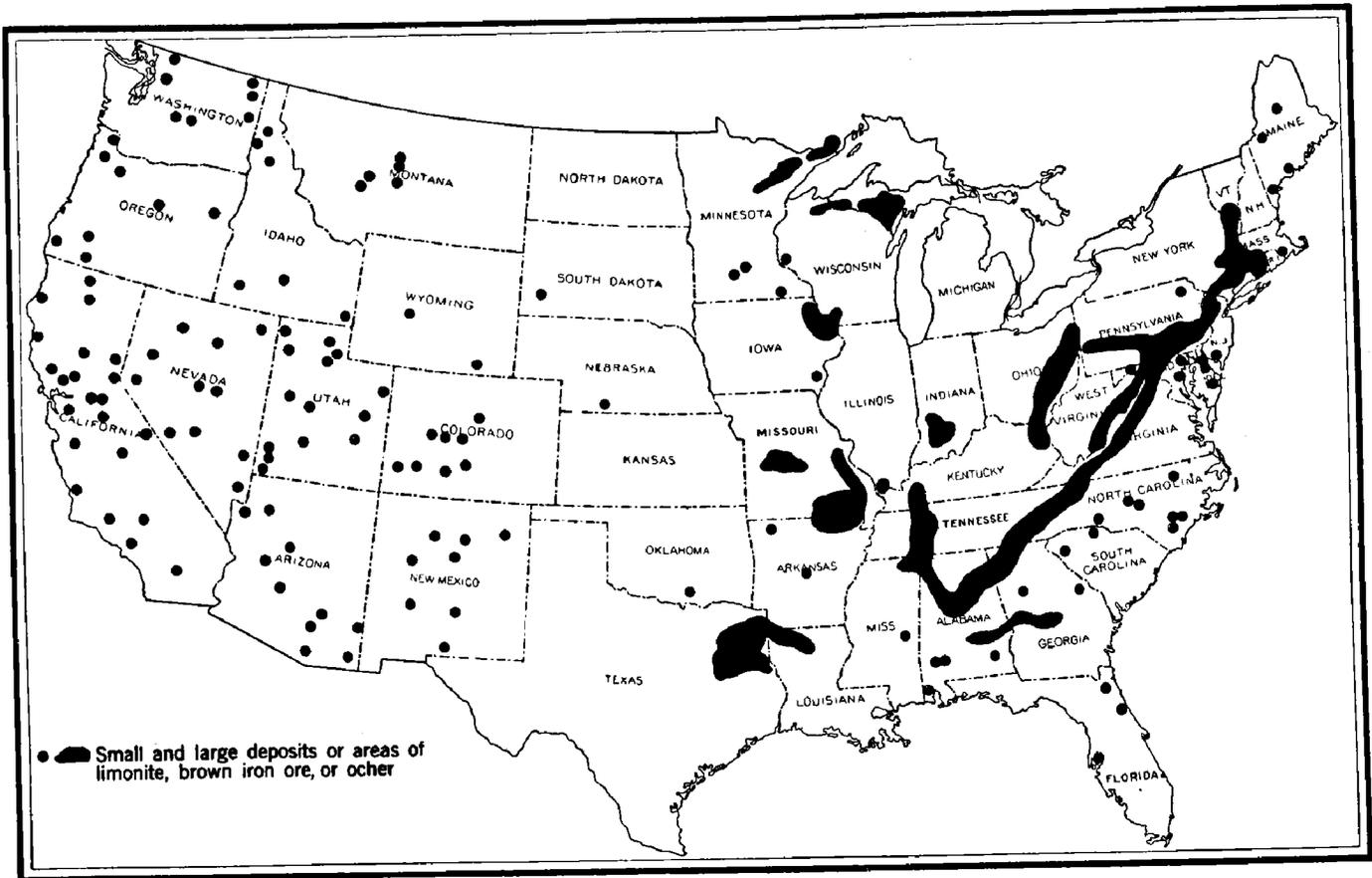


FIGURE 1. - Distribution of limonite, brown iron ore, or ocher in the United States (103, p. 13, modified according to 12).

Since 1955, growth of the taconite industry, which relies primarily on processing low-grade magnetic iron ores, has seriously affected hematite and limonite mining and many iron ore mines have been closed. Today, there are only three natural iron oxide pigment producers, one of which is also an iron ore producer.

The United States imports 10,000 to 13,000 tons of natural iron oxides per year, and in 1978 natural iron oxides accounted for half of the total iron oxide pigment output in the United States. This contrasts, however, with 97% of total production in 1921. Natural pigments were 18% of the total quantity of iron oxide pigments imported in 1978. Inexpensive synthetic iron oxides, derived from sources such as steel industry pickle liquor and steel plant dust, have captured much of the natural oxide market for ferrites.

Sizable domestic production of sienna and umber has never been possible; the main reason was the apparent lack of suitable material that could compete in quality and price with foreign imports. Although umber and sienna are now domestically produced from natural U.S. ores in Virginia on a small scale, most U.S. needs for umber and sienna are met by imports. With the closure of the Mather mine in Michigan in 1979, domestic requirements for hematite pigment may also be met by imports.

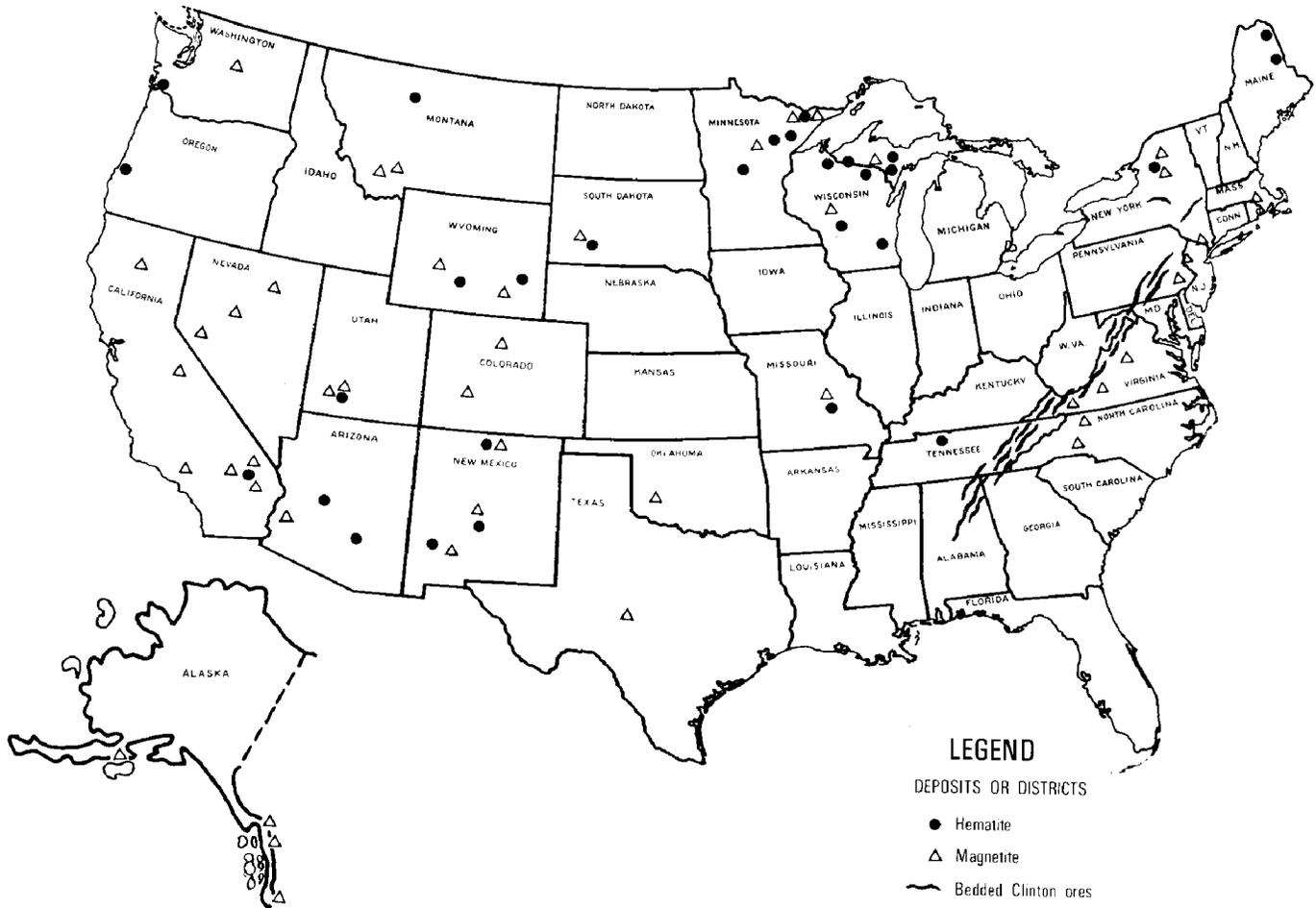


FIGURE 2. - Occurrence of principal hematite and magnetite deposits in the United States.

During wartime, the use of domestic ochre has temporarily increased as foreign sources became less accessible. It was found that some domestic ochres could be made equal to French ochres by cleaning and floating and by some additional tinting with chrome yellow. In general, however, U.S. ochre has differed from the French ochre in having silica chemically combined in clays, rather than free, and most U.S. ochres have required more grinding (5). The free silica (as quartz grains) of the French ochre caused it to work more freely, to adhere to wood, and to act as a filler.

Consumption of certain natural pigments has been increasing in recent years, largely because of the increased use of micronizing. Micronizer mills, which reduce particles to micrometer size by means of high-pressure air or steam, currently make natural pigments more competitive with synthetic pigments (43). Also, the relatively stable prices of the natural pigments make them increasingly attractive, when compared with the rapidly rising prices of synthetics. In 1978, the average value of synthetic iron oxides was more than five times greater than that of natural pigments (16). It might be concluded, therefore, that although consumption of natural iron oxides is not likely to rise dramatically, and mining for them may not increase in the United States, certain types and grades are assured of an expanding market in the future.

Particularly desirable qualities and demand determine the viability of a natural iron oxide deposit, but costs of production and transportation are also important considerations. In the United States, the price of natural iron oxide pigments is usually low because this product is a coproduct of another material, such as barite or iron ore, which largely pays for the capital investment. Many pigment mines associated with iron ore as the major product were abandoned not because they were worked out of suitable pigment material, but because mining for iron ore became unprofitable as iron ore prices dropped or as mining became more expensive during certain periods, such as the 1920's, the early 1930's (65), and the 1970's. The inroads that synthetic iron oxides made into the market after 1920, and that organic pigment materials made later, also assured that the deposits would not be reopened and mined for pigment alone.

The apparent lack of interest in developing new natural iron oxide pigment sources in the United States is partly the result of the increasing availability of highly competitive synthetic and organic pigments. The chief advantage of natural ores has been their cost, which thus far has been maintained far below that of equivalent synthetics. On the other hand, synthetic organic pigments provide more colors, and some are more brilliant.

Hematite Deposits

Location and Production

In the mid-1950's, prior to the advent of pelletizing magnetic ores, hematite accounted for about 80% of the iron ore produced, yet it accounts for less than 20% of the iron ore mined in the United States today. Because hematite used for pigment was most often a byproduct of the deposits mined for iron ore, the drop in domestic hematite mining has also influenced the availability of domestic ore for pigments. In the United States, natural hematite for pigment was recently produced (along with iron ore) from only one mine in Michigan; in the past it was mined from deposits in other States, including Minnesota, Wisconsin, New York, Georgia, Tennessee, Pennsylvania, Alabama, Virginia, California, Nevada, Wyoming, and Utah. Specular hematite occurs at many localities in the United States, but it is currently mined for pigment only in Europe.

The Mather mine in Michigan, operated by the Cleveland-Cliffs Iron Co., was the last underground iron ore mine in production on the Marquette Range. Production at the Mather mine began in September 1943 and terminated in July 1979. Shipments of iron oxide for pigments apparently did not begin until about 1951. In 1964, the Negaunee Mining Co. joined with Cleveland-Cliffs Iron Co., McLouth Steel Corp., Bethlehem Steel Corp., Republic Steel Corp., and Sharon Steel Corp. to expand the Mather mine and change to pelletizing operations. This enabled the remaining hematite underground to be mined. The hematite ore was dried and screened with the fine fraction pelletized and a coarse fraction shipped as lump ore. The use of the Mather hematite as a pigment declined in recent years as the color became less desirable and foreign ores became more available; the pigment was used primarily in undercoatings and primers.

Although not presently worked, the Clinton Formation hematitic ores of the Eastern United States have been extensively mined in the past for both iron ore and pigment. In 1850, hematite ores from Pennsylvania accounted for more than half of the entire production of iron ore in the United States (79). Much of this production was derived from the Clinton Formation which is distributed through at least 11 counties in central Pennsylvania.

Clinton ores also constitute one of the largest known iron ore resources in New York State, extending 120 miles between Herkimer and Monroe Counties. In Oneida County, at Clinton, the hematitic ores that were mined for pigments in the 1950's (12) included two types, a lower oolitic ore and an upper "red flux." The "red flux" contained 40% to 55% calcium and magnesium carbonates and 10% to 20% iron. The oolitic ores were siliceous and ranged from 35% to 45% iron. The bed was mined continuously from about 1810.

A few deposits of Clinton hematite were also found to be of commercial value in Alleghany, Lee, and Wise Counties of Virginia and were mined on a small scale. In Tennessee, the main belt of the Clinton ore outcrop extends, although not continuously, nearly 300 miles across the State. About 115 miles of this belt are reported to contain an ore bed that is more than 2 feet thick. Some years ago, a considerable tonnage of red fossil iron ore was mined for use as pigment in northwest Georgia near Chattanooga, Tenn. The Clinton-type ore bodies in Alabama are found in Red Mountain on the east side of the Birmingham Valley. The Red Mountain Formation here is 200 to 500 feet thick and includes four well-marked ore horizons each of which may be up to 30 feet thick. Iron content here may be as high as 54% (78.2% hematite), but it is usually less. These iron ore bodies have been mined extensively. None of the Clinton-type hematite deposits is currently exploited; they have not been mined since 1970 when production in Alabama ceased.

Geological Description

Hematite occurs in deposits of sedimentary origin, in deposits derived by secondary leaching of lower grade material and accumulation or redeposition as a higher grade material, in deposits derived from hydrothermal deposition (replacement bodies or veins, sometimes with igneous affiliation), or as gossan derived from underlying sulfide deposits. In addition, any of these deposit types may be metamorphosed or otherwise altered from its original state.

There are two geographic regions containing abundant deposits of hematite that have been of major importance to the iron ore and pigment industries in the United States. They are the Precambrian iron formations of the Lake Superior region; and the Silurian-age Clinton Formations that extend from New York to Alabama. Iron-rich rocks of Silurian age in Alabama are called the Red Mountain Formation, and some iron-rich hematite sandstones of Silurian age in Virginia are in the Rose Hill Formation. Precambrian sedimentary iron ores also occur in widely scattered areas of South Dakota, Wyoming, Montana, Idaho, New Mexico, and Arizona. Other deposits, such as those in New York and New Jersey originally may have been sedimentary, but they have since been affected by deformation, metamorphism, and igneous activity to such degree as to

disguise the original source. In recent years none of these deposits has compared in importance with the Lake Superior or Clinton ores for either iron ore production or pigment use.

Precambrian Iron Formation

The largest known concentration of Precambrian iron formations in the United States occurs in the Lake Superior region. Geologic events have altered the original sedimentary deposits, creating new minerals, changing their grain size, and concentrating iron in some places. Leaching of lower grade iron formations has resulted in removal of silica and the concentration of iron into high-grade hematite ore deposits.

At the Mather mine in Michigan, the ore body is up to 400 feet thick in the north limb of the main Marquette Range syncline, and it is in the lower 300 feet of the Negaunee iron formation of middle Precambrian age. The ore is earthy hematite and martite with minor amounts of goethite; it ranges in color from reddish brown and red to bluish gray. The ore grade averages 54% iron and 7.4% silica. The ore body dips south from the shaft and is mined by block-caving methods, at the 3,250- and 3,500-foot levels.

Clinton Formation

The Clinton Formation and equivalent rocks of the Eastern United States are the result of widespread iron sedimentation as oolitic and fossiliferous hematite, and as diagenetic redistribution of iron oxides. In general, these deposits are not of sufficient size or grade to constitute iron ore, but in some places, particularly in Alabama, they have been mined extensively. The usual iron content in the ores is 25% to 45%. Calcium carbonate is usually present, and the silica content usually ranges from 11% to 33%. Some of the earlier mined Clinton deposits were leached of the carbonate and contained up to 60% iron. The Clinton Formation is comprised of sandstone, shales, and limestones within which one or more hematite-rich zones are commonly associated. There are silica-rich and carbonate-rich zones of minable thickness. Two types of ore are usually found, an oolitic ore and a fossiliferous ore. The hematitic oolite ore has cores of quartz cemented with iron oxide; chamosite oolites are also altered to hematite.

Other Occurrences

Other minor hematite occurrences, some of which have been used for pigment, include the "filled-sink" deposits of the Ozark Plateau in Missouri, where accumulations of hematite and limonite occur in sinkhole accumulations in Lower Ordovician Gasconade Dolomite (12). The iron was derived from overlying Pennsylvanian strata and reprecipitated, first below the water table as iron sulfides, and later by uplift and oxidation as iron oxides. Hematite may also occur along with magnetite in heavy mineral sands that in a few places (notably California) have been rich enough to be exploited for iron ore. Hematite also occurs commonly as gossan associated with the copper deposits of the Southwestern United States.

Hematite was derived from the residues of pyrite roasting operations by the Rico Argentine Mining Co. from its pyrite mine at Rico, Dolores County, Colo. A brilliant red hematite, this product was last shipped for pigment in 1969 (35, p. 27).

The Seligman (Cowden) Juniper Mountains occurrence in Arizona is comprised of several small replacement hematite bodies. The hematite is massive to powdery and of fairly high purity. The deposit is also known as the Iron Chancellor; the last shipment for pigment purposes was in 1972 (34).

Specular hematite occurs in many localities in the United States, including the Lake Superior region, but has never seriously been considered for use as a pigment. Massive hematite and specularite occur as replacement deposits in Paleozoic sedimentary rocks in Arizona, as siliceous specular hematite in the Shady Dolomite Formation of Cambrian age in the Cartersville district of Georgia, as replacement veins of specularite with minor magnetite in the Precambrian Belt Series of Idaho, in Permian marbles of Iron Mountain also in Idaho, in the Paleozoic limestones of New Mexico, and in the bedded specularite-martite-magnetite iron formation of the Precambrian Nemo Series in South Dakota (12). Specular hematite has also been reported from the Blue Ridge area of Bedford, Botetourt, and Roanoke Counties, Va. (103).

Magnetite Deposits

Location and Production

Magnetite used for ferrite material and for pigments is produced at the underground Pea Ridge mine located in southeast Missouri, just south of Sullivan in Washington County. Small irregular shipments of magnetite used for ferrite material also have originated from mines in New York, North Carolina, and Pennsylvania in recent years.

The Pea Ridge mine is currently operated by the Pea Ridge Iron Ore Co., a wholly owned subsidiary of St. Joe Minerals Corp., and was formerly operated by the Meramec Mining Co., owned jointly by Bethlehem Steel Corp. and St. Joe Minerals Corp. Shipments of high-quality iron oxide pellets began in 1964; \$52 million and 7 years were required for development and construction. The annual production capacity in 1976 was 1.8 million tons of low-silica iron oxide pellets (25) suitable for use in direct reduction steel plants, as well as in blast furnaces. Smaller amounts of concentrates have been sold for ferrite and pigment uses.

The oxide for ferrites and pigments is obtained from a special concentration circuit which increases the iron content to 71%-72%, compared with 67% for blast furnace pellets. The particle size of much of the material is 8 to 12 micrometers. Approximately 95% of this material is used in the ferrite industry, and the rest for pigments. Some is used for magnetic printing inks and brake linings. Pea Ridge ferrite-grade M-25 oxide has the following composition (13) in percent:

Fe ₃ O ₄	94.00	} 71.8% Fe	Al ₂ O ₃	0.090
Fe ₂ O ₃	5.00		(Al.....)	.050)
SiO ₂ .....	.20		P.....	.040
(Si.....)	.08)		Mn.....	.036
CaO.....	.20		S.....	.010
(Ca.....)	.14)			
MgO.....	.12			
(Mg.....)	.07)			

Specific gravity 5.0, and screen analysis is 97% through 325 mesh.

The Cranberry mine in Avery County, N.C., is one of the oldest in the country. Since the Revolutionary War, Cranberry has produced approximately 1.6 million tons of iron ore (89). A high-purity magnetite concentrate for use in ferrites and heavy media in coal-washing plants was most recently produced from the underground mine and old surface dumps. No production has been reported since 1974, and the property is currently owned by McGlothlin, Inc., of Pounding Mill, Va.

Geological Description

The principal sources of magnetite used for ferrite and pigment purposes in the United States have been the contact metasomatic ores of Missouri, North Carolina, New Jersey, and New York. These massive magnetite and hematite ores have been mined extensively for iron ore; the pigment use has been minor and sporadic.

The Pea Ridge ore body of southeast Missouri is one-half mile long, up to 600 feet wide, and tabular in shape. Although the depth is not known, the deposit extends more than 3,200 feet below the base of the Paleozoic sediments. About 1,300 feet of Ordovician and Upper Cambrian sediments overlie the ore body. Magnetite comprises most of the ore body, averaging 55% iron. Specular hematite, quartz, apatite, monazite, and pyrite are also present. The hematite occurs in thin lenticular masses, principally on the footwall and the upper parts of the deposit. Brecciated rhyolite-porphry in the hanging wall is cemented by magnetite and specularite, assaying about 35% iron. The deposit is presumed to be contact metasomatic in origin.

All of North Carolina's magnetite deposits occur within the State's Piedmont and Blue Ridge areas. The Cranberry ore of North Carolina occurs as parallel lenses or sheets of disseminated magnetite in the Cranberry granite gneiss. Reserves were estimated to be 1.5 million tons in 1944 (89).

Limonite Deposits

Location and Production

Domestic production of ocher, although limited in size, has had a long history. The first record of iron ore mining in America was in 1609 at the Jamestown Colony in Virginia, and ocher mining in that State soon followed.

Ocher has also been mined since colonial times in Pennsylvania, Missouri, California, Colorado, Alabama, Illinois, Iowa, and Vermont. Ocher is currently derived from deposits in Georgia and Virginia. Sizable domestic production of sienna and umber, however, has never been possible; the main reason was the apparent lack of suitable material that could compete in quality and price with foreign imports. UMBER and sienna are now domestically produced from natural U.S. ores in Virginia on a small scale, but most of these natural pigments are all imported.

Ocher production reached 17,300 tons per year, valued at \$186,707, by 1900, but dropped to 12,725 tons by 1903. Pennsylvania produced 59% of the national total in 1902, but dropped to 39% of the 1903 production. Georgia was the leading producer in 1903 with 41.6% of the total. Arkansas, Iowa, California, Vermont, Virginia, Missouri, and Illinois also produced ocher in 1903 (80). Output of ocher from 1889 to 1914 totaled 123,000 tons. In 1914, ocher was produced in Georgia, Pennsylvania, Virginia, Alabama, Iowa, California, and Vermont, with the Cartersville district in Georgia producing about 60% of the total. Mines located in Berks, Northampton, and Lehigh Counties in Pennsylvania produced a little less than 27% (39). Iron oxide pigments were produced from a mine near Muirkirk, Md., for a time, but production was discontinued shortly after World War II. At present, ocher is derived solely from deposits in Georgia and Virginia.

Some of the earliest ocher mining began in 1820 in Vermont and continued until 1916. The extent of the ocher pockets and beds is limited, but large pockets still occur. The most productive part of the Vermont belt extended along the western base of the Green Mountains through Addison, Rutland, and Bennington Counties.

In 1885, common ocher was extensively mined in Maryland and Pennsylvania. There were about 12 sienna mines in 1885, but the principal deposit was located near Bethlehem, Pa., where the best quality was found. The principal umber deposits were also located in Pennsylvania where less than 1,000 tons was marketed in 1885.

The Reichard-Coulston, Inc., iron oxide pigment deposit was one of the largest in eastern Pennsylvania. Located half a mile south of Topton, the deposit was worked by opencut. The grade of the product averaged 14% to 15% Fe_2O_3 . The C. K. Williams and Co. deposit was one of the most important in the State, located on the steep slope of South Mountain, and mined by underground methods. The ocher occurs there as layers or small pockets in clay. The ocher was separated by hand from the clay, and the clay was then used to fill old workings.

Much ocher of the Pennsylvania mines contained small amounts of manganese oxide, but only in a few localities was the manganese content sufficient for the mixture to be called umber. One locality was near the eastern edge of the Allentown quadrangle, 2 miles northeast of Springtown; another was located 2-1/2 miles north of Bethlehem in Northampton County. Sienna was mined at Neversink Mountain, Reading, Pa., in 1933 (103).

Iron carbonate was mined for paint at Lehigh Gap, Pa., and along a belt extending almost entirely across the southern end of Carbon County. These ores, mined by the Prince Manufacturing Co., were unique and were known in the trade as "Prince's Metallic Paint" and "Prince's Double Label Mineral Brown" (103). The manufacturers claimed that the marketed paint had some of the properties of a portland cement.

Ocher was mined for many years in Page County, Va., along the western base of the Blue Ridge Mountains. In 1872, Bermuda Ocher Co. mined near Bermuda Hundred, along the Appomattox River in Chesterfield County, Va. Deposits near Marksville, Va., in Chesterfield County, were mined in the late 1800's (5). Deposits have also been mined in Rockbridge, Warren, Loudoun, Augusta, Bedford, and Franklin Counties. A map showing locations of some of these deposits may be found in a 1964 Virginia Division of Mineral Resources Report (46), which also describes some of them.

Hoover Color Corp., which currently mines umber and sienna from three mines at Hiwassee in Pulaski County, Va., purchased the property in 1973 from Hercules, Inc. Production began in 1920 by the American Pigment Corp., which sold the mines to Hercules in 1964. Ochers, siennas, and umbers are mined at three mines within a 5-mile radius of the plant. The ore at the Hiwassee deposits is worked selectively, depending upon the type of ore needed. Because of the nature of the ore, siennas are mined and graded by hand, and production is limited to 3 to 4 tons per week (fig. 3). Ochers and umbers are mined by front-end loader. About 40 feet of overburden was initially removed over the 36- to 40-foot thickness of iron oxide, and present overall rate of production is 5 tons per day. The material is trucked to the processing plant, where it is broken in a hammer mill, dried at low temperatures in a controlled steam-tube dryer, ground to minus 20 micrometers, graded, blended, and packaged for shipment (46).

The Cartersville district of Georgia, one of the oldest in continuous mining activity in the Southeastern United States, is located 40 miles northwest of Atlanta in Bartow County. Ocher was first mined there in 1877 when the crude ocher was hauled in wagons to town for further processing; manganese oxides were also produced from the mines. With the advent of systematic mining and more sophisticated preparation equipment, the ocher industry became firmly established in Bartow County from about 1891.

The Riverside Ochre Co. first started mining in Bartow County, Ga., in 1912. When the old plant burned down and was rebuilt, the company was renamed New Riverside (48). The company started mining barite in 1925 and now produces about 30,000 to 50,000 tons of barite per year, in addition to being the leading ocher producer in the United States.

Both limonite and hematite ores were mined in at least 14 counties in California from about 1890 to 1928. Several plants treated the ore to provide uniformity in color and quantity; none of these deposits is being mined today. The last shipment of brown iron ore for paint from the Iron Springs placer mine in San Miguel County, Colo., was in 1970. The Southern Ochre Co. in Illinois stopped production in the 1950's. Several deposits in Washington and



FIGURE 3. - Hand mining and grading for sienna at Hoover Color Corp., Hiwassee, Va.

Oregon were investigated for their potential (104) but apparently never became major producers. Sienna was also obtained in the late 1800's from deposits in Lisbon, Maine; West End, N.J.; Scott County, Mo.; and near St. Louis, Mo. (5).

Geological Description

The principal sources of ocher and other limonite-type pigment deposits in the United States have been bog iron ores, minette-type ores, and brown iron ores. Other residual and weathered ores such as gossans and transported river sediments have been locally important.

Bog Iron Ores

Bog iron ores in Vermont and Pennsylvania have been mined for pigment. During the colonial period, bog iron ores that had been formed by stream precipitation were commonly used in New England for barn paint. The bog iron deposits that are fairly common in all of the Pennsylvania counties north and west of the Allegheny Front have been mined for paints (79). The deposits are located in large flat areas where swampy waters accumulated on benches and terraces of steep tributary valleys, on narrow flood plains, and at the foot of many large talus slopes bordering the Allegheny Plateau. Many of the bog ores contain up to 5% manganese.

The Iron Springs placer deposit of San Miguel County, Colo., is a bog iron ore deposit; limonite occurs as a well-consolidated deposit more than 1,500 feet long and up to 15 feet thick. The deposit is of spring origin and is still forming. Iron is taken into solution by ground water passing through iron sulfide-bearing rocks and veins and redeposited on the marshy slopes and in the creek bottom (35, pp. 73-75). In California, iron hydroxides deposited from high-iron spring waters have also been used for pigments (103).

Residual Ores

Brown iron ores have been extensively exploited throughout the Eastern United States for both iron ore and pigments, but production for pigments was most significant in Pennsylvania, Virginia, and Georgia.

Yellow ocher is coextensive with brown iron ores (limonite) in the limestone belts in Northampton, Lehigh, Berks, Lebanon, Chester, Lancaster, York, Cumberland, Franklin, Centre, Blair, and other counties of Pennsylvania (103). The mines were mostly worked by opencut methods. The most important ocher district in Pennsylvania extended from Easton to Reading in a narrow belt of limestones and quartzites. The relation between geologic structure and these ocher deposits is important because most iron-rich deposits occur in regions in which there has been intense faulting and folding.

Ocher is usually associated with the brown iron ores, occurring as irregularly distributed pockets in clays or as strata representing original rocks that have been wholly replaced. The limonitic iron ore represents a more concentrated form of hydrated iron oxide than that of ocher. Limonite is irregularly distributed as nodules or alternating layers throughout the ocher and clay. Residual chert from limestone is also found in many of the ocher deposits.

Meteoric waters were responsible for ore concentration in the brown iron ores; the iron was dissolved as water passed through the rocks and was reprecipitated at select places along the main watercourse. The faulted and fractured zones favored passage of water, thus localizing many deposits in those areas. The iron, which was originally distributed in small quantities throughout a great thickness of strata, is presumed to have begun to accumulate at its present position as soon as the rocks emerged from the sea and were subject to leaching in the late Paleozoic. It continues to accumulate today.

The Appalachian Mountain province of Virginia may be subdivided into the Blue Ridge, the Great Valley, and the Alleghany Ridge. The Blue Ridge is largely composed of Precambrian rocks, but sandstones and shales of Cambrian age are exposed along the western slopes. The Great Valley region is composed of Cambrian to Carboniferous sediments, limestones, shales, and sandstones. In these areas, the brown iron ores are referred to as "valley" brown ores, or "mountain" ores (32); both varieties have been mined for ocher. The valley brown iron ores occur as porous masses derived from the Shady Limestone in the New River district, or the Natural Bridge Limestone in the Blue Ridge Belt. The deposits, currently mined by Hoover Color Corp. in Virginia, also occur at the contact of the Erwin and Shady Formations of Cambrian age, and belong to

that class of valley brown ores. The ore occurs as stringers and pockets, which are mined by hand in places and stockpiled for later use.

The valley brown ores of Virginia occur with clay in fragments or porous masses mixed with ocher. The mountain ocher ores of the Blue Ridge are disseminated through dark red clay at the surface and do not extend to any great depth. The valley ores are of greater depth, up to 50 feet deep, in the Shady Limestone of the New River district. The bases of the ocherous clays are uneven, and the clays are most abundant near limestone "horses." The valley ores are generally richer and have fewer impurities than the mountain ores, which also are porous and honeycombed and may locally contain considerable ocher. Phosphorus in the brown ores ranges between 0.1% and 0.2%; manganese is below 1%. Both valley and mountain brown ores were derived from the limestones in which they occur and from overlying formations where the iron was carried down in successive stages and became more concentrated toward the base (32).

In Virginia, Cambrian-age residual ocher has been mined from the iron-bearing shales of Page County and from the Potsdam Formation of Rockingham County, where it was also mined for iron ore. Ocher of Cambrian and Ordovician age occurs near the contact of the valley ores or Shenandoah Limestone and the Hudson River Slates of Ordovician age. This ocher was fine textured and brown and generally contained 52.28% ferric oxide, 1.15% manganese oxide, and 40.22% clay (98). Ocher also occurs in the Shenandoah Limestone in Augusta County, where it follows the strike of the formation, forming decomposable argillaceous layers interstratified with limestone. The limestone is cherty and somewhat fractured in places. The clay is associated with a rock that grades from nearly pure chert to an umber or ocher which may be accompanied by manganese wad. The layer containing wad may be up to 50 feet thick, but the dark brown ocher forms the greater part of the deposit. Ocher was also reported in beds mined for iron ore near the Ross furnace in Buckingham County, Va., and in micaceous and talcose schists.

In general, the ocher and umber deposits in the Cartersville mining district of Georgia occur in the residuum of the Shady Formation. The colluvial cover has made exploration of these deposits difficult; hence few have actually been mined out. Figure 4 shows the typical geologic occurrence of the Cartersville deposits (49). The ocher deposits of the Shady Formation are thin-bedded and conformable with underlying Weisner Quartzite of Cambrian age. Manganese ores (psilomelane) are also occasionally associated with the ocher. The crude ocher usually contains 45% to 56% Fe_2O_3 . Jasperoid in irregular masses occurs most abundantly where faulting has cut the Weisner and Shady Formations. Residual barite also occurs in these zones. A little ocher occurs irregularly along tension fractures in the Weisner Quartzite. In the past, most of the ocher in the district was mined from underground workings, although locally some of the larger deposits were stripped.

The ocher at the New Riverside mine occurs as irregular deposits in the Weisner Quartzite that are presently mined from opencuts with a bulldozer. The ocher is passed through a washer and then processed. The New Riverside ocher contains about 49% ferric oxide and may contain more than 1% manganese

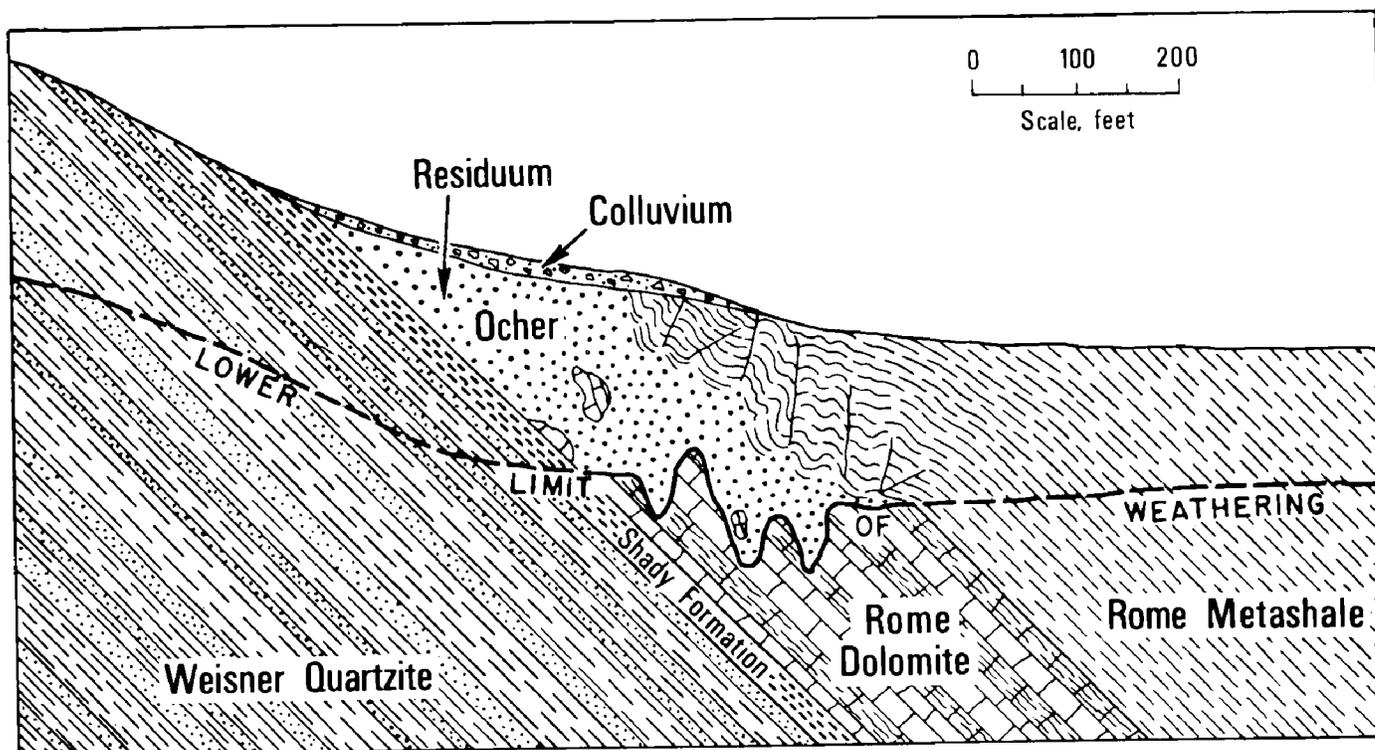


FIGURE 4. - Diagrammatic cross section showing typical geologic occurrence of ocher deposits of the Cartersville district, Georgia (49, p. 52).

oxide. The footwall of the ocher deposit consists of decomposed sandy quartzite up to 3 feet thick. The ocher ranges from a few inches to 65 feet thick, but the average thickness is 15 feet. Boulders of unaltered brownish quartzite as well as streaks of barite, barite nodules, or manganese nodules may occur in the ocher, which is faulted with displacements of up to 10 feet. The hanging wall consists of yellow clay with a sharp demarcation line between ocher and clay. Above the clay, which may be 200 feet thick, is a barite layer that ranges from a few inches to 30 feet thick. The barite layer may be a mixture of barite nodules and lumps in brownish sandy clay.

The Great Gossan Lead, traceable for more than 20 miles in southwestern Virginia, was a main producer of residual limonite (40% to 41% iron content), which was used for iron ore and less so for pigment. The limonite deposits resulted from weathering of pyrite and pyrrhotite. Similar deposits occur in Grayson, Carroll, Pulaski, Montgomery, Louisa, and Spotsylvania Counties, Va. Gossan alterations associated with sulfides have also been utilized in California for pigment (103).

Minette-Type Iron Carbonate Ores

The iron carbonate ores of Pennsylvania, which resemble impure blue limestone, are dark blue when fresh, but soon redden on exposure to air. This is caused by the oxidation of iron present originally as carbonate. Oxidation and hydration also weaken the rock structure so that the ore is easily broken.

Two theories have been proposed to account for the origin of the iron carbonate "paint" bed of Pennsylvania. The first is that the iron was present in the bed since its deposition in the Devonian seas. Fine brown or red mud with high iron content was deposited in the ocean along with calcareous matter, and iron was reduced and combined in carbonate form. The second theory is that the ore bed is merely part of the "cement bed" now associated with the iron carbonate, wherein iron carried by descending waters replaced part of the calcium in the original calcareous layer. The bed of clay beneath the ore body would have effectively stopped downward percolation of iron-bearing waters. The pyrite that is found in the ore is also believed to have been formed by combination of iron with sulfur, associated with organic matter in the overlying Marcellus-Hamilton carbonaceous shales.

Redistributed Deposits

Tertiary sands and clays of the Virginia coastal plain contain ocher, and for a time, ochers from deposits along the Appomattox River competed favorably with the French ochers. Ocher also occurs at numerous localities along the eastern base of Little Catoclin Mountain in Virginia. The deposits occur beneath the surface of a peneplain and are usually covered by 2 to 8 feet of gravel and sand. Ocher apparently resulted from breakdown of Catoclin Schist and reprecipitation of iron where it encountered calcareous solutions in the Newark conglomerate. The ocher is fine grained and relatively free of impurities.

Ocher occurs in Vermont as a part of a series of unconsolidated sediments (Brandon Formation) consisting of kaolin, ocher, quartz sand, iron and manganese oxides, and coal of Miocene age. The Brandon Formation lies unconformably on the metamorphosed basal sediments of the Green Mountains. The sediments are the result of Tertiary alteration of the Precambrian gneisses and the Vermont Formation.

FOREIGN ORES

General Discussion

Iron oxide pigment deposits occur in nearly every country, but have been exploited significantly in only a few. Countries that have been historically famous for their iron oxide pigment production include Iran (Persian Red), Spain (Spanish Red), Italy (sienna, umber), France (French ocher), Cyprus (Turkish umber, ocher), and Austria (micaceous hematite). Although production of natural iron oxide pigments in other countries at times has exceeded output from these countries in tonnage, the fame accorded to pigments from these six countries is apparently unmatched. Popularity and world acceptance of a pigment play a decisive part in its use, and once a pigment is accepted, only a world war, internal political strife, and diminishing supplies cause drops in demand.

Countries with recent significant production in iron oxide pigments include India, Brazil, Pakistan, and South Africa. India is currently the largest natural iron oxide pigment producer (in recorded production), showing a progressive increase since the early 1950's (table 1). Pakistan has also had notable increases in production in recent years. The United Kingdom, Australia, Canada, and the Federal Republic of Germany in the past have had significant pigment production which has diminished in more recent years, owing to increased demand for synthetics and higher mining costs. Venezuela and Burma are known to produce some natural iron oxides for export, and new deposits of red and yellow ocher are being investigated in Israel. However, no data were available on these deposits at the time of publication (table 1). Some U.S. producers of finished pigments were reportedly buying Venezuelan hematite as a substitute for the declining Michigan ores. Specular hematite has apparently been mined for pigment in the United Kingdom, the Federal Republic of Germany, Norway, Sweden, France, Spain, and Sierra Leone, but the most acceptable grades come from Austria (43).

TABLE 1. - Mine production of natural iron oxide pigments, by country

(Metric tons)

Country	1977 ^p	1976	1975	1974	1973	1972	1971	1970	1969	1968	1967	1966
Argentina.....	176	174	240	139	167	264	256	60	310	85	40	65
Australia.....	62	1,025	-	38	62	599	71	660	678	534	364	2,488
Austria.....	9,805	10,627	8,722	9,546	9,796	8,194	7,969	7,734	8,363	9,959	5,268	4,780
Brazil.....	6,630	5,957	7,490	10,309	5,432	1,247	NA	NA	NA	NA	NA	NA
Burma.....	399	190	214	129	127	78	-	-	-	-	-	-
Canada.....	-	-	-	-	-	-	-	-	-	-	-	-
Chile.....	8,146	6,941	9,085	16,482	25,462	21,065	14,900	19,937	18,516	17,761	19,765	29,199
Cyprus.....	12,300	10,000	4,489	13,456	26,035	20,920	14,932	11,458	17,729	6,776	6,720	5,692
Egypt.....	32	100	472	81	-	-	-	-	-	385	345	-
France.....	13,000	13,000	12,702	8,123	NA	1,139	2,542	3,260	2,159	5,100	5,049	3,145
Germany, Fed. Rep. of ¹	26,000	23,000	18,000	18,000	20,000	18,000	15,000	15,000	16,000	15,000	9,000	21,000
India.....	68,010	89,662	98,320	80,500	53,560	67,409	53,018	39,708	39,089	39,928	37,854	32,033
Iran ²	4,600	4,500	6,000	6,000	5,000	12,500	4,600	8,000	5,100	9,700	9,500	9,310
Italy.....	NA	NA	6,550	1,850	1,640	1,150	1,190	1,330	1,600	1,980	-	540
Morocco.....	-	14	47	24	36	25	37	36	36	24	-	36
Pakistan.....	14,310	15,940	1,713	15,236	6,183	3,720	5,248	2,672	659	338	1,139	543
Paraguay.....	120	120	140	110	90	60	45	40	15	25	22	10
South Africa, Rep. of.....	2,170	2,411	3,285	2,623	2,321	8,447	3,097	3,151	3,185	3,894	8,632	5,767
Spain: Ocher.....	NA	8,990	8,432	6,229	8,184	10,602	12,897	12,480	20,780	17,165	15,327	16,146
Red iron oxide	NA	NA	51,924	51,501	50,825	50,944	50,526	51,610	50,345	51,040	43,920	40,130
United States..	53,735	60,643	39,313	52,157	46,380	31,305	37,519	35,017	36,832	52,254	36,196	57,334
	1965	1964	1963	1962	1961	1960	1959	1958	1957	1956	1955	
Argentina.....	48	25	70	129	92	202	2,030	3,992	209	250	13	
Australia.....	NA	NA	NA	NA	NA	NA	NA	17,000	7,361	NA	NA	
Austria.....	5,283	4,304	4,120	3,308	3,516	3,459	2,939	2,805	2,887	1,835	2,541	
Brazil.....	-	-	-	-	-	-	-	-	-	-	-	
Burma.....	-	-	-	-	-	-	-	-	-	-	-	
Canada.....	213	937	887	699	626	825	1,107	1,481	6,985	7,824	-	
Chile.....	11,596	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Cyprus.....	14,846	7,206	6,510	7,347	4,627	4,556	4,841	4,305	4,788	4,824	NA	
Egypt.....	370	325	-	-	-	-	748	994	NA	91	18	
France.....	4,513	5,625	4,747	5,698	7,772	6,011	6,178	NA	NA	12,500	13,472	
Germany, Fed. Rep. of ¹	10,000	10,000	11,000	10,000	11,000	18,300	19,300	58,785	57,004	54,930	60,853	
India.....	34,850	32,520	26,410	22,800	18,800	20,650	21,190	20,410	15,440	12,814	16,480	
Iran ²	8,980	7,024	NA	NA	8,330	9,800	7,500	4,742	NA	13,689	6,162	
Italy.....	680	4,990	-	-	6,608	9,104	8,109	-	3,741	-	-	
Morocco.....	48	866	869	1,237	1,541	1,411	2,107	1,927	1,670	1,173	1,374	
Pakistan.....	142	159	561	651	413	458	284	235	408	396	265	
Paraguay.....	60	55	-	-	-	-	-	-	-	-	-	
South Africa, Rep. of.....	4,741	4,975	3,966	4,559	5,104	5,784	4,999	5,538	8,839	9,406	11,312	
Spain: Ocher.....	21,243	20,170	15,208	18,664	19,125	17,692	15,667	39,364	39,114	37,389	24,859	
Red iron oxide	33,670	23,820	13,825	NA	NA	NA	NA	NA	16,965	15,156	16,150	
United States..	51,709	53,796	45,450	52,163	41,730	63,775	48,897	49,623	44,724	48,897	50,984	

Dashes indicate no production.

^e Estimate. ^p Preliminary. NA Not available.¹ Includes production of Vandyke brown.² Iranian calendar year (March 21 to March 20), beginning in year indicated.

Sources: BuMines Minerals Yearbook, v. I, Iron Oxide Pigments, 1955-62. BuMines Minerals Yearbook, v. IV, country chapters, 1963-69. BuMines Minerals Yearbook, v. III, country chapters, 1970-77. Ministerio das Minas e Energia (Brasilia). Anuario Mineral Brasileiro (Minerals Yearbook of Brazil). V. 5, 1976, p. 253. Brabers, A. J. M. Mineral Pigments. South African Geol. Survey, Mineral Resources of the Republic of South Africa, 5th ed., 1977, pp. 391-393. Servicio Sindical de Estadística, Estadísticas de Producción Industrial (Industrial Production Statistics). Madrid, 1975, p. 512. Indian Bureau of Mines, Ministry of Steel and Mines (Nagpur, India). Ochre. Indian Minerals Yearbook. 1970, p. 471. Comisión Asesora y de Estudios Técnicos de la Industria Química Española (Madrid). La Industria Química en España (The Chemical Industry of Spain). Madrid, 1973, p. 98.

South Africa and France are probably the two most important sources of yellow ochre in the world today. Ancient hematite mines that have been worked for over 40,000 years are also found in South Africa, as well as in Southern Rhodesia, Swaziland, and Lesotho. Recent investigations suggest that pigment workings at Bomvu Ridge in western Swaziland on the borders of the Transvaal, South Africa, are the oldest known mining operations in the world (14). Radioactive carbon dating indicates that these workings are more than 40,000 years old and may be 80,000 years old.

Deposits of greatest significance to iron oxide pigment production are those resulting from secondary enrichment or those of residual origin. This includes deposits originating as laterites, gossans, redistributed ores, minette types, evaporitic basin sediments, and brown iron ores. Iron carbonates and jarosite deposits have also been exploited, but are of lesser importance. Itabirite and other Precambrian enriched iron formations are most important in India and Brazil. Usually, however, it is the secondary local modification of these more extensive iron ore types that provides good pigment material.

This paper presents general descriptions of most principal pigment producers of the world. Some lesser producers and prospects are included when information was available. Time has not permitted as thorough an investigation as might have been desired, but the interested investigator will find this report a starting point for a more detailed search; an extensive bibliography was included for this purpose.

Australia

Location and Production

Pigment-grade iron oxides occur in every State of Australia (fig. 5 and table 2). Recent (1974-77) production figures indicated on table 1 were obtained from the Bureau of Mineral Resources of Canberra through the Australian Embassy (24). Production since the 1950's has been irregular.

TABLE 2. - Iron oxide pigment localities in Australia
(Numbers correspond to those shown on fig. 5)

Location	Pigment types
Queensland:	
1. Mount Oxide, Cloncurry district.	Hematite, hard, compact.
2. Kangaroo Hills.....	Hematite with manganese.
3. Iron Island.....	Hematite, massive.
4. Pittsworth.....	Hematitic clay.
5. Benarkin.....	Hematite.
6. Mount McGuire.....	Mixed limonitic and hematitic clay.
New South Wales:	
7. Gulgong.....	Mixed red and yellow clays.
8. Glen Innes.....	Hematitic ocher.
9. Dubbo.....	Yellow ocher.
10. Wingello (Moss Vale).....	Do.
11. Michelago and Mudgee.....	Do.
Victoria:	
12. Bendigo.....	Pigment clay.
13. Nowa Nowa.....	Hematite-magnetite.
14. Mirboo North.....	Pigment clay.
15. Point Addis.....	Jarosite.
16. Gordon.....	Pigment clay.
17. Heathcote.....	Do.
18. Ballarat region, Lillicur, Ouyen	Do.
19. Dookie and Balnarring.....	Do.
20. Buchan.....	Limonite gossans.
Tasmania:	
21. Spalford.....	Hematitic ocher.
22. Mowbray.....	Hematite and limonite.
23. Mount Vulcan.....	Chrome-bearing hematite and limonite.
24. Smithton district.....	Limonite.
South Australia:	
25. Malcolm Creek.....	Micaceous hematite.
26. Copper King mine.....	Siderite and copper carbonate.
27. Maltese Cross mine (Oodla Wirra)	Limonitic ironstone.
28. Birdwood.....	Limonite gossan.
Western Australia:	
29. Wilgie Mia.....	Hematite, banded iron formation.
30. Eastern Hamersley Range.....	Hematite.
31. Carbarup-Kendenup.....	Hematite, limonite, sienna.
32. Karara Station.....	Hematite.
33. Pinnacles.....	Do.
34. Rothsay.....	Do.
35. Boddington.....	Do.
36. Kalgoorlie.....	Hematite and limonite.
37. Mogumber.....	Hematite.
38. Toodyay.....	Do.
39. Wyndham.....	Do.
40. Mount Monger.....	Hematitic clays.
41. Balkuling.....	Hematitic ocher and sienna.

TABLE 2. - Iron oxide pigment localities in Australia--Continued

Location	Pigment types
Western Australia (Con.):	
42. Carnamah.....	Hematite.
43. Cossack.....	Hematite and limonite ochers, sienna.
44. Geraldton.....	Hematite ocher, sienna.
45. Widgiemooltha.....	Hematite.
46. Weld Range.....	Limonite.
47. Meekatharra.....	Do.
48. Jarrahwood.....	Raw and burnt sienna, high-iron.
49. Beverly.....	Sienna.
50. Kundip-Eyre Ranges.....	Sienna, umber.
Northern Territory:	
51. Rumbalara.....	Limonite.
52. Jay Creek.....	Limonitic ocher.

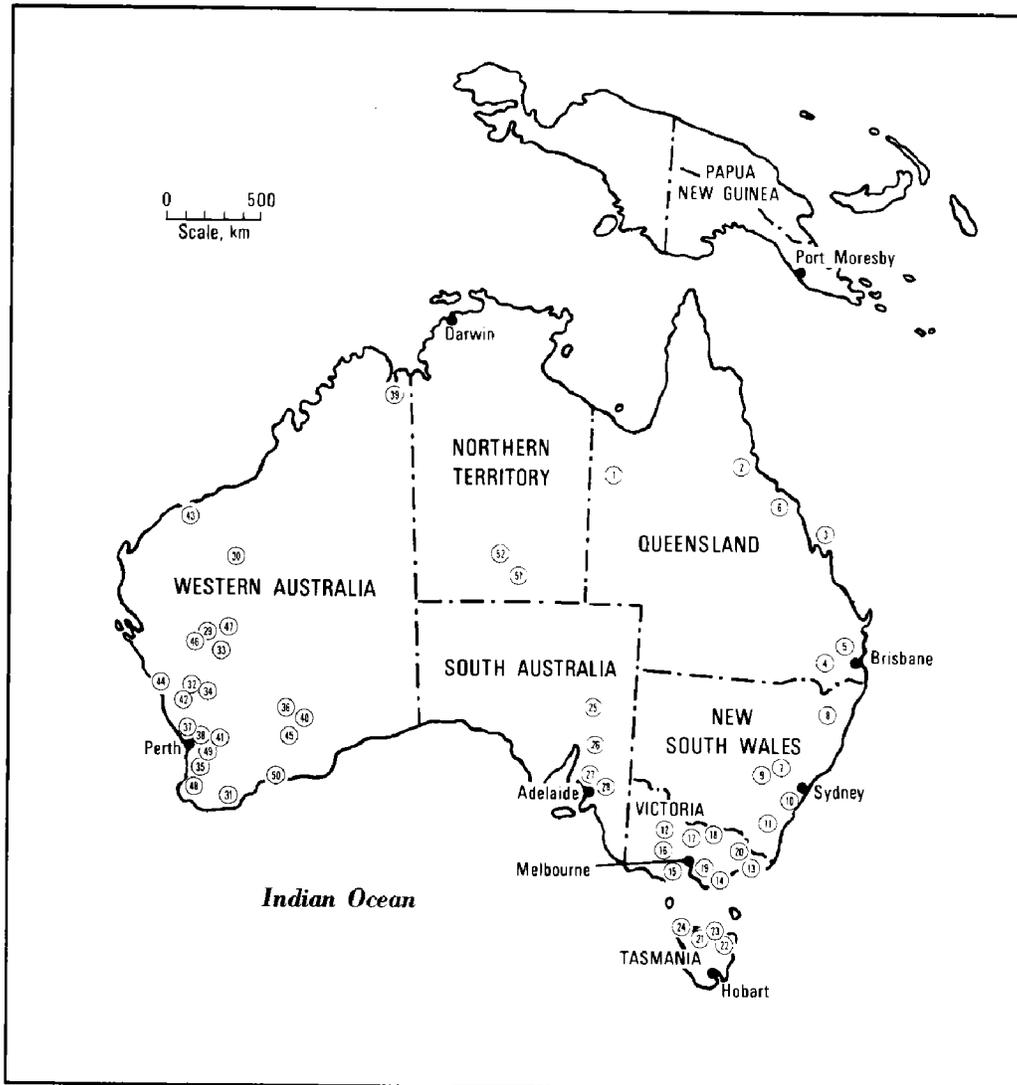


FIGURE 5. - Iron oxide pigment deposits in Australia (51, pp. 293-296).
See table 2 for explanation of numbered locations.

By 1973, two mineral pigment suppliers were listed by the Review of Australian Mineral Industry (3): (1) Mineral Supplies Pty. Spalford, Tasmania 7315, and (2) Universal Milling Co. Pty. Ltd., Welshpool, Western Australia 6106. All recorded production for 1974 consisted of red and yellow ocher from Tasmania. Since 1976, Universal Milling, active in Western Australia, and Minerals Proprietary Ltd. (100 Eastern Road, Alexandria, New South Wales), active in South Australia, have both shown some production.

Official records of the Australian Bureau of Minerals Resources show a small amount (20 tons) of micaceous hematite mined for pigment in South Australia in 1977. Universal Milling was the only company mining small quantities of iron oxide from the Weld Range in Western Australia in 1976-78. The deposit is located about 450 miles northeast of Perth near the town of Cue. The finished pigment is red ocher. About 2,000 tons per year was mined, although only about 400 tons was actually consumed (64).

In 1973, Mineral Industries Pty. Ltd., at Nowa Nowa, sold 449 tons of iron oxide for gas purification. Iron oxide production in Australia, other than that used for iron ore, totaled 65,881 tons in 1971, 38,364 tons in 1972, and 71,292 tons in 1973. This included iron oxides used for gas purification, cement, and coal washing (3). Iron oxides used for pigments were not distinguished.

Historically, there has been production from a number of localities throughout Australia. Some of these are described in the following paragraphs.

Queensland

A deposit of red ocher (ferruginous red to purplish clay), about 8 kilometers northeast of Pittsworth in Queensland, was worked approximately 65 years ago for paint. During 1947-51, 150 tons of red ocher from a deposit near Benarkin was railed to Brisbane for treatment. However, the color was not acceptable, and selective mining was impracticable. Attempts to develop a marketable product from the abundant hematite and hydrated iron oxides in Queensland have never resulted in sustained production. The hematite of Iron Island, located 68 kilometers northeast of St. Lawrence, was quarried as a flux, but has pigment potential.

New South Wales

The last recorded production of mineral pigment in New South Wales was in 1960. Producing areas are listed in table 2.

Victoria

The pigment deposits of Victoria are small and erratic in grade. From 1908 to 1937, 4,702 tons was produced, including 4,592 tons of pigment clay and 110 tons of red oxide produced from roasting jarosite at Point Addis. Nearly half (1,918 tons) came from Ballarat in 1926.

Tasmania

A total of 2,498 tons was produced in Tasmania to the end of 1966; in 1974, 38 tons was recorded. This production came from Spalford and Mowbray in the Launceston district, from Mount Vulcan in the Beaconsfield area, from the Smithton district, and from the Carlton district of southeast Tasmania. Both red and yellow ocher were produced. Chrome-bearing iron oxide deposits at Mount Vulcan produced a variety of pigments including yellow, red, green, and chocolate.

South Australia

Production of yellow and red ochers from South Australia was intermittent and ceased entirely in 1953 when 4,062 tons had been recorded. Ocher was produced from siderite at the Copper King mine, located 16 kilometers north of Beltana. Yellow and golden-yellow ochers containing up to 80% Fe_2O_3 were mined at the Maltese Cross mine near Oodla Wirra. Yellow ocher was also produced from a deposit located 5 kilometers north of Birdwood. More recently, laboratory and pilot scale tests have indicated the commercial potential of a micaceous hematite deposit located at Malcolm Creek, 50 kilometers northeast of Adelaide. The material would be upgraded by flotation and milling to a product meeting the specifications of welding rod coatings, structural paints, and concrete and ceramic pigment. A company was formed to develop the deposit (51, p. 295), and 20 tons was produced in 1977.

Western Australia

Production ceased in 1972 at the Wilgie Mia deposit of the Weld Range, but mining began again by 1976. This is the oldest (worked since the ninth century (51) by Aborigines as indicated by carbon dating) and largest known ocher mine of the area. The Aborigines were estimated to have removed 46,500 tons; commercial European efforts produced 7,783 tons from 1945 to the end of 1972. Although yellow ocher occurs in pipes at Wilgie Mia, no production is known; 404 tons of yellow ocher was produced at the western end of the Weld Range.

Other known production from Western Australia included 3,860 tons of high-grade red ocher mined from the eastern part of the Hamersley Range between 1938 and 1944. Main production came from 13 kilometers south of Poonda out-camp. Both raw and burnt sienna have been produced from the Jarahwood deposit. A total of 12,751 tons of red and yellow ochers was produced in Western Australia to the end of 1972. Since then, no production has been recorded.

Northern Territory

The most significant production of ocher has been from the Rumbalara deposits located 200 kilometers south of Alice Springs. These deposits have provided the best yellow ocher available in Australia, and the Aborigines prized the ocher for body and weapon decoration. The Australasian United Paint Company Ltd. of Adelaide held the mining leases in Rumbalara. An extensive limonitic ocher occurrence has been mined near Jay Creek, 40 kilometers

west of Alice Springs. Production was limited because of its less attractive color. Manganese oxide at Groote Eylandt, which gives a deep black color, and finely divided hematite at Frances Creek, which gives an attractive purple shade, have never been developed for industrial use.

Geological Description

Iron oxide pigments in Australia have been derived from a variety of deposit types. The most common geological occurrences include extensive laterite deposits such as those in Queensland and the Northern Territory; gossans such as those in Queensland, Victoria, and New South Wales; and massive hematite bodies such as those occurring in Queensland and Victoria. Other types include the iron carbonate deposits of South Australia and the jarosite deposits of Victoria. Brief descriptions by territory of a few of these deposits follow.

Queensland

Iron-rich gossans are abundant throughout the metalliferous areas of the State, but details concerning their suitability as a pigment source are lacking (51, p. 293). Other potential pigment sources are the widespread areas of Cenozoic laterite cover. Pure hematite also occurs in significant quantities in the Cloncurry district. Exploitation here is handicapped by the remote location and the fact that the mineral is hard and compact. Massive hematite bodies occur at Kangaroo Hills and on Iron Island. Pigment material occurs as disjointed veins and nodules up to 45 millimeters in diameter, surrounded by gray clay in an earthy ironstone capping near Benarkin. At Mount McGuire, the ocherous material was a localized boulder-type deposit of 6,000 tons. The ocher consisted of both limonite and earthy hematite mixed with clay and fine sand; colors varied through reddish brown and brown to yellow.

New South Wales

Iron oxides suitable for pigments are widespread in New South Wales and are found in association with a variety of rock types. Iron hydroxides derived from weathering are mixed with clay and other impurities by the decomposition of igneous and metamorphic rocks and by the alteration of sulfide deposits. Circulation of iron-rich waters also yields ocherous deposits that are associated with silica and calcium and magnesium carbonates in many places.

Victoria

Pigment clays and pigment obtained from roasting of jarosite ($\text{KFe}_3(\text{OH})_6(\text{SO}_4)_2$) have both been produced in Victoria. The iron ore deposits of the Buchan-Nowa Nowa region are also a potential source of mineral pigments. The three types of iron ore deposits known in the region are the hematite-magnetite lodes of Nowa Nowa, the manganiferous iron deposits of Mount Tara, and the limonite gossans of Buchan. Reserves of these areas are as follows: (1) hematite-magnetite (Five Mile and Seven Mile deposits), 5.61 million tons; (2) limonite (Buchan), 6.8 million tons; (3) manganiferous iron ore (Mount Tara), small; material from this deposit was reported to have good covering

and staining power. Most of the pigment clay production came from the deposit at Ballarat.

Northern Territory

At Rumbalara (91), located 831 miles north of Adelaide, numerous mesas are composed of horizontal, leached shales and sandstones of Cretaceous age that are 150 feet thick and capped by siliceous laterite, or "grey billy." The Rumbalara Shale is the name given for these beds, which rest unconformably on the eroded surface of the flat-lying De Souza Sandstone. The ocher occurs in the Rumbalara as beds 1 to 4 feet thick; the best grade consists of soft, friable, golden yellow material that is free from grit and has good properties for paint. The ocher appears to be of sedimentary origin, as it always occurs at the same stratigraphic horizon. The deposits were estimated to be extensive. The main ocher bed forms the basal bed of a Cretaceous marine sequence and may have originated as a bacterial sediment formed by Cretaceous microorganisms at the time of marine sedimentation, or as a result of laterization related to Miocene peneplanation.

The ocher at Rumbalara consists mainly of yellow ferric hydroxide (45% to 55%) and kaolin, with accessory quartz grains and muscovite flakes. It is considered to be a good grade of yellow ocher, although soluble chlorides and a slight acidity might render it unsuitable as an ingredient in special anti-corrosive paints.

Austria

Location and Production

Although specular hematite (specularite) deposits and mines have been reported in numerous countries, the largest and best known commercial deposits of micaceous hematite used for pigments are in Austria. Specular hematite for pigment is mined and processed by the Karntner Montanindustrie GmbH of Klagenfurt from large, relatively continuous deposits near Waldenstein (38). One early drawback was the large size of the flakes, which tended to stick in spray nozzles. Grinding after mixing with paint reduced particle size without breaking up the platy structure, and Karntner's output was expanded in the early 1970's to about 8,000 tons per year. Austrian exports are mainly to the Federal Republic of Germany, the United Kingdom, and Japan.

The quality of the Austrian specularite ore lies in its high Fe_2O_3 content, extremely low content of soluble salts, and surface area of the flakes. A typical assay follows (75): 95.00% Fe_2O_3 , 3.74% SiO_2 , 0.47% Al_2O_3 , 0.18% CaO , 0.19% MgO , and 0.078% water-soluble salts. The particle sizes range from about 5 to 100 micrometers, placing them in the coarser size class of pigments available for paints.

Geological Description

Most of Austria's iron ore deposits are of the Bilbao type (94) developed in Paleozoic limestone formations. These deposits usually consist of low- to --

medium-grade iron ores of siderite, goethite, and hematite. The Erzburg, Radmer, and Huttenberg iron ore deposits, currently mined, were formed in Upper Devonian to Lower Silurian limestone. The micaceous nature of the ores resulted from tectonic stresses that occurred during Alpine folding.

Brazil

Location and Production

Brazil produced 5,957 tons of iron oxide pigments in 1976, all from the State of Minas Gerais (69). Production since 1972 is shown on table 1. Pigments are mined in Ouro Prêto, Congonhas, and Nova Lima (Belo Horizonte). In the past, small deposits were also mined for local use in the Alegria district. Ocherous clays occur at Paraiba, but mining has been only sporadic.

Brazil produces iron oxide pigments mainly for domestic use and for export to nearby countries. A range of colors is produced, including black magnetite and yellow and red ochers. The most desirable pigment is a red iron oxide produced by calcination of limonite; a cherry red is obtained by milling hematites. When manganese and/or organic materials are present in the ores, brown siennas and umbers are produced (1).

Brazil also produces small quantities of synthetic pigments by calcination of iron sulfate or by precipitation of ferric hydroxides.

Geological Description

Most of Brazil's iron ore and iron oxide pigment deposits occur in the southeast part of the State of Minas Gerais in a region known as the Quadrilatero Ferrifero. Estimated reserves of pigment-grade iron oxides at mines in Minas Gerais are reported as follows, in metric tons:

<u>District</u>	<u>Measured</u>	<u>Indicated</u>	<u>Inferred</u>
Belo Horizonte.....	15,271	452,000	None.
Congonhas do Campo..	10,000	None...	Do.
Itabirito.....	214,314	..do...	Do.
Ouro Prêto.....	2,887	..do...	Do.
Santa Barbara.....	508,869	202,026	2,000
Total.....	751,341	654,026	2,000

Source: Ministerio das Minas e Energia (69, p. 229).

Deposits of red and yellow ocher are scattered through the area. The pigment deposits are apparently developed in parts of the iron formation that are commonly mined for iron ore, and in the hard, indurated capping known locally as canga, which has a limited use as iron ore but may be important for pigments.

The iron-bearing formations of the Quadrilatero Ferrifero occur mostly within the Itabira Group of the Precambrian Minas Series. The Minas Series is divided into three groups and many formations. At the base is the Caraca Group of clastic rocks with some phyllite at the top. These rocks are

overlain by those of the Itabira Group, which are sedimentary rocks of chemical origin that include the Caue Itabirite at the base, and carbonate rocks of the Gandarela Formation above. The Piracicaba Group overlies the Itabira Group and consists of clastic rocks with some dolomite.

Both the Caue Itabirite and the Gandarela Formation are sources of iron oxide pigments. The Caue Itabirite is a low-grade metamorphosed oxide-facies iron formation composed of alternating hematite-rich and quartz-rich laminae. The Gandarela Formation contains ferruginous and dolomitic phyllite and itabirite. The term itabirite denotes a laminated, metamorphosed, oxide-facies formation, in which the original chert or jasper bands have been recrystallized into granular quartz and in which the iron is present as hematite, magnetite, or martite. A 25% iron content distinguishes it from ferruginous chert and 66% iron content from pure hematite.

Canga is a Brazilian term for a surficial rock widely developed on, or adjacent to, an iron formation, and less commonly on other types of rock relatively rich in iron. It is typically composed of fragments of itabirite and hematite that are cemented by yellow-brown and red-brown iron oxides that have been precipitated from ground-water solutions. Canga forms a hard surface capping that is very resistant to erosion. It may have developed during different erosion cycles and may be of different ages in the same area. The canga is, in general, thought to be Tertiary. Two different chemical processes form canga: one in which iron is precipitated at or very close to the source, as in laterites, and another in which iron remains in solution and is carried some distance away into the subsurface before it is precipitated. The division between canga and laterite is indefinite, and gradations range from firmly cemented canga to incoherent laterite. The types range from "canga rica," composed of hard hematite blocks with minimal limonite cement, to cellular limonite with no fragmental material.

In the Belo Horizonte area (27), weathered, earthy, yellow-brown ocherous rock developed in the Caue Itabirite is common, particularly in the upper part of the formation. In some exposures the ocher occurs as thin layers alternating with darker brown magnetic iron oxide, or a phyllitic oxidized yellowish platy silicate. The ocherous material absorbs water readily and may become saturated. It may "splash" when hit and has earned the local name of "splash rock." In ocherous itabirite, magnetic and yellow-brown iron oxides are generally dominant in contrast with the normally dominant hematite. The gradation of isolated ocherous laminae within the itabirite indicates that some ocher development occurred during chemical sedimentation which was continuous from itabirite to the unweathered source rock of the ocherous itabirite. The source rock of the ocher was thought to be dolomite, or dolomitic itabirite. Deep weathering has caused the original rock to soften and become enriched with leaching or eluviation of the silica and carbonate and addition or redistribution of iron. The average itabirite contains 40% to 45% iron, whereas weathered itabirite generally contains 50% to 65% iron and sometimes more.

A deposit of yellow ocher developed in the Caue Itabirite has been worked at a small paint factory near Triangulo and Kilometer 16 on the highway from Belo Horizonte. Yellow ocher also occurs some distance southwest of the

factory and extends northeast for about 3 kilometers where it is observed along the highway. The ocherous zone comprises about 500 meters out of a total width of 600 meters for the entire Caue Itabirite. Ocherous magnetic iron formation also occurs at the top of the Caue Itabirite northwest and north of Sabara.

Irregular masses of ocher, along with nodules, and angular fragments of hard dark-red ferruginous material occur in the soil and decomposed rock at several places within the Congonhas District (30). Some ocher deposits are veinlike or concretionary and have banded or concentric internal structure; others faintly preserve bedding and cleavage and resulted from replacement of phyllite by iron oxide or hydroxide. An analysis of the latter type is 72.7% Fe₂O₃, 11.9% SiO₂, 8.7% Al₂O₃. The ocher is related to canga in origin with special conditions of ground-water circulation and concentration of the iron. Most ocher is in phyllite near outcrops of iron formation, and the general geologic relationships suggest that a structural disturbance facilitated its formation. Thus, the principal mines are in a small klippe straddling the Sao Julio-Casa de Pedra border 1 kilometer south of Fabrica, and smaller deposits are located about 1 kilometer to the west-northwest. Both areas are near a thrust plane where the upper Minas Series phyllite lies on itabirite of a younger age.

Small deposits of red and yellow ocher occur sporadically through the Alegria District (62), and a few tons have been produced for local use as paint pigment. The ocher deposits occur where the canga grades laterally into a layer about 10 meters thick of soft, yellow, ocherous material containing nodules of hard red ocher and thinly disseminated, tiny magnetite octahedra. This grades upward into a 3-meter layer of fine-grained hematite and specularite. The bottom 6 meters consists of hematite and specularite interbedded with thin layers of ocherous clay and quartz, which become thicker and more numerous with depth.

Chile

Location and Production

Iron oxides are produced in Chile for use in cement, in gas purification, and as paint pigments. Three producers were listed for 1974-76 (70): Cemento Cerro Blanco de Polpaico S.A., Casilla 9908, Santiago; Armando Calderon V., Las Heras 138, Los Andes; and Marcial Silva V., El Magui 684, Puente Alto. Following is a list of production by province, 1967-76, in metric tons:

	Santiago	Coquimbo	Aconcagua	O'Higgins	Valparaiso	Total
1967.....	2,639	10,720	5,504	-	902	19,765
1968.....	1,000	10,550	6,208	-	3	17,761
1969.....	120	14,000	4,396	-	-	18,516
1970.....	700	13,000	5,335	-	902	19,937
1971.....	202	10,955	3,743	-	-	14,900
1972.....	-	19,186	1,879	-	-	21,065
1973.....	-	23,662	1,800	-	-	25,462
1974.....	-	14,475	1,800	207	-	16,482
1975.....	-	¹ 8,485	² 600	-	-	9,085
1976.....	-	¹ 6,941	-	-	-	6,941

Dashes indicate no production.

¹Region IV.

²Region V.

Production has dropped in recent years, from a high in 1966 of 29,199 tons to 6,941 tons in 1976.

Chile possesses a relative abundance of iron oxide pigment deposits (97). Some of the pigment varieties mined have included red earths, yellow earths (ochers and siennas), green earths (chiefly iron silicates with alkalis and magnesia), umbers, and iron sulfate derivatives. The deposits are usually massive horizontal lenses, mined by open pit methods. Although the operations are usually hand-mined, earthmoving machines are sometimes used.

The most abundant supply of pigment in recent times has come from Coquimbo, Santiago, and Aconcagua Provinces. In Coquimbo Province, limonite (33% Fe_2O_3) and red iron oxides (53% Fe_2O_3) are both exploited in the Sierra del Cerro Negro deposits, located 15 kilometers north of Vicuna. The Santiago deposits are located near the communities of Til-Til and Montenegro. Hematite and limonite pigments are exploited at Manto Jardin in Atacama Province from deposits located near Mineral de Elisa de Bordos and the community of Tierra Amarilla, and in Antofagasta Province near Calama. Pigments are also found in Linares Province at Catillo (red oxide) and near Nacimiento in Bio-Bio Province (red and yellow).

In Tarapaca Province, yellow ocher was mined at Chislluma in the Altiplano region, at Quelrada de Allane, and at Camarana. The Camarana deposits, located 60 kilometers from Cerro Gordo station, included a pigment of intense yellow color, similar to chromium yellow. Deposits at Cuja, located near Quebrada de Camarones, were used for a red pigment that was reportedly equivalent to some of the Spanish-red iron oxides.

Geological Description

In general, the pigment deposits of Chile occur in residual deposits and gossans as alterations of sulfides, other iron minerals, and carbonates. They are frequently derived from decomposed kaolinized rocks that are colored with iron oxides. The red hematitic pigments are most common and are generally highest in iron content (80% to 95% Fe_2O_3). A red pigment is also obtained from calcination of iron sulfate and the yellow earths. In some cases, the yellow color is attributed to a high iron sulfate content as well as to limonite. The umbers are more rare, and at times occur as efflorescent deposits developed on manganiferous hematite or siderite.

Iron sulfate and limonite deposits have been exploited in Tarapaca Province. Limonite (ocher) deposits occur as minor extensions of iron sulfate deposits at Chislluma in the Altiplano region, and at Quelrada de Allane. Hydrated iron sulfates are fairly common in Chile owing to the low rainfall and desert environment. The deposits occur as secondary alterations of pyrite and marcasite. The iron sulfate minerals include copiapite ($\text{Fe}_4(\text{OH})_2(\text{SO}_4)_5 \cdot 18\text{H}_2\text{O}$) and coquimbite ($\text{Fe}_2(\text{SO}_4)_3 \cdot 9\text{H}_2\text{O}$).

In Aconcagua Province, sienna, which is mined from horizontal lenses on level ground, contains 76% Fe_2O_3 and about 14% water. In Antofagasta Province, along the Capana Hill pediment, near the community of Calama, red iron oxide (82.5% Fe_2O_3) was exploited from irregular pockets or lenses. The deposits of Til-Til and Montenegro in Santiago Province are limonite and hematite in horizontal lenses that are exposed at the surface. At Montenegro the material contains 60% to 70% Fe_2O_3 , and at Til-Til the yellow ochers contain 50% Fe_2O_3 .

Cyprus

Location and Production

The iron oxide pigments of Cyprus, which are sometimes referred to as Turkish pigments, include umber, yellow ocher, sienna, burnt sienna, and terra verte. Some micaceous iron oxide (hematite) also has reportedly been produced (43). Table 1 shows production since 1956. Exports of umber, ocher, and terra verte for the years 1973-76 are shown in table 3. Both the United States (importing 6,359 tons in 1977) and the United Kingdom are significant importers of Cypriot iron oxide pigments.

TABLE 3. - Iron oxide pigment exports of Cyprus, 1973-76

Pigment	1973		1974		1975		1976	
	Metric tons	Value (U.S.)						
Terra umbra..	13,292	\$795,036	9,690	\$736,895	4,205	\$361,236	10,115	\$809,563
Yellow ocher.	97	9,305	606	101,350	221	45,700	442	72,519
Terra verte..	-	-	-	-	3	1,086	-	-

Dashes indicate no exports.

The following Cypriot companies are currently engaged in mining natural iron oxide pigment material (77):

Cyprus UMBER Industrial Co. Ltd. of Larnaca
P. O. Box 22
Larnaca, Cyprus

A. L. Mantovani & Sons Ltd.
P. O. Box 109
Larnaca, Cyprus

Messrs. Oryktako Ltd.
P. O. Box 1157
Nicosia, Cyprus

Messrs. Talyou Ltd.
P. O. Box 3646
Nicosia, Cyprus

Messrs. Zenon Pierides & Sons Ltd.
P. O. Box 25
Larnaca, Cyprus

The Troulli Mines Corp., formed in 1962 as a joint operation by American Metal Climax and Cyprus Mines Corp., mines copper as well as umber (57). The principal pigment exporters were the Mantovani and Pierides firms of Larnaca.

Geological Description

Most of the umber and ocher pigment deposits of Cyprus occur in the Cretaceous sediments of the Perapedhi Formation, at localities situated around the Troodos Massif and the Troulli Inlier (fig. 6). The Perapedhi Formation is associated with, and lies everywhere unconformably upon, the volcanic rocks of the Troodos Pillow Lava Series. The Perapedhi sediments form the lowest part of the Lafka Group (table 4) and appear to have been the result of filling in hollows formed either by subaerial erosion or by wave action of a shallow sea on the lava surface. The high relief of the pillow lava surface prior to sediment deposition suggests uplift, with considerable subaerial erosion before the first marine transgression and sedimentation. The thickness of the formation rarely exceeds 15 meters. In places, the Perapedhi sediments may be tilted or folded either by orogenic movements or by local slumping.

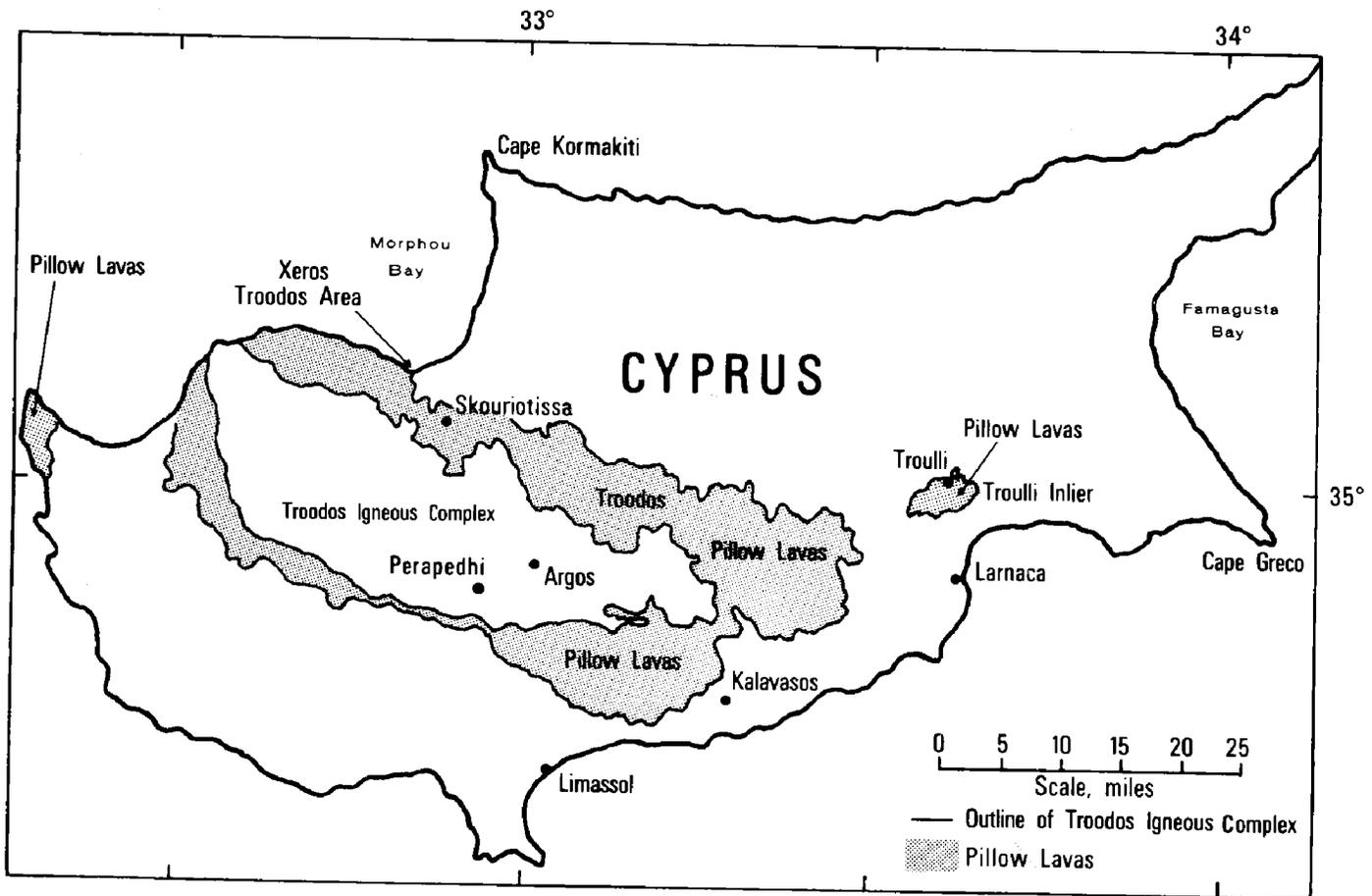


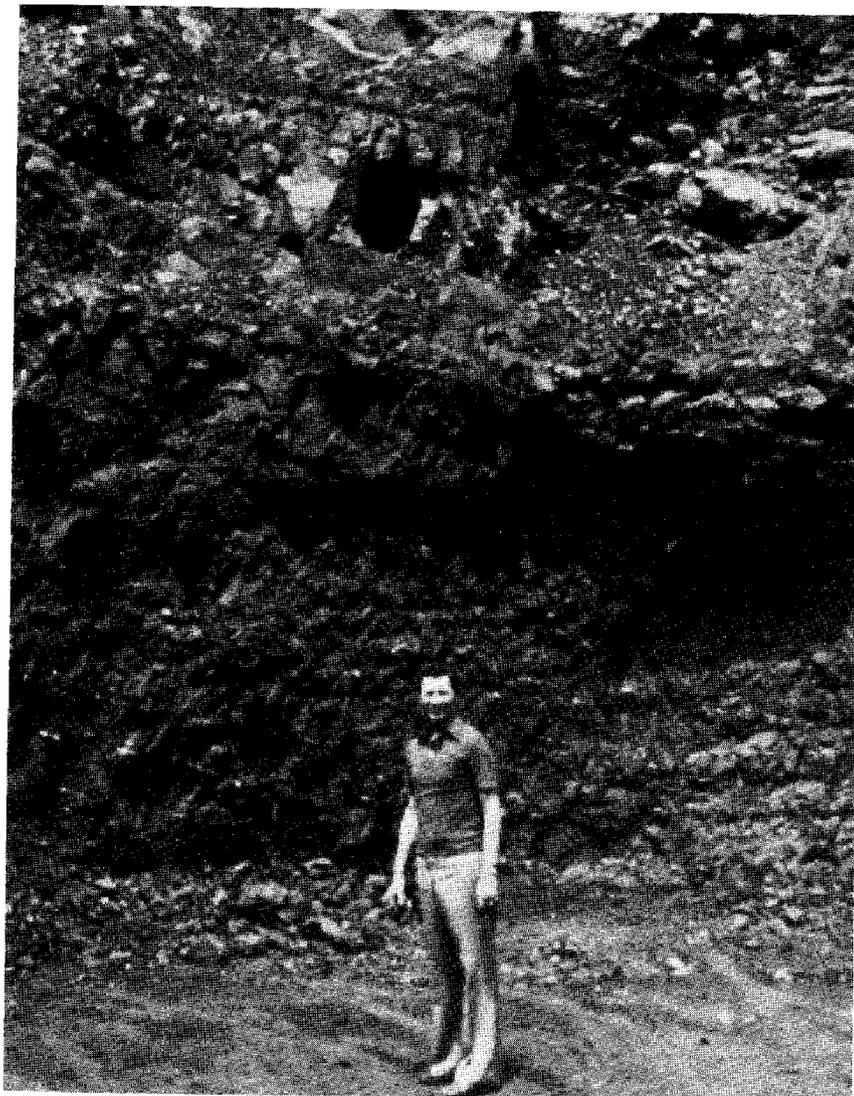
FIGURE 6. - Geologic outline of the Troodos Igneous Complex and pillow lavas in Cyprus. The iron oxide pigment deposits occur at scattered localities around the Troodos Massif and fill in hollows formed on the eroded pillow lava surface.

TABLE 4. - Sedimentary formations in Cyprus (78)

Era	Age	Group	Formation	Description	Maximum thickness, meters	
	Recent			Soils, havara, kafkala	0-4	
Tertiary	Pliocene	Mesaoria Group	Nicosia-Athalassa	Grits, pebble beds, fragmental limestone	250	
			Pliocene marls	Gray to buff marls		
	Angular disconformity					
	Upper Miocene to Middle Miocene	Dhali Group	Pakhna	Creamy chalks, buff marls, shales, gypsum, limestone	20	
	Angular disconformity					
	Lower Miocene to Oligocene			Upper Lefkara	Flaggy chalks and marls	150-180
				Angular disconformity		
	Eocene to Paleocene		Lefkara Group	Middle Lefkara	Massive chalks	5-25
					Chalks with cherts	125-150
	Angular disconformity					
Upper Cretaceous	Maestrichtian		Lower Lefkara	Pink marls Grayish-white chalks	20-25	
	Campanian	Trypa Group	Perapedhi	Umber, bentonitic clays, siltstones, radiolarian cherts	0-63	
Unconformity						
Preupper Cretaceous			Troodos	Pillow lavas and agglomerates		

The Perapedhi rocks are characterized by the absence of calcareous and arenaceous sediments. Umbiferous shales, umbers, and radiolarites, jaspers, and cherts are less frequent constituents. According to most investigators, there seems to be little doubt that the provenance of the Perapedhi sediments was the Troodos igneous complex. The tuffaceous material represents reworked material of volcanic origin. The bentonitic clays indicate a similar provenance.

Figure 7 illustrates the occurrence of umber and umbiferous sediments within volcanic rocks at a mine at Avdhellero, north of Larnaca. Mining is by power equipment, and the umber must be separated from large amounts of volcanic waste rock before calcination. The hole in the rock that is shown at the top of figure 7 resulted from mining by hand in former times; miners crawled into tunnels through such holes, broke up the umber, and carried it out in baskets.



The umbers are dense, homogeneous, and extremely fine-grained rocks with a conchoidal fracture and a soapy surface and are largely composed of mixed oxides and hydroxides of iron and manganese. Shades of brown, dark brown, and yellowish or reddish brown predominate, ranging to black in places. Silicified umber (hornstone) is often encountered as fragmental blocks in the northeast part of the pillow lavas in the Troulli Inlier. UMBER from the Skouriotissa mine, located in the northwestern part of the island, contains between 0.47% and 13.5% manganese dioxide. UMBER from a mining area near the town of Perapedhi, located in western Cyprus, indicated a content of 53% to 43% ferric oxide and 6.94% manganese dioxide. Table 5 shows chemical analyses of umbers and clays taken from the Troulli quarries located at the southeastern border of the Troodos Massif near Larnaca.

FIGURE 7. - UMBER mine of Mantovani UMBER Industries, Ltd., located about 15 miles north of Larnaca at Avdhellero, Cyprus; Mr. Tony Mantovani, Managing Director. (Courtesy, Willard A. Burns, Reichard-Coulston, Inc.)

TABLE 5. - Chemical analyses of umbers and clays from Troulli quarries, Cyprus
(Weight-percent)

Analyses	Sample No. ¹							
	15	18	19	39	62	67	49	42
SiO ₂	19.47	20.99	23.85	19.06	20.36	23.01	19.98	9.40
Al ₂ O ₃	7.44	4.85	4.95	2.38	7.48	4.99	8.74	5.90
Fe ₂ O ₃	53.36	48.67	51.80	65.22	49.46	51.81	44.76	51.78
Mn ₃ O ₄	11.20	13.12	7.25	3.20	12.26	7.96	4.38	15.39
CaO.....	1.66	2.54	2.73	2.42	None	2.78	2.38	.70
MgO.....	1.47	1.60	1.46	1.89	.do..	1.49	1.29	None.
SO ₃.....	.15	.18	0.16	.31	0.29	.16	.09	Do.
Loss on ignition.....	5.25	8.04	7.80	5.52	10.15	7.80	18.38	16.83

¹Samples 15, 18, 19, 39, 62, and 67 are burnt powdered umbers from Troulli quarries, Cyprus Umber Corp. Samples 49 and 42 are raw powdered umber from Troulli quarries, Cyprus Umber Corp.

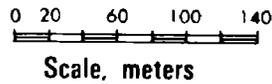
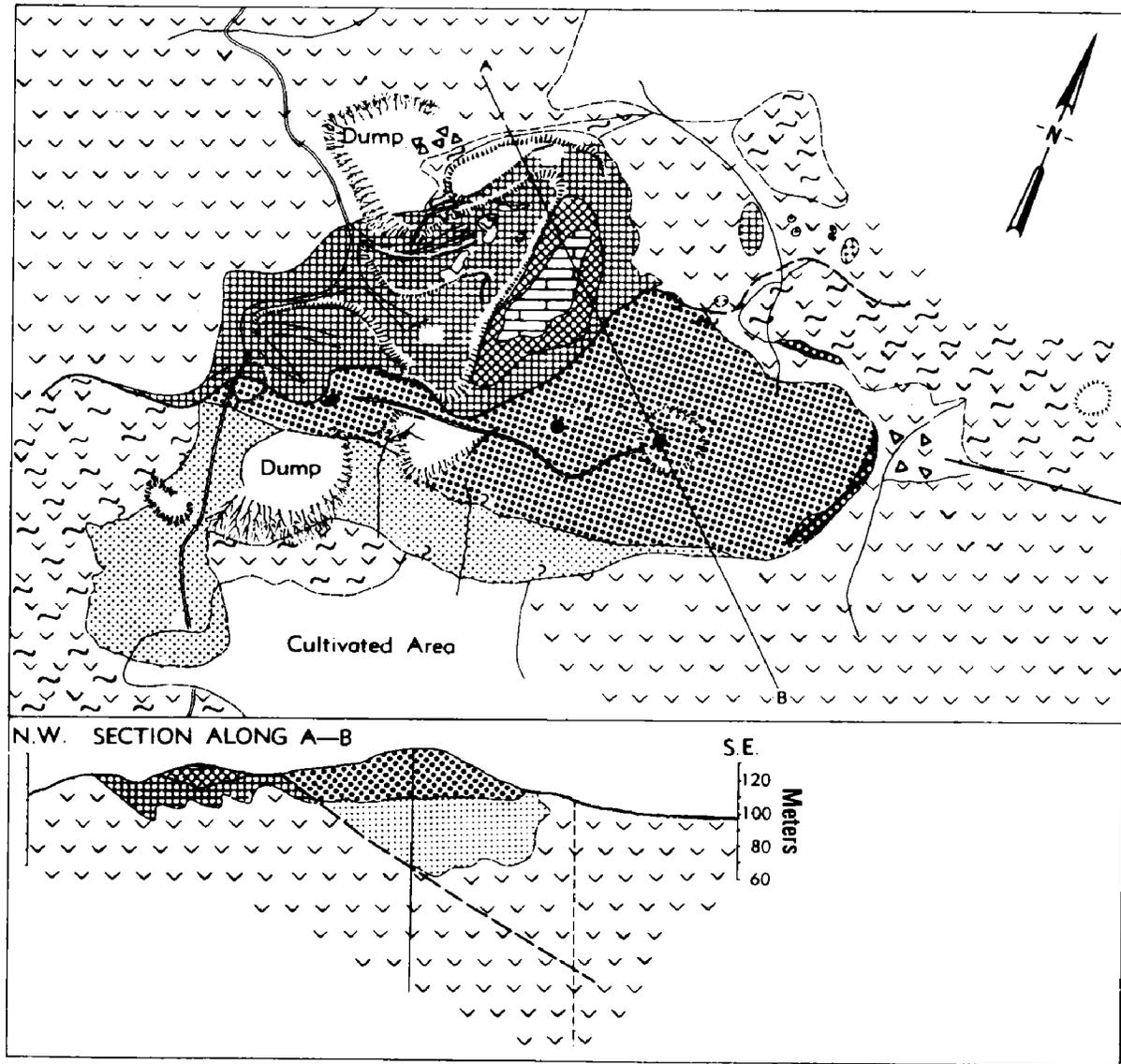
Source: Lilljequist (57, p. 70).

The Perapedhi umbers may also contain trace amounts of copper and zinc, as shown by analyses of selected umbers from the Troulli area. Black umber from the Kokkinopetra prospect located in the Troulli Inlier (fig. 8) contained 1,550 parts per million copper and 900 parts per million zinc. Samples of dark brown umber from the southern pit and from the Arsos pit located north of the Kokkinopetra prospect each showed, respectively, 800 and 1,050 parts per million copper and 500 and 450 parts per million zinc. The Perapedhi sediments in general, however, do not contain sulfide ores of economic importance. It has been suggested (78), furthermore, that these sediments, which are relatively impermeable and chemically inert, acted to prevent the ascent of sulfide-mineralizing fluids, allowing extensive replacement of the underlying rocks and formation of the sulfide ore bodies of the district.

Compared with umber, occurrences of ocher and terre verte are rare in these deposits. Terre verte, which occurs in economic quantities at only a few places, is a green earthy material having a composition similar to celadonite (a silicate of iron, magnesium, and potassium with lamellar or fibrous habit), associated with minor intrusions of the Lower Troodos pillow lavas. Red and yellow ocher occurs at the Skouriotissa lease, where both Limassol Chemical Products Ltd. and Umber Corp. of Larnaca have held permits.

In the quarry situated close to Ayios Yeorghios, ocher formed an almost horizontal bed, 6 feet thick, between chalky marls and gray clay. The marls above the ocher contained small nodules of malachite and azurite. Small patches of red ocher were found in the yellow ocher. Jarosite (an iron sulfate) was also associated with the ocher, and it was speculated (44) that these minerals could be attributed to the mineralizing fluids that also formed the Skouriotissa sulfide ore body.

The ochers of Skouriotissa may have originated (85) by a combination of submarine oxidation, later surficial erosion, and redeposition of the altered



LEGEND

- | | |
|--|---|
|  Lapithos chalks |  Breccia |
|  Perapedhi clays |  Hematitic staining |
|  Umber |  Weak gossans |
|  Upper pillow lava flow |  Strong gossans |
|  Upper pillow lavas |  Lumps of pyrite in clay |

FIGURE 8. - Geological map and cross section of the Kokkinopetra prospect, Cyprus Mines Corp., located 2 miles east of Troulli Village (57).

sulfide ores, with simultaneous chemical precipitation of iron-rich minerals from hydrothermal solutions. The following are analyses of ocher and burnt sienna from the Ayios Yeorghios quarry in percent:

<u>Ocher</u>		<u>Burnt Sienna</u>	
Al ₂ O ₃	4.50	Al ₂ O ₃	3.41
SiO ₂	8.79	SiO ₂	11.10
Fe ₂ O ₃	71.70	Fe ₂ O ₃	78.09
Mn ₃ O ₄.....	.22	SO ₃	3.78
CaO.....	.38	H ₂ O, etc....	3.62
MgO.....	.04		
CuO.....	.50		
SO ₃.....	.23		
H ₂ O, etc....	13.64		

France

Location and Production

Historically, French ocher has been famous for its high quality; the yellows have been considered superior to those of any other country in the world. French ocher usually has a low iron oxide content (about 20%), but its physical properties account for its superiority as a pigment. The principal deposits of commercial value are at Apt, in the Department of Vaucluse in southeastern France, and Auxerre, in the Department of Yonne, southeast of Paris (fig. 9). Other deposits have been identified near Thiviers in the Department of Dordogne and near Villers le Tourneur in the Department of Ardennes. World demand for French ocher has declined in the last 20 years owing to economic competition from synthetic iron oxides. However, it is still in demand and mined in substantial quantities by the following companies: Société des Ocres de France, Etablissements Lamy, and Société des Ocres du Roussillon (7). Distributing agents and dealers in French natural and synthetic iron oxide pigments follow:

A.P.C., S.A., 62/68, rue Jeanne-d'Arc, 75646 Paris Cedex 13.

Bayer-Chimie, 47, rue du Général-Leclerc, 92130 Issy-les Moulineaux.

Charpentier (Division Matières Plastiques de Leroy Matières Colorantes S.A.), 255, rue de Paris, 93 - Montreuil (natural oxides as well as synthetics).

Compagnie Française des Pigments, 96, rue Victor-Hugo, 94200 Ivry-sur-Seine.

Dumont (Ets P.), 9, rue de la Guadeloupe, 75881 Paris Cedex 18.

Franc S.A. (Henry), 19, rue Marc Antonie Petit, 69002 Lyon.

Klein et Roubinet, 47-49, rue de Geneve, 93 - La Courneuve (Bayer A.G. distributors).

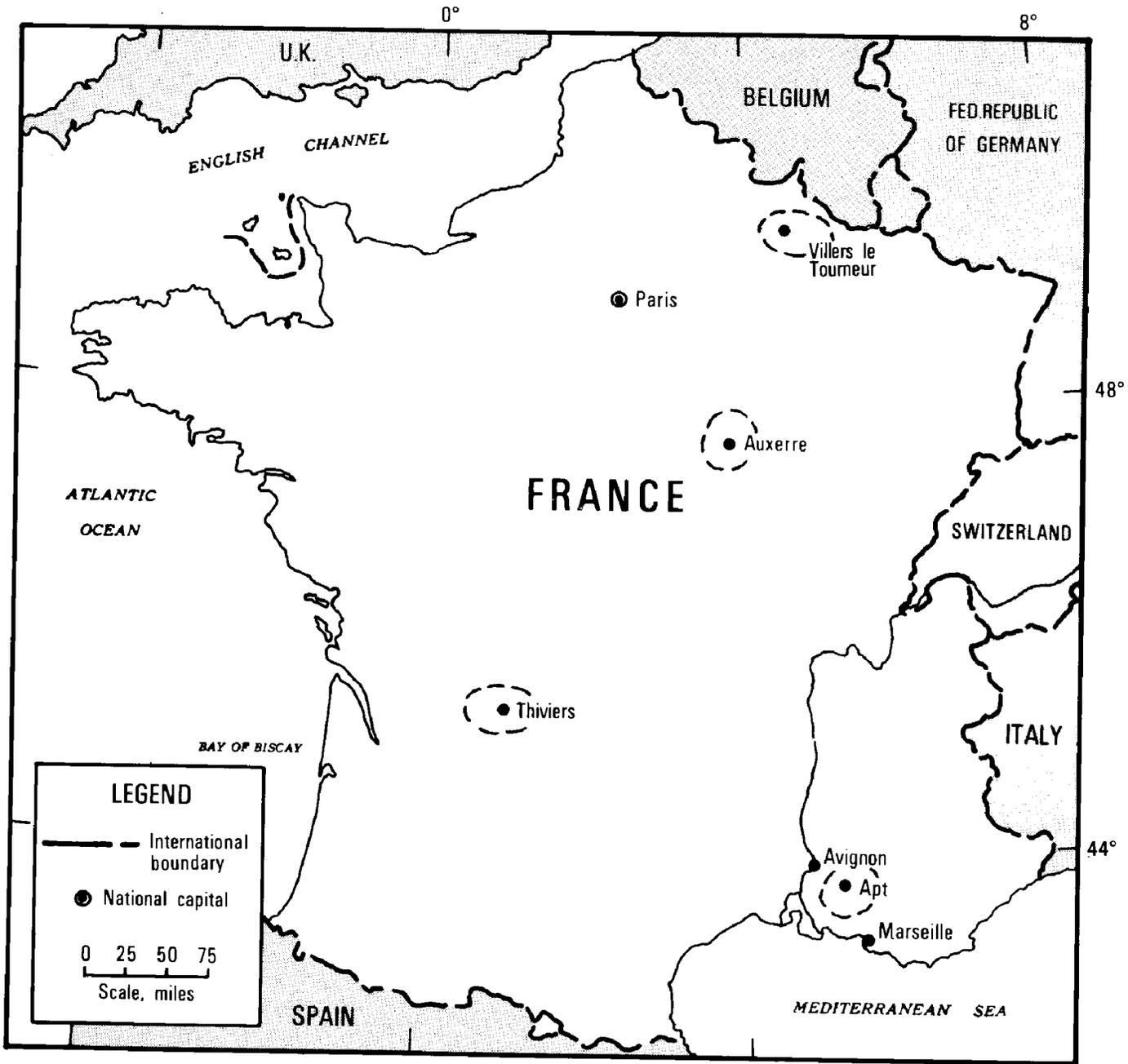


FIGURE 9. Iron oxide pigment deposits in France. (Broken circle indicates areas of pigment deposits.)

Lamotte et Coiffard Produits Chimiques, 38 à 46, rue Raspail, 94 - Ivry (natural and synthetics, agents for Ets. Moris Ashby of Great Britain).

Produits Sandoz, 92505 Rueil-Malmaison, Brun Graphot GLPV.

Rhone-Poulenc Chimie Fine, 21, rue Jean-Goujon, 75360 Paris, Cedex 08.

Sogemet, S.A., 161, avenue Charles-de Gaulle, 92202 Neuilly.

Natural iron oxide production attained about 6,000 to 8,000 tons in 1975, mostly from the region of Apt, where ocher, both red and yellow, has been exploited since the end of the 19th century.

The principal district for ocher production is in the vicinity of the village of Apt, where deposits are concentrated principally in two valleys of the Provence Alps: at Calavon Torrent between the Luberon and Vaucluse mountain ranges, and at Auzon River between the Vaucluse and Ventoux Ranges. A full color range of ochers exists in the area, from light yellows to deep reds. The French Satin grade of canary and lemon yellows from the Gargas field in Vaucluse was formerly considered to be the premium yellow iron oxide on the world market (87).

Much activity took place in the area prior to World War I. There are many remains of old quarries, open pits, or underground mines, sometimes connected by channels to settling basins. The remains of these workings can be seen in mushroom and asparagus fields where the ochery sands provide fertile soil and where farmers historically mined ocher in their off-seasons (87). Small private operations coexisted with larger plants, but they eventually gave way to organized companies with more modern equipment.

Geological Description

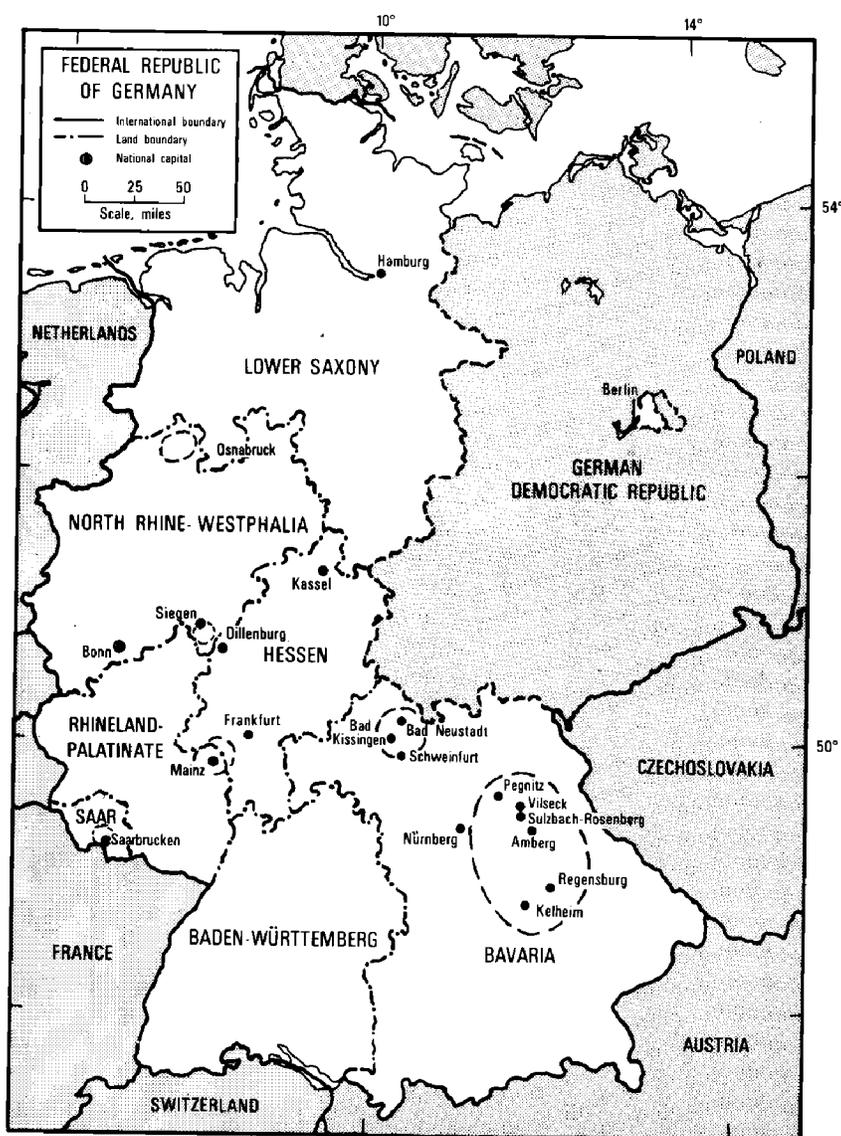
The age of the deposits is uncertain because the occurrence of fossils in the ochery sands is rare. However, most investigators concur that they are probably marine sediments of Middle Albien (Middle Cretaceous, ref. 92) age, as has been determined by correlation with surrounding beds of fossiliferous sandstone. The Middle Albien series is famous in the Apt region, where it is almost exclusively represented by a facies of ocher-rich sand. The series is usually about 20 meters thick, with a few exceptions, notably in the region between Gignac and Oppedette where there is faulting and some facies changes. At other places, as in the Conlon karst region, post-Cretaceous erosion has caused thinning of the ocher unit (86).

The lithologic succession varies, but the base usually consists of yellow glauconitic sands in which pockets of ocher occur. The upper part of the succession is usually red and weakly cemented. The morphology and mineralogical composition of the ocher is as follows: quartz sand grains are usually 0.2 to 0.3 millimeter in diameter and are never larger than 2 millimeters. The grains frequently show traces of wind erosion, which has been interpreted as having occurred prior to marine erosion. Flakes of muscovite and glauconite also occur. The presence of glauconite and foraminifera is interpreted as evidence of a marine environment. Glauconite ordinarily is not altered except at the surface, where it has been replaced by goethite or hematite. The minerals include calcite, dolomite, apatite, chlorite, biotite, zircon, rutile, sphene, monazite, tourmaline, garnet, fluorite, hornblende, and staurolite. The other part of the ocher formation is the matrix composed of kaolinite, iron salts, and micrometer-sized quartz. The origin of the ocher has been attributed by various authors to marine deposition (86) or to continental weathering processes. It may also have been derived from alteration products of glauconite, deposited in wind-blown or marine sands.

Federal Republic of Germany

Location and Production

Natural iron oxide pigments in the Federal Republic of Germany are composed of both red hematitic and brown and yellow limonitic ochers. Coloring earths and iron oxides are widely distributed throughout the country, with deposits in Bavaria, Rhineland-Palatinate, Hessen, North Rhine-Westphalia, Lower Saxony and Saar Provinces (fig. 10). The Sulzbach district east of Nürnberg, Bavaria, has been by far the most important area of pigment production (37). At one time more than 20 companies mined ores for pigment, but the number declined after 1960 (29).



Historically, many small ocher deposits were mined by hand from rectangular pits that were sunk to a depth of only 1 or 2 meters. When a deposit was exhausted, a similar pit was sunk only a few meters away, creating a cratered appearance in some areas. However, many workings of the district were 5, 10, or 20 meters deep, and two workings in the vicinity of Königstein were reported to be 112 meters and 70 meters deep (29). As late as 1971, a few of the old workings were still in operation on a seasonal basis, but owing to diminished demand for natural pigments, only one company, Ockergrube Leonhardszeche Steinbach, now produces pigments. This company exploits pigment deposits from Upper Cretaceous sediments of the Frankish hills east of Nürnberg and produced 10,630 metric tons of ocher from three mines in 1975 (52).

FIGURE 10. - Iron oxide pigment deposits in the Federal Republic of Germany. (Broken circle indicates areas of pigment deposits.)

The richest ores occur east of Nürnberg in Bavaria, associated with folded structures known as the Sulzbacher, Trondorfer,

Neukirchener, and Königsteiner domes, and the Königstein saddle. The best known and most numerous deposits of coloring earth (farberde) lie like a mantle in semicircular fashion around the Hahnbach dome, northeast of Sulzbach. Also in Bavaria, ocher was mined in deposits along the Salle River between Bad Kissingen and Bad Neustadt.

A pigment known as Cassel brown is produced near Kassell, Hessen Province. The pigment is not technically an iron oxide, owing to its high organic content (61). However, it is imported into the United States under a Tariff Schedule classification for iron oxides and is sold in the United States as Vandyke brown. The producer is Zeche Hirschberg von Waitz KG (52).

Geological Description

Numerous occurrences of coloring earth (also variously referred to as ochers) are found in the Cretaceous sediments of the Frankish hills east of Nürnberg. Cretaceous rocks associated with the pigments consist of sands, sandstones, clays, conglomerates, marls, and limestones; they are from several meters to over 100 meters thick. There are generally three forms of deposits. (See figure 11, an idealized drawing showing the spatial relations of iron oxide pigment ores.) The most common form is a trough or pocket filling; other, less common, forms are deposits in crevices and/or cavities, which have the purest and most salable ocher. Mining of these deposits is limited

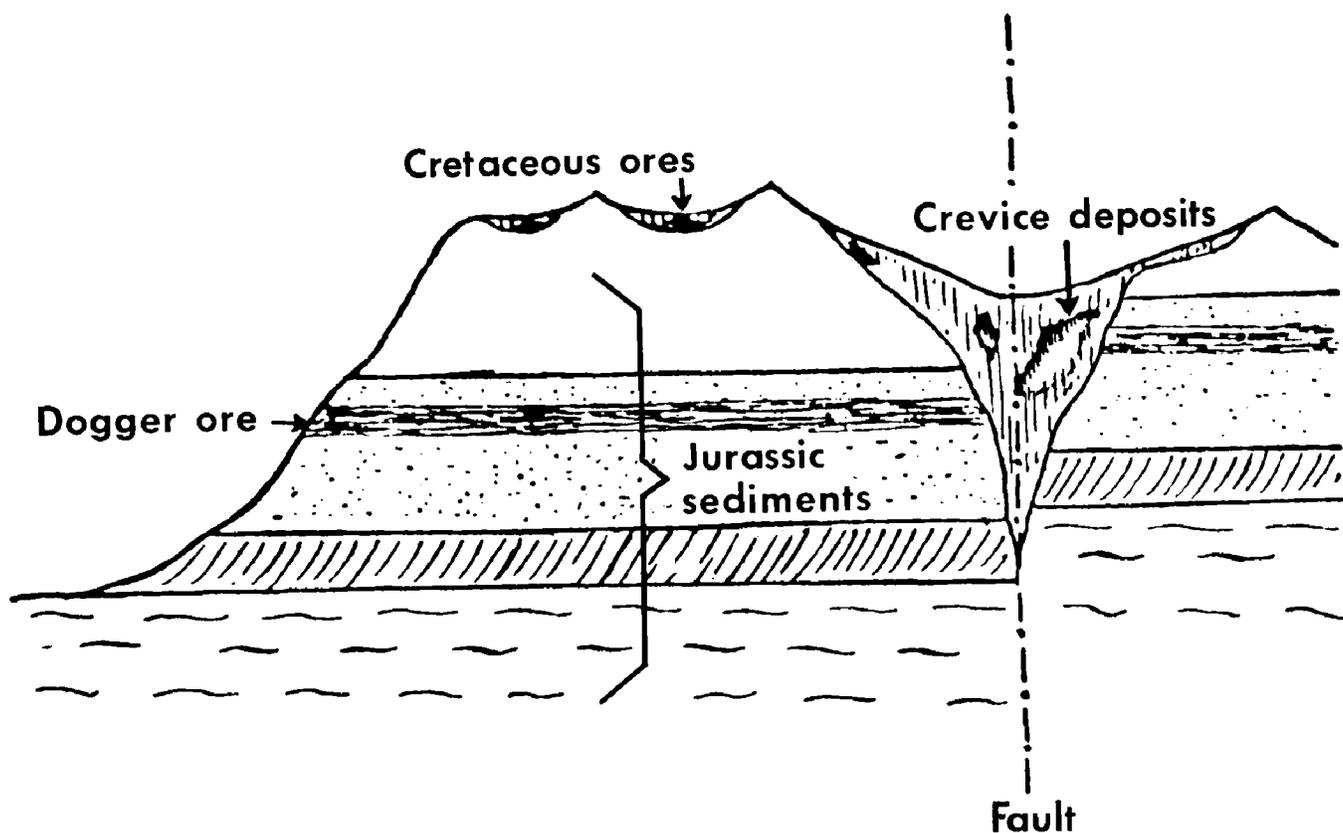


FIGURE 11. - Schematic profile of the Frankish hills, showing idealized spatial relationships of the iron oxide pigment ores, modified after Krehn (53), p. 7.

because of water seepage at the boundaries of the deposits; therefore, only the center of the deposits can be worked.

Ochers in the Cretaceous deposits are of two types. The first type consists of iron hydroxide and iron oxide-containing coloring earths that are difficult to separate on the basis of either origin or stratigraphy from the Dogger brown iron ores of Jurassic age with which they are closely associated, and from which they are probably derived. This group includes soft, earthy, bright yellow to dark brown clays that are intermixed with brown iron oxide and an earthy brown iron ore with an iron content of about 60%. When the manganese content is high, the ore is grayish black. According to investigators, these ochers were derived from brown iron ores, as suggested by the gradation of brown iron ore into ocher in many places, as well as by inclusions of clay and sand, fragments of brown iron ore and sandstone, and glauconitic clay veins in the pigment. Ocherous materials that are rich in manganese appear to be derived from remnants of the older, fractured Dogger ores. Coloring earths may also be iron oxide-colored sediments that are composed of brownish-red, red, and gray-white sands or sandstones, or of several colors of clays. They may be overlain by a yellow potter's clay, with or without hornstone and sandstone. Coloring earths also sometimes contain glauconite and have a rough ferruginous sandstone skin.

The second type of Cretaceous pigment found east of Nürnberg is a mixture of hydrous iron oxides and iron silicates; approximately 45% is iron oxide, with some manganese oxide, 18% silica, 9.5% clay, and 27.5% water. It was known commercially as Amberger golden ocher, but is no longer mined.

Iron oxides and hydroxides of Jurassic origin are found northeast and southeast of Nürnberg, on either side of the Cretaceous formations. At Keilberg, east of Regensburg, Jurassic coloring earth known as ruddle or bolus occurs in ironstone; it also occurs northeast of Pegnitz, near Troschenreuth. Located about 10 to 12 meters below the upper boundary of Dogger sandstone, it consists of an unindurated brick- or scarlet-red clay, up to 2 meters thick. If manganese is present, the material is usually violet red. The ruddle or bolus occurs 10 to 14 meters above the Dogger red iron ore layer. In the region surrounding Pappenburg, north of Vilseck, a yellow clayish ocher known as the Pappenburger bolus overlies the Troschenreuth ruddle.

At Gunzendorf, northeast of Pegnitz and south of Troschenreuth, ocher with iron sulfate and bog iron ore of Quaternary age was mined. The iron sulfate content of the bog iron ore and ocher resulted from breakdown and redistribution of pyritic and lime-rich material that occurred at the boundary between opaline clay and the Jurassic Dogger sandstone. When mined, the Gunzendorf ocher was not separated from the iron sulfate, but both were roasted with bog iron ore in a calcining furnace. This produced a special product with finely mixed organic material. After roasting, it contained about 93% Fe_2O_3 and was used as iron ore in the foundries as well as for pigment. It was also used as a polishing agent for mirrors and optical glass.

The ocher in deposits along the Saale River between Bad Kissingen and Bad Neustadt is an iron hydroxide from mineral springs that was deposited in

cracks up to 20 meters deep during the Quaternary period. The ocher is yellow to rust red and contains inclusions of porous, honeycombed brown-to-rust-red bog iron ore.

In the Kelheim region south of the Sulzbach district, some ore was mined for coloring earth from the Bohn ores of Tertiary age. However, the operation was not commercially important.

Although the major commercial region for mining iron oxide pigments in Germany has been in Bavaria, deposits have been identified in several other regions of the country. Coloring earths of the Tertiary period are located northwest of Saarbrücken in Saar Province, and near Mainz in Hessen Province; coloring earths and brown iron ores of Devonian age are found west of Dillenburg, southeast of Siegen, near the border of North Rhine-Westphalia and Hessen; and pigments of Permian age lie west of Osnabrück, near the border of North Rhine-Westphalia and Lower Saxony.

An earthy, brown iron ore of Keuper (upper Triassic) origin is found northeast of Schweinfurt. This is a weathered clay containing brown or yellow chalk layers up to 1 meter thick. The ore is brightly or darkly colored, fine grained, and closely fractured. It occurs in the gray shell clays of the Lettenkeuper, or potter's clay Keuper.

Cassel brown, or Vandyke brown, pigment is produced from Tertiary strata near Kassel in Hessen Province. The deposits are closely associated with the area's lignite deposits (52).

India

Location and Production

India is probably the largest producer of natural iron oxide pigments in the world (table 1). Indian ocher includes a broad category of red, yellow, brown, or green natural mineral pigments whose pigmentary quality is due to iron oxide. Both hematite- and limonite-based pigments are considered collectively under this general class. Depending upon color, they are specifically termed red ocher, yellow ocher, green earths, sienna, and umber. Other names such as "earth colors" or "red oxide (Persian Gulf Type)" may also be used.

Natural pigments (ocher) are found extensively in the country. They are mined in Andhra Pradesh, Madhya Pradesh, Gujarat, Maharashtra, Karnataka, Rajasthan, and West Bengal States (table 6 and fig. 12). Jaitwara in Satna district, Madhya Pradesh, is well known for red and yellow pigments. Ramallakota area in Kurnool district of Andhra Pradesh produces mostly yellow pigments. The Bellary district of Karnataka (formerly Mysore) is important for red pigments, which are associated and mined with the hematitic iron ore of this region. Here, run-of-the-mill ore is finely ground and washed to produce pigment-grade material. India is considered self-sufficient in iron oxide pigments and consumes the greater part of the production domestically. Tables 6 and 7 show State production (1966-76), and national exports and imports (1962-71). Combined reserves from all districts mined were estimated at 5.5 million metric tons (41).

TABLE 6. - Iron oxide production in India, by State, 1966, 1971, and 1976

(Metric tons)

State	1966	1971	1976
Andhra Pradesh.....	3,884	4,485	1,878
Gujarat.....	280	145	431
Madhya Pradesh.....	17,518	14,747	15,889
Maharashtra.....	1,226	1,849	1,182
Karnataka.....	6,146	15,323	16,267
Rajasthan.....	2,158	16,449	51,820
West Bengal.....	821	20	-
Uttar Pradesh.....	-	-	2,195
Total.....	32,033	53,018	89,662

Dashes indicate no production.

Source: Madan, A. K. Problems, Progress & Prospects of Mineral Production. Institute of Economic & Industrial Survey, New Delhi, 1979, p. 137.

TABLE 7. - Exports and imports of iron oxide pigments for India, 1962-71

(Metric tons)

Year	Exports		Imports	
	Earth colors	Red oxide (Persian Gulf type)	Earth colors	Red oxide (Persian Gulf type)
1962.....	14	383	3	1,576
1963.....	55	515	4	1,576
1964.....	416	593	12	1,683
1965.....	290	401	60	2,033
1966.....	1,274	152	58	1,542
1967.....	243	176	133	2,304
1968.....	621	1,165	77	1,830
1969.....	447	3,903	16	1,830
1970.....	1,267	5,093	765	1,809
1971.....	1,542	3,275	29	1,270

Source: Indian Bureau of Mines, Ministry of Steel and Mines (Nagpur, India). Ochre. Indian Minerals Yearbook, 1970, p. 41.

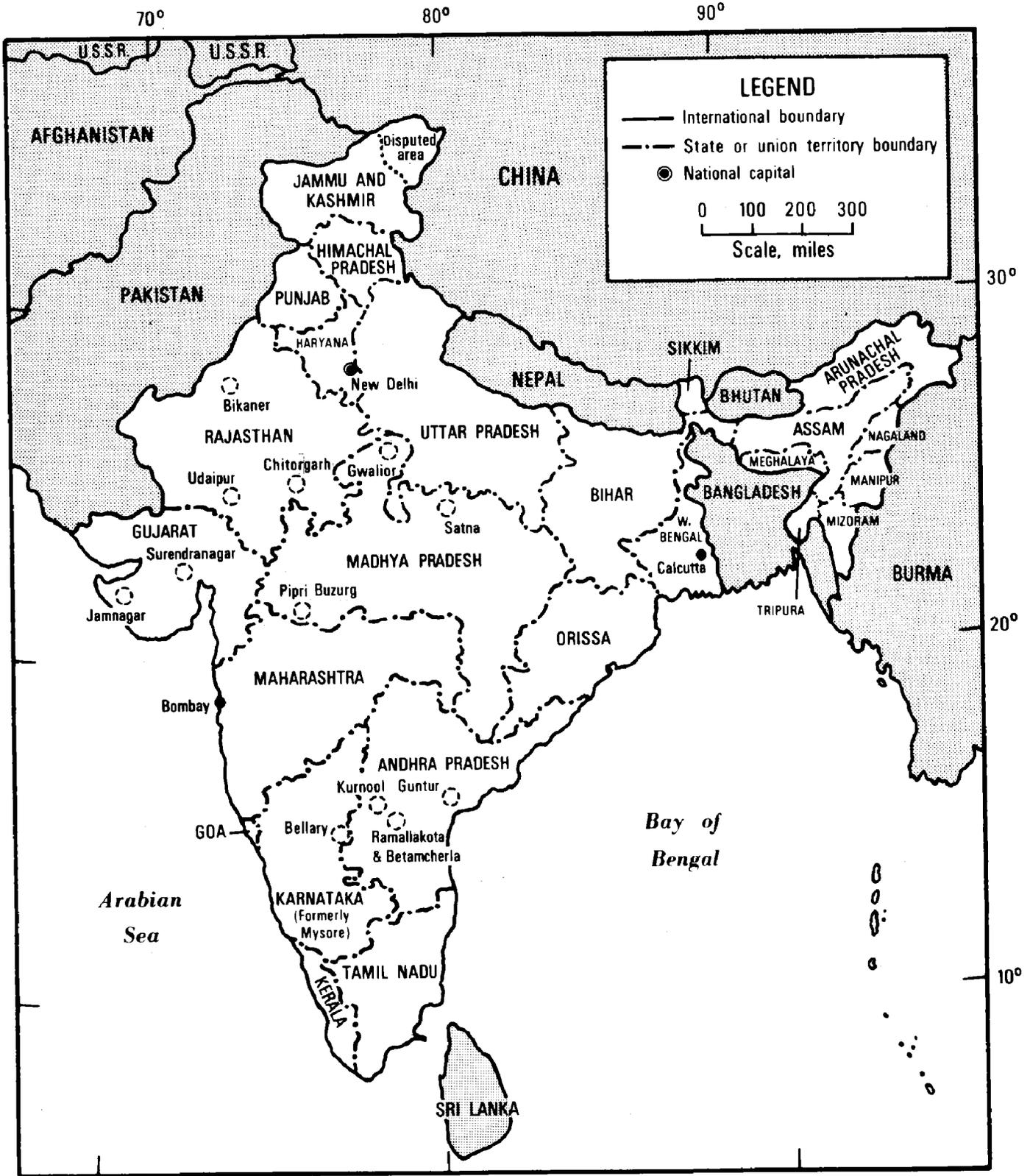


FIGURE 12. - Iron oxide pigment deposits in India. (Broken circle indicates districts of pigment deposits.)

Table 8 lists reserve estimates for each district. There are also many other deposits whose resources have not been included in this tabulation. In 1971 (the latest listing available), 55 mines were operated by the 8 principal producers of ocher, listed below:

Birla Cement Works, Chitorgarh district of Rajasthan (red ocher).

Tiffin's Barytes, Asbestos and Paints Ltd., 49, Cantonment, Ballary-2, Karnataka (formerly Mysore); also 272/273 Angappa Naicken St., P.O. Box 73, Mochras 600001. Mines with Associated Mining Corp. in Cuddapah district of Andhra Pradesh (red oxide).

E. K. Venkatesan, P.O. Betamcherla, Kurnool district of Andhra Pradesh (yellow ocher).

Gogga Gurusanthiah & Sons, P.O. Sandur, Bellary district of Karnataka (formerly Mysore)(red oxide).

Hiralal Rameshwar Prasad, P.O. Jaitwara, Satna district of Madhya Pradesh (yellow and red ocher).

Harish Mineral Supply Co., P.O. Jaitwara, Satna district of Madhya Pradesh (yellow and red ocher).

Indori Lal Narsingpura, c/o Fatehlal Tikamchand, Bara Bazar, Udaipur district of Rajasthan (red ocher).

The Andhra Pradesh Mining Corp. (State Mining Enterprise) mines barite and red oxide in Andhra Pradesh.

Generally, ocher mining in India is done manually in small open pits except where it is produced as a coproduct of iron ore mining. The material is sold both in lump and powder form. Some mines operate grinding mills, and some sell the ore to pulverizers. The Hindustan Mineral Product Co. Ltd. of Bombay, one of the main importers and processors of foreign ocher in India, purchases local material, processing and marketing it after blending with imported pigments. The material sold must meet Indian standards (46 and 47) established in 1950 for natural red and yellow oxides of iron. The bulk of domestic production is consumed in the building industry in paints and cement.

TABLE 8. - Iron oxide pigment reserves of India, 1971 (42)

(Metric tons)

Location	Reserves
RED OCHER	
Gujarat State, Surendranagar district: Rajur..	3,048,000
Madhya Pradesh State:	
Gwalior district:	
Sumowli.....	} 85,000
Rangwan.....	
Bahat.....	
Dhiroli.....	3,043
Satna district:	
Amirthi.....	55,880
Partapur.....	30,480
Jaitwara area.....	56,896
YELLOW OCHER	
Andhra Pradesh State, Guntur district:	
Bellamkondavaripalem.....	1,727,000
Madhya Pradesh State:	
Satna district:	
Lindra hill.....	35,560
Khogaha hill.....	30,480
Ganga Sheo hill.....	2,540
Moorbaba hill.....	4,064
Quolia.....	3,565
Sambhar hill.....	7,620
Sataiya hill.....	8,128
Amirthi.....	22,352
Partapur.....	50,800
Kailaspur.....	25,400
Madhogarh.....	50,800
Birpur.....	25,400
RED OXIDE	
Karnataka State (formerly Mysore), Bellary district: Bellary Group of Mines and Ubbalagundi Mines.....	227,100

More than 48% of India's total 1971 output was accounted for by three mines which produced over 5,000 tons each. In 1967-71 (41) exports increased at a rate of 50% for earth colors and 162% for red oxides. The Philippines (56%) was the principal buyer of pigments with Thailand and Ceylon each also importing more than 10% of India's exports. Nearby African and other Middle Eastern countries were also consumers of Indian ocher. Most of the red oxide exports, however, went to Italy, West Germany, France, and the United Kingdom. India was also a significant importer of Persian Red pigment from Iran, which India apparently reexported under the Persian Red label.

Geological Description

India is considered (94) one of the richest countries in terms of high-grade iron ore reserves. With the exception of Quaternary age laterites, most iron ore and iron oxide pigment deposits of India occur in iron-bearing formations of Precambrian age, including banded iron formations of the Lake Superior type, weathered ferruginous quartzites or ironstones, and siderite.

The ochers of Bhannajar and Jammagar districts of Gujarat State are reported (41) to be associated with lateritic deposits. These ochers require dressing and washing before use. The ochers of Jaitwara in Satna district, Madhya Pradesh State, are derived from weathered ferruginous sandstones resulting from leaching of silica and consequent iron oxide concentration. These occurrences are scattered over a 259-square-kilometer area in Jaitwara. Red ocher of the Gwalior district, Madhya Pradesh, is derived from alteration of iron-bearing shale and occurs over a 116.6-square-kilometer area. Green earths are reported from Pipri Buzurg and other areas in Madhya Pradesh.

Ochers in Rajasthan are associated with iron ores and ferruginous breccias of the Chitorgarh district. In Bikaner district of Rajasthan, ochers occur in shales overlying coal seams. Yellow ocher production of Andhra Pradesh State is centered about Ramallakota and Betamcherla where the ore was formed by alteration of iron-bearing shale; red iron oxide in Andhra Pradesh is recovered as a byproduct of barite mining. The principal iron deposits of the Bellary area in Karnataka State are hematitic Lake Superior-type banded iron formations. In West Bengal, iron deposits occur as Mesozoic-age ironstones and siderite.

Iran

Location and Production

Hematite deposits that have long been famous for their color occur in Iran. Widely known as Persian Red, these iron oxides are derived principally from the Island of Hormuz, located in the Persian Gulf along the southern border of Iran, 23 kilometers southeast of Bandar Abbas. Deposits have also been mined and are known to occur on the islands of Abu Musa, SIRR Abu Nu'Air, Hengam, and Qishm, as well as inland along the southern coast of Iran. Oxide mining was done from 1935 to the 1950's by the Golden Valley Ochre and Oxide Co. of Bristol, England, on Abu Musa and SIRR Abu Nu'Air Islands, utilizing Persian labor from Sirri. Loading to lighters was done from a crude concrete pier and thereafter by ship's boom.

Historically, the most important deposit was that mined on Hormuz, where exploitation began in the early 1900's by a private merchant. In the late 1920's, about 20% of the production went to the United States and 60% went to the United Kingdom. In 1935, the mine was taken over by the Government, which has mined it since. The Iran Metals and Mining Co. (IMMC), under the Ministry of Industries and Mines, was formed in 1936 to exploit minerals as well as to maintain supervision over private Iranian mining operations (45). The operating company for the IMMC is the Hormuz and Qishm Mining Corp., which also mines salt.

To reduce the excessive soluble salt content of the hematite, and high mining costs, IMMC began a new project for upgrading the product in 1974. Foreign specialists were engaged and a new processing plant was planned with a capacity of 5,000 tons annually. In the past, about 150 workers were employed, and the daily production was about 150 tons. No work is done from July to September because of the excessive heat. There is no fresh water on the island.

Persian red supplies and demand have dwindled in recent years. In Iranian year 2536 (March 21, 1977 to March 20, 1978), red iron oxide production was almost 4,600 tons, compared with over 13,000 tons in 1956 (table 1). Decrease in demand has occurred owing partly to the peculiar composition of the ore, partly to mining and transportation difficulties, and partly to a general decline in natural pigment use and the increased prices of the Persian Reds. In the 1960's, the United Kingdom (46%), Egypt (16%), India (11%), and Oman (6.5%) were principal recipients of the exports.

Geological Description

The Hormuz deposit is overlain by 20 to 30 meters of sand and gravel, cemented by gypsum and salt, and is mined by opencast methods. The following is a chemical analysis of Persian Gulf red iron oxide, in percent:

Fe ₂ O ₃	76.95	Na.....	0.9
Al ₂ O ₃	1.14	NaCl.....	2.29
SiO ₂	14.78	KCl.....	.15
CaO.....	.34	SO ₃.....	.53
MgO.....	.18	P.....	.15
Cl (total).....	1.77	Moisture at 110° C....	2.29
K.....	.08	Loss on heat at 900° C	2.92

Source: Iranian Embassy. Private communication, Dec. 3, 1969. Available upon request from J. L. W. Jolly, Bureau of Mines, Washington, D.C.

The ore body is located on the south side of the island and is about 200 meters long with an average width of 65 meters. Reserves in 1976 were estimated as measured 66,000 tons, and indicated 65,000 tons (96). There are also salt and iron ore mines on the island, which are not presently exploited. All these deposits are developed around salt plugs, which are numerous not only on Hormuz Island, but in the general area (fig. 13).

The age of the salt is generally thought to be Cambrian (54). These great cylindrical salt stocks, circular or oval in section, do not exceed 50 kilometers in diameter and average 2 to 3 kilometers. Having forced their way up through the overlying Cretaceous and Tertiary strata, they often tower over the surrounding countryside. Some offshore islands, such as Hormuz, Qishm, and Hengam, are partially or entirely composed of salt domes. There are more than 200 salt domes reported around Hormuz and Hengam Islands (76). On Hormuz Island, salt intrusion associated with the other deposits is presumed to have occurred early in the Cretaceous period.



FIGURE 13. - Cambrian salt plugs and Hormuz Island in Iran (54). Iron oxides associated with salt plugs are mined on Hormuz Island.

The Hormuz Series derives its name from the Hormuz Island dome where rocks and salt have intruded together. The Hormuz Series is normally a "chance assemblage" brought to the surface by the salt, but may be generally divided into four groups: (1) salt rock; (2) purple sandstones, grits, and shales; (3) volcanic tuffs and agglomerates, generally gypsiferous, with sediment fragments from group 4 and interbedded with rhyolitic flows; and (4) dolomitic limestone and shales, often gypsiferous with some interbedded rhyolite flows. Fossils found in these shales indicate the age is Cambrian. Iron oxides appear in most of the salt plugs and provide the coloring matter to the associated clays and sandstones. The salt extrusions appear red and some have been mined for pigment, such as the deposits of red earthy hematite found on Hormuz Island.

red and some have been mined for pigment, such as the deposits of red earthy hematite found on Hormuz Island.

There is apparently a great similarity between the Hormuz Series and sediments of the Salt Range in Pakistan (originally western India)(36). The Cambrian environment in both areas appears to have been one of arid conditions and shallow seas that extended from Arabia to India, resulting in the deposition of extensive salt beds and related sediments. The evaporite basin of the Hormuz Group is bounded on the northeast by the main Zagros Reverse Fault line, and on the east by the Oman structural high (6).

Italy

Location and Production

Domestic needs for iron oxide pigments in Italy are met primarily by production from mines and plants located around Verona and on Sardinia (95). Total domestic production is shown in table 1. A major producer is Societa Italiana Ossidi di Ferro (SIOF), Via Antonio Rissano 55, 37100 Verona, which obtains about 1,000 tons per year from three quarries located in the Verona area. Should demand warrant it, this could be increased to a maximum of 4,000 to 5,000 tons. SIOF also operates two modern plants for production of both natural and synthetic oxides, one in Verona and the other at Pozzolo Formigaro

in the Province of Alessandria. Of more modest size is another Verona producer, Dolci Arturo di M. Dolci, Via Cantarane, 16, 37100 Verona.

On Sardinia, five quarries are operated by Ucceddu Giuseppe, located at Via Danero, Carloforte, Isola di S. Pietro, Cagliari. According to company officials, Ucceddu production does not exceed 400 to 500 metric tons per year, although production could be increased to 800 tons per year if demand warranted. Sardinian production is shipped to the firm of Pellegrini and Limmi, Livorno (Leghorn), which exports most of the material that is shipped to the United States. Approximately 1,000 tons is exported yearly to the United States (43).

Italian raw sienna, a yellow limonite ore, derives its name from the northern Province of Siena (Tuscany) where it was originally mined as "terra di sienna." Sienna is still one of the principal pigments mined and is calcined to produce reddish-brown burnt sienna. All of these natural pigments are now available in micronized form. Although umber takes its name from the province of Umbria in Italy, the major source of umber today is Cyprus.

Geological Description

The iron deposits of northern Sardinia and the associated pigment material are of the bedded minette type. Reserves of pigment are said to be large. The pigment and iron ore deposits of northern Italy are similar in origin to the Bilbao deposits of Spain (94). These pigments contain 50% to 62% Fe_2O_3 (increasing to 68% when calcined), about 22% SiO_2 , 13% Al_2O_3 , and 0.45% water-soluble salts. The iron also occurs associated with silica and alumina as silicates and aluminates, which account for the peculiar translucency of the pigment in oil (61).

Pakistan

Location and Production

In recent years, ocher has been produced from deposits located near Hyderabad in Sind Province, in the Sargodha division of Punjab Province, and at Dera Ismail Khan and Peshawar of the Northwest Frontier Province. Table 1 shows a history of production and figure 14 shows the location of principal ocher deposits. There were 29 mining leases for ocher recorded for Pakistan in 1962 (82), and ocher production has steadily increased. A Raymond roller mill was reportedly installed in 1962 at Rawalpindi for grinding red iron oxide ore and barite, and a factory was established at Lahore for paint production.

Some ocher producers are listed below (2, 82):

A. Karim, 3 Abdul Karim Rd., Lahore.

M/s Mines and Minerals Ltd., 1 McLeod Rd., Lahore Industries, Shah Alam Market, Lahore.

Syed Noor Zaman Shah, Ushali, Mehali, Tehsil Khushab, district of Sargodha.

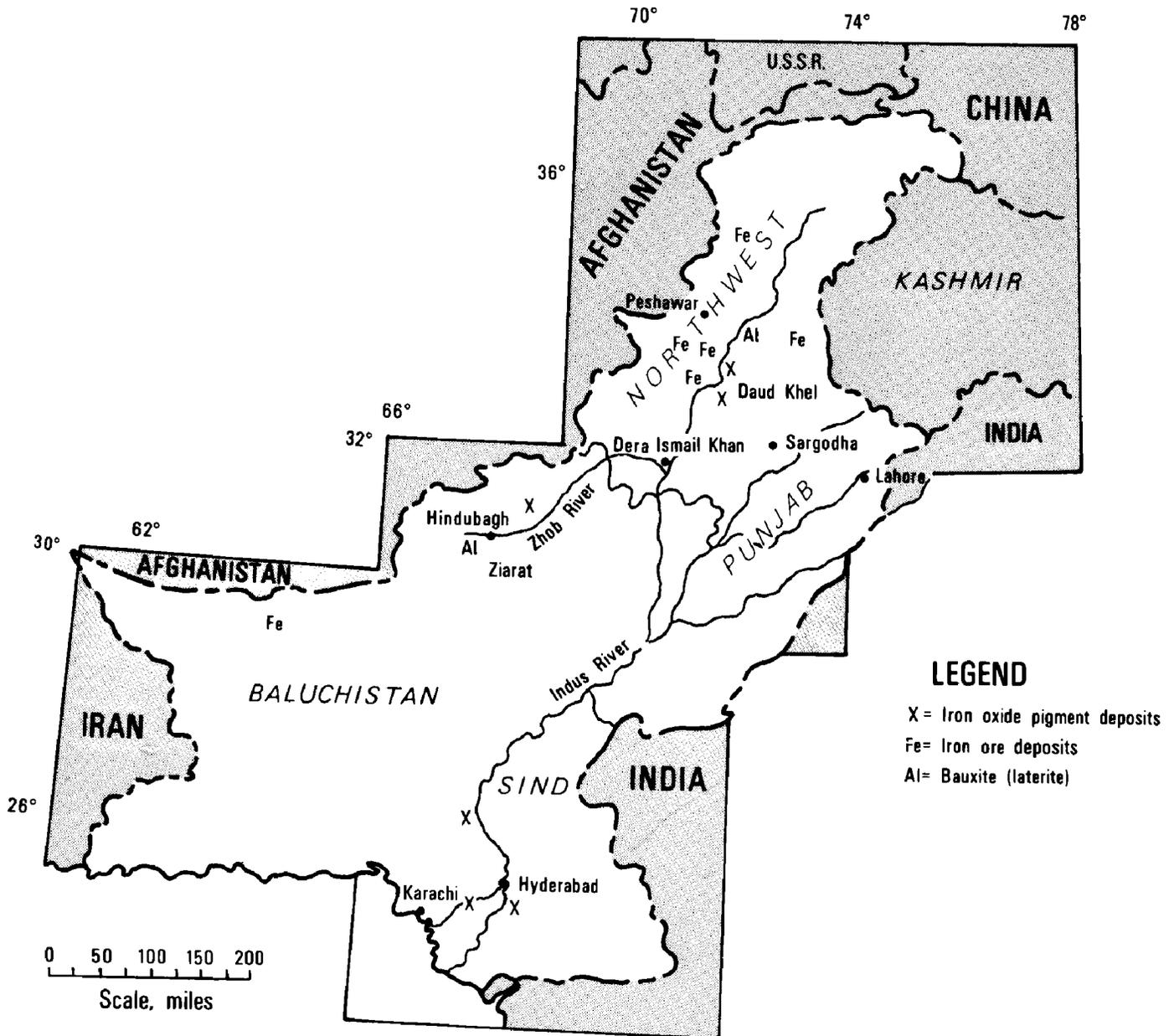


FIGURE 14. - Iron oxide pigment deposits, iron ore, and bauxite (laterite) in Pakistan.

M/s Sultan Muhammad Khan and Co., H. No. 254, 1/S Add. Talagang, Bus Service Mianwali.

M/s Malik Sultan Hohd. Kahn & Co., Dhok Ali Khan, Mianwali, district of Sargodha.

Ch. Muhammad Ashraf, c/o Crescent Terpentine Industries, Shah Alam Market, Lahore.

In 1975, 859 tons was produced from Punjab Province and 10,220 tons from Sind Province.

Geological Description

Ocher deposits in Pakistan were formed by deep weathering on positive, preorogenic (topographic high) structures. Some are residual, formed in a manner similar to laterite, but others were transported and occur along margins of orogenic structures, adjacent to the iron-rich igneous terrains from which they were derived. These deposits consist of nodular red, yellow, or brownish hematite and goethite, which may contain 20% alumina in clay constituents. Thick iron-rich blankets of laterite commonly occur over ultramafic rocks that have high primary iron content. These laterites may be an ore of iron, aluminum, or manganese. Ocher occurs with the laterites of Ziarat, Hyderabad, and the Mianwali district of Sargodha division. A typical ocher analysis from Sargodha shows (82) 26% to 47% Fe, 25% to 54% SiO_2 , 1% to 6% Al_2O_3 , 0.5% to 2.8% CaO, and traces of Mn, S, and P. The ochers near Ziarat are residual, while those in Hyderabad are the transported and redeposited types. Other ocher deposits of lesser importance are found in the Zhob district; there also are the transported types (40).

In Sind Province, ocher has formed in an erosional interval separating the Ranikot Group of Paleocene age and the Laki Group of Eocene age. Three deposits at this horizon are found in the Hyderabad district. One deposit, a 10-foot bed of poorly stratified clay with streaks and patches of limonitic ocher, occurs about 1 mile northwest of Jhol Dhand at the foot of a scarp formed from Laki limestone. It was estimated to contain 3,500 tons of recoverable ocher. Another deposit is an 8- to 10-foot interval of ocherous laterite beds that occurs 7 miles southwest of Khano; the beds consist of lateritic sandy limestone with irregularly distributed ocher and patches of jasperoid material. About 20,000 tons of commercially acceptable ocher was estimated as recoverable. A third deposit, containing a thin layer of ocher that appears at several places 6 miles northeast of Jhampir railway station, is estimated to contain a large amount of ocher (40).

The lateritic material of the Mianwali District occurs as Jurassic lateritic clays of the Datta Formation in the Zaluch Gorge, and nearby at the base of the Eocene section at the westernmost edge of laterites in the Salt Range at Daud Khel (2). The transported-type ocher deposits of the Zhob district are in beds of the lower Shaigalu Formation, where it occurs along the north side of the Zhob Valley. Ocher also occurs in the lower Urak group near Kach. These deposits are dark maroon, bright green, or yellow shale beds commonly associated with conglomerate that contains chips and pebbles of weathered serpentine, gabbro, and other igneous rocks. The richest ocher deposits occur near Kach close to the "Central (fold) Axis," a geologic structure of the Zhob district. Moving from the Central (fold) Axis, the ferruginous content and coloration of the same strata decrease, in proportion to the distance from the fold axis. The ocher was derived from the igneous complex of Hindubagh intrusions when the central geanticline supported an emergent and deeply weathered terrain.

Paraguay

Location and Production

Most paint pigment used in Paraguay is imported, but iron oxide pigment has been produced locally, and many potential local pigment sources are known. In 1860, Jesuit priests were reported using local pigment materials for decorating their churches and colleges. Clay mixed with limonite was taken from the soils, calcined, ground, washed, and mixed with a mucilage made from the juice of a local cactus (*Cactus peruvianus*) to make red ocher; yellow and white paints were made similarly. In the 1950's, pigment was mined from a deposit located about 1,500 meters southwest of Tobati. The largest deposit there was about 30 meters long, 2 to 3 meters wide, and 3 to 5 meters high. The rock was soft and easily worked. Blocks of ocher-cemented sandstone were pried out with hand tools, hammered to small pieces, and then disintegrated by soaking in water. When the heavier sand grains sank to the bottom, the ocherous clay was decanted off and dried in the sun. A fine-grained yellow ocher powder with excellent covering and tinting properties resulted (23).

Geological Description

Tobati ocher occurs in deposits along several strong northeast-trending fractures where ocherous clay cements the sandstone grains of the white saccharoidal sandstone of the Caacupe Series. Elsewhere, the sandstone may be friable or is cemented by calcareous or siliceous material. In these fractured areas, the ocher comprises about 2% to 7% of the rock and is composed of clay that is impregnated by secondary limonite, possibly of hydrothermal origin (23). The Caacupe Series is Silurian in age and is divided into three sandstone units and a basal conglomerate. The saccharoidal sandstone occurs at the middle.

Other potential iron oxide pigment sources were described (23) in the area of low-grade lateritic iron ores that covers much of central Paraguay. The reddish-brown limonitic material of the laterites, the specular hematites occurring near Caapucu, and the partly altered siderite concretions and veins that occur in some of the local clay and shale beds of the region were all considered to be potential pigment sources.

Republic of South Africa

Location and Production

Ancient iron oxide workings in South Africa, some of which were of great extent, included workings from which iron ore was extracted for smelting as well as for ocher or specularite pigments. Some iron oxide was used for smearing the body and head (ocher) or for powdering the hair (specularite). Iron oxides were still being mined for these purposes in remote parts of Natal and the northern Transvaal in modern times (101).

The eastern slopes of iron-bearing hills located northeast of Pretoria are riddled with ancient and modern native workings, mainly for specularite

and ocher, which were ground on the site. The deposits were situated on the crest and eastern slopes of a range of hills and valleys carved by an Elands River tributary from an extensive felsite plateau. One of the most famous of the ancient specularite workings is Blinkklipkop (glittering rock hill) or Tsantsabane (a shining stone), which is situated in Postmasburg. Radiocarbon isotope dating indicates that this deposit was mined more than 1,000 years ago (9).

Present South African production of ocher consists mainly of red and yellow varieties mined in the Riverside area of Cape Province. Most of the yellow ocher is exported, but most of the red ocher and umber are used locally. In 1976, 2,411 tons of mineral pigments was produced, of which ochers comprised 53%, umber 15%, and other iron oxides, 31%. Exports of iron oxide pigments were valued at \$64,747 in 1976 (10). In 1975, South Africa produced 1,368 tons of ocher, 556 tons of umber, and 1,361 tons of other iron oxide pigments. Of this amount, 896 tons of ocher and 22 tons of other oxides were exported, valued at approximately \$92,622 (10). Table 9 shows total pigment production from 1958 through 1974 for South Africa.

TABLE 9. - Ochers and iron oxides produced in South Africa, 1958-74

Year	Production, metric tons	Sales, metric tons	Value, ¹ U.S.
1958.....	5,538	4,408	\$79,267
1959.....	4,999	4,107	43,547
1960.....	5,784	5,063	51,001
1961.....	5,104	3,961	63,424
1962.....	4,559	3,542	65,460
1963.....	3,966	3,361	67,169
1964.....	4,975	4,227	79,096
1965.....	4,741	3,697	65,771
1966.....	5,767	3,966	71,186
1967.....	8,632	3,683	68,613
1968.....	3,894	2,619	59,761
1969.....	3,185	2,190	49,579
1970.....	3,151	1,836	54,062
1971.....	3,097	885	33,522
1972.....	8,447	2,193	79,709
1973.....	2,321	3,459	144,860
1974:			
Ochers.....	2,061	2,021	135,022
Oxides.....	562	1,809	92,807

¹Values in U.S. dollars converted from South African rand at the rate of 1 rand = US \$1.15.

Source: Brabers (10, p. 343).

The following companies and mines produce iron oxide pigments in South Africa:

African Gold Ochre Co. (Pty.) Ltd., P.O. Box 18, Riversdale, Cape Province, markets red oxide (40% to 50% Fe_2O_3), green oxide, and yellow ochre.

G&W Albertina Mine, P.O. Box 134, Albertina, Cape Province, 6795, which markets through G&W Base and Industrial Minerals (Pty.) Ltd., produces yellow ochre (64.8% Fe_2O_3 ; 14.4% SiO_2 ; 6.3% Al_2O_3 ; 0.004% MnO, 12.7% ignition loss).

Sunrise Ochre Mine, P.O. Box 117, Albertina, Cape Province, which is owned by the Via Gellia Colour Co. Ltd. of Derbyshire, England, produces yellow ochre (17).

Buffalo Base Minerals (Pty.) Ltd., P.O. Box 7, Ballengeich, Natal, 2942, produces a red oxide pigment containing 70% Fe_2O_3 . The mine is located in Utrecht Townlands district. The same company also produces synthetic oxide containing 90% to 93% Fe_2O_3 .

Zimro (Pty.) Ltd. owns the S. A. Oxides (Pty.) Ltd. operation located in Transvaal (P.O. Box 78069, Sandton, Transvaal). This company markets the ore through G&W Base and Industrial Minerals (Pty.) Ltd., P.O. Box 14052, Wadeville, Transvaal. About 1,500 tons of red oxide has been mined from this deposit, but it is not currently being exploited. South African Oxides and Barytes Mills Ltd. produces red, brown, and blue pigments from oxides of manganese and iron that are milled at its Wadeville plant. Umber and a yellow ochre are produced from the company's manganese mine located near Hotzel in northern Cape Province.

Garieb Minerale (Pty.) Ltd. of Springbok, Cape Province, produces a 70% hematite product that is sold locally to the cement industry for the manufacture of "sulfide cement." This company also produces gypsum.

Yellow and red ochers of good quality occur in the southeastern Riversdale district near Mossel Bay in Cape Province. Mining for ochre began in the 1920's to satisfy domestic markets, but sales extended gradually to supply overseas markets. Early development companies included (98) the Golden Valley Ochre and Oxide Co. (Bristol, England), the African Golden Ochre Co., Sunrise Ochre Mines, and Van As' Ochre Mines (Warden and Hotchkiss).

There is a wide variation in chemical composition, color, and texture, and there are apparently no standard specifications for the different pigments. The suitability of the earth pigment can only be determined by trial (10). There is also considerable variation in nomenclature, with the same pigment being called sienna and yellow ochre by different paint merchants.

Geological Description

In South Africa, rocks from which the ochre and iron oxides were derived include ferruginous shale, slate, beds of iron ore, and occasionally dolerite or diabase dikes. Umber deposits are usually the result of weathering of

impure limestone or dolomite. Ocherous shales have a fairly wide distribution in the Riversdale district in Cape Province.

The ocherous clays were derived in situ from weathering of the Bokkeveld shale in the folded belt of the Cape System. The clays are overlain by up to 6 feet of Late Tertiary quartzite. The quartzite consists of fine-grained angular quartz grains cemented by amorphous silica. In some places, the base of the quartzite is partly decomposed, granular and porous, while the upper part is an indurated siliceous mass. The iron oxide pigments vary in color, depending upon the principal mineral constituent.

In Cape Province, ocher occurs as pockets in the layer of white to yellowish clay. Within the white aluminous clays the ocher is sharply defined, but within the colored clays the borders are transitional. A small amount of saline material (probably CaCl_2 or MgCl_2) is present in the ocher and apparently has presented some problems with the moisture content. An analysis of the yellow ocher from the Van As' quarry follows (98): 51.36% Fe_2O_3 , 24.52% SiO_2 , 10.18% Al_2O_3 , 0.22% FeO , 0.22% CaO , 0.75% MgO , 0.43% K_2O , 0.43% Na_2O , 10.94% $\text{H}_2\text{O}+$. Analysis of samples taken from the ocher, clay, and various altered and unaltered samples of the Bokkeveld shale showed the following trends:

- (1) Silica increases from shale to clay to yellow ocher to red ocher.
- (2) Alumina increases from shale to clay.
- (3) FeO decreases from shale to clay with Fe_2O_3 constant, but Fe_2O_3 sharply increases in yellow ocher and to red ocher.
- (4) Na_2O , K_2O , MgO , and, to a certain extent, CaO are lower in the ocher than in the shales or the clays.

A further conclusion drawn from a study of the chemical trends was that the ocher was formed by surficial leaching of ferrous iron and redeposition of hydrous ferric oxide replacement of silica. The age of the original source of the iron, the Bokkeveld beds, is considered to be Devonian. The ochers, which are secondary deposits, are clearly of a later age. The peneplanation of the surface on which the quartzites rest took place in late Tertiary time. The development of ocher in these beds has gone on intermittently since the end of the Tertiary period and is continuing at present.

Ocher reserves are difficult to estimate because of the irregular size and unpredictable occurrence of the ore bodies. Mining is done by opencast methods, and often by pick and shovel. Other ocher occurrences are known in the Swellendam, Bredasdorp, and Humansdorp districts.

In Natal Province, along the valley of the Buffalo River, east of Newcastle and Dundee, an ocherous zone of a sideritic ironstone bed is mined for pigment (10). At present, it is worked at Hazeldene in the Dundee district and on the Utrecht Townlands. The ironstone has been oxidized to form mixtures of soft earthy iron oxide, and various red and yellow ocher pigments are

obtained. The principal product is a dark hematitic variety called red-oxide pigment. Normal production is between 65 and 150 tons per month. Pigments have also been produced from the Pinetown district where they are associated with clay resulting from weathering of a granite. At Groene Kloof, a bright red clay has formed by decomposition of a basic igneous dike.

No umber or ocher has been mined in the Transvaal since 1967. Umber occurs here at various localities in the Dolomite Series, where it occurs as pockets in the dolomite or along fault planes as the result of alteration and removal of soluble calcium and magnesium carbonates. The umber contains up to 30% silica and has a variable manganese content. Umber from South Africa Oxide's manganese mine near Hotozel gave the following analysis: 69% to 76% MnO_2 , 16% to 20% Fe_2O_3 , 2.5% CaO , 0.6% MgO , 0.4% Al_2O_3 , 0.01% TiO_2 , and 0.2% H_2O .

Spain

Location and Production

In 1975, Spain produced 8,432 tons of ocher and 51,924 tons of natural red iron oxide pigments (table 1). The ocher was derived from seven mines, one in Granada, three in Jaen, one in Malaga, one in Santander, and one in Zaragoza (71). Red iron oxide pigment was derived from products reported as iron ore and is classified as pigment only after the processing stage. Most of Spain's pigment production comes from the mining districts of Jaen, Cordoba, Malaga, Alicante, and Almeria of southern Spain, and from Santander, Zaragoza, and Bilbao in northern Spain. Figure 15 shows the approximate location of the iron ore districts mined for pigment. In 1975, Jaen (4,291 tons), Malaga (1,250 tons), and Zaragoza (1,806 tons) were the biggest producers.

The United States imported 1,101 tons in 1976 and 872 tons in 1977 from Spain. After Cyprus, Spain is the second largest supplier of natural pigments to the United States. The quality of Spanish ocher has declined in recent years, and exports decreased from 17,130 tons in 1970 to 10,325 tons in 1973 (88).

Oxidos Rojos de Malaga S.A., a subsidiary of Golden Valley Colours, Ltd. of the United Kingdom, is a principal pigment producer. The red oxide is mined, treated, and ground at the company's plant at Malaga before shipment. By law, no Spanish material leaves the country in the raw state (43). The Malaga plant has the capacity to produce 12,000 tons per year of superfine and micronized grades of red oxide. Most of the output is exported. A new factory was built (43) by Oxidos Rojos in the "Poligino Industrial" area of Malaga in 1971.

Oxidos del Sur S.A. operates a plant near Almeria which has a 3,000-ton-per-year capacity for red oxides, as well as a 1,500-ton-per-year capacity for micaceous iron oxide. The latter differs from Austrian micaceous iron oxide and is generally considered less desirable. Iron oxide pigments from the Zaragoza Province include red, yellow, and black oxides from the Tierga plant of Productos Minerales para la Industria S.A. (Promindsa). The Promindsa

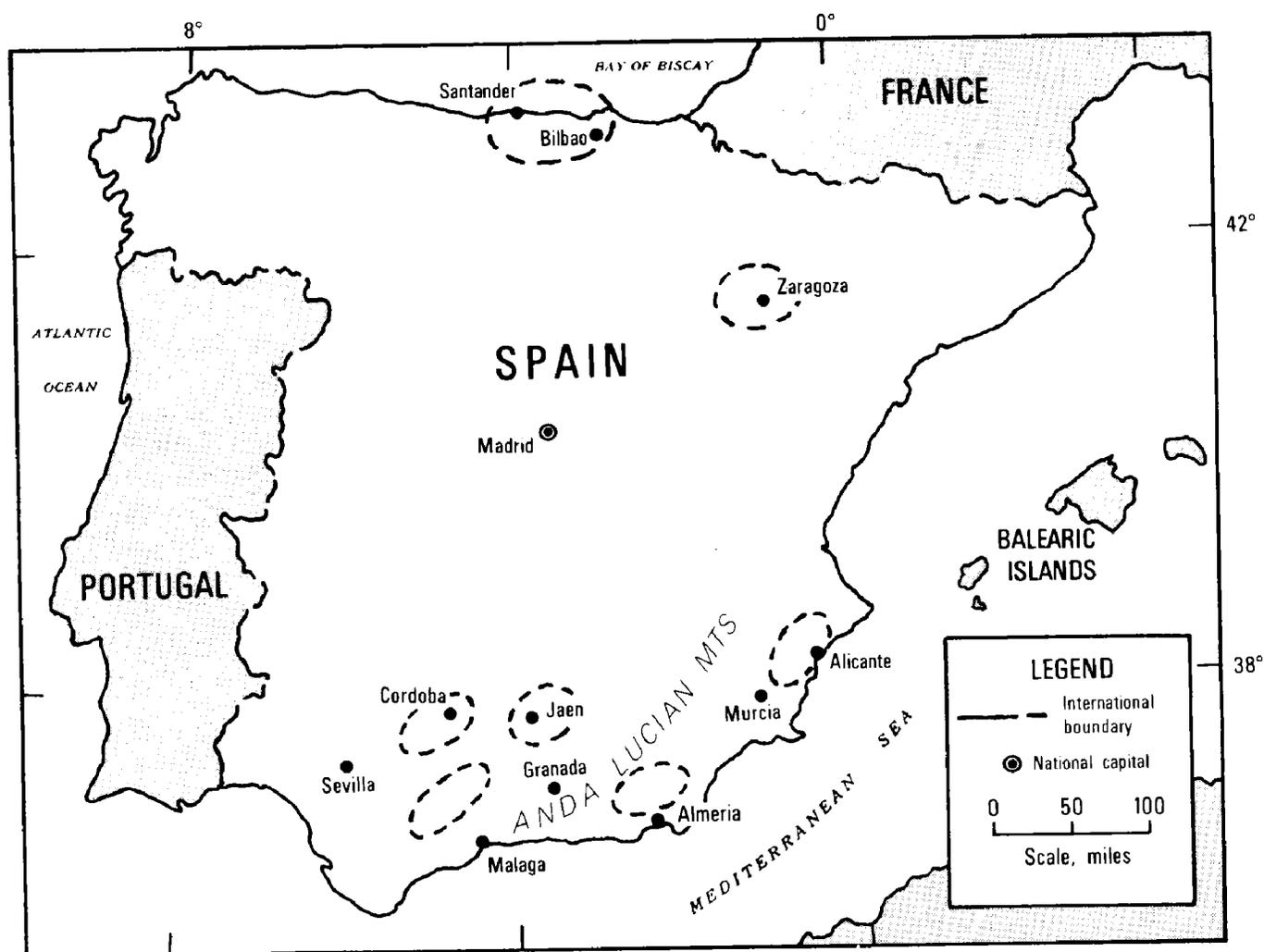


FIGURE 15. - Principal areas of iron oxide pigment deposits in Spain. (Broken circle indicates areas of pigment mining.)

operations are centered around Tierga in northeast Spain. At the end of 1973, Promindsa took over a pigment-grinding company near Bilbao, adding new equipment. The mine is an underground operation that produces a red oxide with a minimum of 82% Fe_2O_3 and a yellow ochre that occurs in pockets in a brown ore. A black (magnetite) iron ore is also mined in the same general area and processed at the Tierga plant. Annual production capacity is about 6,000 tons of red oxide, 1,200 tons of yellow oxide, and 1,200 tons of black oxide. The products are sold to local markets principally for concrete, tiles, rubber, and paints.

Production of pigment ore in Jaen Province has been 2,500 to 4,000 tons per year for the last 5 years. These mines are now primarily recognized for their importance to the pigment industry, their use of iron ore having diminished in recent years. There has been a dropoff in productivity, and the number of workers has decreased.

Alicante Province once produced a red oxide "ocher" for the paint industry from approximately 56 mines between the towns of Alicante, Sex, and Benidorm. Today none of these mines is working, having been abandoned for some time (82). In northern Granada Province, near Antequera and Archidona, four mineral concessions provide red oxide for pigment. The comparatively elevated price commanded for pigment apparently allows for continued mining even though only one mine was reported producing ocher in 1975.

Geological Description

Much of the Spanish red iron oxide pigment occurs as the "Bilbao type" of iron ore, named after the district in which this type of deposit is dominant. These are iron oxide deposits that have basically formed as accumulations in karst topography caverns, developed along structurally controlled rock folds and associated fractures. Iron sulfides near the surface were oxidized and the iron redeposited in the karst-developed caverns. Because of the nature of their deposition, these iron oxide deposits are of limited extent and are not continuous in depth. Mineralization in the northern mining districts of Santander and Bilbao is developed in dolomitic limestones of Upper Cretaceous age and consists of hematite, goethite, and siderite (21). Average analysis of the ore is 48% Fe, 5% SiO₂, 0.2% P, 0.45% S, 3% Al₂O₃, 0.5% Mn, and 2.2% CaO. Roasting the carbonate raises the iron content to 55%.

Deposits of the "Bilbao type" also occur in Almeria, Murcia, Cordoba, and Jaen Provinces, in Triassic dolomites, and in the limestones of the Carboniferous highlands. About 80% of the iron deposits of the Cordoba and Jaen Provinces occur in Triassic dolomites, and 8% occur in Paleozoic limestones. The mineral here is hematite, and the ore contains between 47% iron in the Triassic deposits and about 53% iron in the Carboniferous deposits. Hematite and goethite of the Bilbao type occur in Granada Province in limestones of the Mischungzone (a mixed zone) and have an average analysis of 57% Fe, 4% SiO₂, 4% CaO, 1.8% Mn, 1.8% Al₂O₃, 0.15% P, 0.02% S, and 0.3% MgO.

The Granada deposits occur in the Triassic zone that is a continuation of the deposits of Malaga. The most important iron deposits in the Malaga Province occur in the Betica zone of the Andalusian mountains (Betica Cordillera), but the deposits of lesser importance that occur in the Subbetica zone are those used for pigments. Iron oxide pigment mining in the Malaga Province began between 1916 and 1926 when there were at least six active concessions. Only one is presently being worked in the Ronda-Archidona zone of the Subbeticas. These deposits, which are mostly hematite with some limonite and magnetite, occur at the Triassic-Jurassic contact in the Lias limestone and dolomite. Most are karst cavern accumulations, produced by a period of emergence, erosion, and formation of laterite during the orogeny at the end of the Triassic. All consist of red hematite except one which consists of pyrite. The only producing mine of the area produces about 1,250 metric tons per year of material averaging 55% iron, solely for pigments (ocher). Reserves are given as 3.7 million tons with about 8 million tons of additional resources.

Most of the mineralization in Cordoba and Seville consists of metasomatic replacement of dolomite by hematite, limonite, and magnetite in Triassic

carbonates. The analysis is approximately 40% to 50% iron, 2% to 7% silica, 0.5% to 8% CaO, and 1% to 2% alumina. The amount of magnetite in this type of ore is small, but large enough to show as magnetic anomalies useful for geo-physical prospecting. The ores commonly have a high manganese content and are low in phosphorus and silica. The minerals mined are given the local names of "sangrinos" (red) and "violados" (violet); their principal uses in the past have been for paints, lead metallurgy, and iron ore.

United Kingdom (excluding Northern Ireland)

Location and Production

The United Kingdom was once a leading producer of natural iron oxide with a number of plants in operation in the southwest and northwest of England and in Wales. Both red and yellow ocher were produced as well as micaceous iron oxide. There was a considerable decline in the late 1960's when some of the larger companies ceased production. One of the largest companies to stop production was Golden Valley Colours Ltd. from its works at Wick in Bristol. The micaceous hematite mine at Hennock in Devon stopped producing, as did the Millom Hematite Ore and Iron Co. Ltd. of Cumberland. In 1966, the production of ocher in southwest United Kingdom alone was 7,000 tons. The United Kingdom is not included in table 1 because complete production statistics are not available.

Presently in the United Kingdom, there are approximately 18 suppliers of raw iron oxide pigments (63). Among the companies there is a large variation as to size, specialization, and enterprise. The majority, however, are strictly manufacturers of synthetic pigments in that most of their products are the result of several stages of chemical processing. Table 10 shows iron oxide imports and exports for 1966-76, including synthetics. Only a few companies are engaged in mining primary natural ores, such as Via Gellia Colour Co. and W. Hawley and Son, both of which produce natural iron oxide pigments at Derbyshire. Via Gellia Colour Co. extracts pigment raw material from two mines in Wales. W. Hawley and Son obtains pigments from Winford Red Ltd., which operates a mine at Winford, near Bristol. In both cases, the ore is blended with high grade imported material to produce finished pigments (43, p. 15).

TABLE 10. - United Kingdom imports and exports of iron oxides, 1966-76

(Thousand metric tons)

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Imports:											
Micaceous oxide (natural).....	None	None	None	None	2	2.2	1.7	2.8	1.9	1.7	2.1
Under 70% Fe ₂ O ₃	5.3	5.3	6.2	5.8	3.3	3.6	2.8	3.6	4.8	2.4	2.8
Over 70% Fe ₂ O ₃	4.2	3.2	3.8	3.1	2.1	1.3	.5	2.5	2.8	2.1	2.4
Exports:											
Micaceous oxide (natural).....	None	None	None	None	.08	.4	.4	1.4	1.6	.9	2.0
Under 70% Fe ₂ O ₃ :											
Red.....	1.9	1.9	2.4	2.1	1.2	1.5	1.2	1.3	2.3	2.8	2.4
Other.....	2.0	2.2	3.6	3.3	1.0	1.0					
Over 70% Fe ₂ O ₃	None	None	None	None	.8	1.2	.8	1.2	None	.4	.4

Source: Institute of Geological Sciences. United Kingdom Minerals Statistics. 1974, p. 132; 1977, pp. 142-143.

Via Gellia, deriving its name from the Romans, has been operating for a hundred years in Derbyshire. The plant and main office are in Matlock. Via Gellia also manufactures micronized colors with a maximum particle size of only 5 micrometers. A large extension to the micronizing plant was completed in 1972, raising the company's total grinding capacity to about 22,000 tons per year; about 25% of its sales are exported. Iron oxide pigments are also produced from British Steel Corp.'s Beckermets mine at Cumberland. Hematite found here is also often collected for jewelry and specimen purposes. Beckermets also produces about 150,000 tons of iron annually; peak production was 30,000 tons in 1929. Winford Red of Wick near Bristol is the largest red oxide producer. Ocher was also recovered from many mines throughout the metaliferous mining region of the southwest United Kingdom. In some places, such as at Indian Queens Mine, St. Austell, the iron ores were worked for ocher alone, but more often ocher was only periodically recovered (20).

Geological Description

The red iron oxide pigment at Cumberland was formed by replacement of Carboniferous limestone (11). Ocher in the southwest United Kingdom (20) was formed by the decomposition of pyrite and accumulated in cavities within gossans. When the material was washed, the coarse, sandy particles were easily removed and a fine, yellow-brown or red pigment resulted. Some ocher workings also developed from decomposed basic or pyroclastic rocks, such as in the Liskeard district. Umber was primarily derived from deposits that resulted from the decomposition of limestone in Devon and at the Cornwall umber works near Dartmoor.

Deposits in Other Countries

Argentina

Ocher is produced in La Rioja and Salta Provinces for local use only; it is used mainly for ceramics and paint pigment. The largest producer has been a mine in La Rioja Province, which was listed as the Willy I-II-III and IV mine in 1975 and as the Las Tres Marias mine in 1976 (70). Six persons were employed at the Willy mine, which also produced magnetite. Two mine workers were employed on one property in Salta Province. Ocher production for 1974-76 is shown below, in metric tons:

<u>Province</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>
La Rioja....	98	203	142
Salta.....	<u>41</u>	<u>37</u>	<u>32</u>
Total....	139	240	174

Annual production totals for 1956-77 are shown in table 1.

Canada

Production of natural iron oxide pigments in Canada was significant in the 1950's, but recent output is unknown. Natural iron oxide umber exports from Canada to the United States have actually been reexports, and not local production.

Natural iron oxide production reached 6,985 tons in 1957, but decreased to 1,481 short tons by 1958 (38). This drop was attributed to the declining use of manufactured gas for which large quantities of iron oxide were used as a cleansing agent. The known Canadian deposits of pigment grade were bog ores. Two of the more recently worked deposits were located in Champlain County, Quebec. A processing mill was located at Red Mill, 7 miles east of Three Rivers, Quebec. Natural iron oxides decreased to 865 short tons by 1960, the lowest production since 1894. In 1961, much of the refined iron oxide material was being exported and the balance used for abrasive purposes.

Egypt

A small deposit of limonitic ocher is located at W. Umm Girifat (lat. 25° 35' N., long. 34° 34' E.), about 7 kilometers from the Red Sea coast. El Nasr Phosphate Co. has had an exploitation contract since 1975. The limonite occurs as a lenticular bed in shale and limestone of middle Miocene age. The deposit is exposed along a dry stream bed for 1 kilometer and is up to 5 meters thick. Yellow and red ocher has been formed by weathering of the associated sediments. This bed has been mined from time to time and used in making tile colors. Eighty-one tons of crude iron oxides used for color was produced in 1974 (26).

Jordan

Ocherous ore at Mugharat el Warna, located south of Ajlun, has been described (8). This deposit, known as the Tel Ekweder mine, was mined in ancient times for iron ore and ocher. Two varieties of ore were reported, a hard, compact dark brown ore (93.5% iron oxide), and a limonitic and ocherous ore (78.6% iron oxide). The ocherous material contained both calcareous and siliceous impurities. The limonite and hematite ore occurs along brecciated zones in Upper to Middle Cretaceous limestone. Ascending waters rich in iron accumulated after passing through the underlying Nubian sandstones and deposited the iron minerals along these zones.

Ocher deposits also have been reported west of Jericho and west of the Dead Sea, southwest of Ma' daba. At several places along a plateau formed by Lower Cretaceous sandstones near Humrat Ma'in, north of Wadi Zerga Ma'in (28), the yellow ocher occurs with dark brown, impure, earthy manganese ore and gypsum. Both occur as layers or lenses up to 1 meter thick.

Kenya

During World War II, paints and washes were difficult to obtain and recourse to local Kenyan materials was necessary. Red, yellow, and brown pigment materials were readily obtained from several localities directly from oxidized clays and other superficial sediments, or from calcined products of these materials. Green pigments were obtained from chloritic claystones from near Lodwar in Turkana and green clays in Kitui (81). A yellow ocher was mined at Kitande, Machakos district, and yielded a satisfactory yellow-orange pigment (gamboge) after calcination. In the same area, a pink pigment was obtained from Iveti, a green material from the Embu and Makonga Rivers at Kola,

near Kalama, and a red-brown ocher from Mkonouko, also near Kalama. Yellow and red ochers were also obtained from Kaamasai near Songhor, and from Mwingiukazzi of northern Kitui district. A reddish brown ocher was used on a limited domestic scale for coloring limewash derived at Kiriundu near Ol Kalou. An ocher from Sotik has also been used as a color wash pigment. Red ocher also occurs 1 mile southwest of Muteithu summit, associated with iron-stained kaolin in the Kitui area, and has been reported from Kaboi in the Nandi Reserve of western Kenya. In both places, it is used on a small scale by the local people (22). Red ocher is also used locally to color animal salt produced from the Lake Magadi soda lake deposits.

Mexico

The geographic distribution of ochers in Mexico coincides with that of iron ore deposits, and both are associated with the same residual rocks. They occur as cappings or manto-type deposits as well as lenses and irregular pockets, owing to their origin by secondary alteration and oxidation of the minerals from which they are derived. Mining is usually by open pit, very rarely by underground methods. Ocher is generally produced as a byproduct of other mineral production. All oxide produced is consumed in the country. In 1942, ocher production was 51,250 kilos from the town of Teotlaca, in Puebla State (83); in 1956, the production was estimated at 100 kilograms per year (84). No current production figures were available when this report was prepared.

Morocco

Although production has dropped off since 1963 (table 1), Morocco is currently a producer of iron oxide pigments. Goethite is exploited (66) by Aknouch Hakj from the Foulkine mine in Marrakech Province. This mine produced 14 tons valued at \$3,182 in 1976 (67), and had produced 24 tons valued at \$24,500 in the first 8 months of 1977. All of the ocher is exported, principally to Algeria, France, and the United Kingdom. Exports have also occasionally gone to the Republic of Congo, Australia, Guinea, and the Netherlands. Ocher has also been mined along with pyrite and pyrrhotite from the Kettara deposit, located 35 kilometers northwest of Marrakech. The Kettara mine, operated by the Society for Exploitation of Pyrite at Kettara (SEPYK), is owned 49.2% by the Bureau de Recherches et de Participations Minières (BRPM) and 50.8% by Compagnie Minière et Métallurgique (CMM). The pyrite-pyrrhotite from Kettara was used for production of sulfuric acid needed by chemical and fertilizer complexes nearby (19).

Southern Rhodesia

Red ocher is currently produced at the ZOE mine, located in the Gwelo district at Zutphen and S/D 1 Yeoville. It is operated by the G & W Industrial Minerals Company (Box ST 280, Southerton). No production figures were available.

BIBLIOGRAPHY

1. Abreu, S. F. Recursos Minerais do Brasil (Mineral Resources of Brazil). Ministério do Trabalho Industria e Comércio Instituto Nacional de Tecnologia (Rio de Janeiro), v. 1, 1960, pp. 312-313.
2. Ahmad, Z. Directory of Mineral Deposits of Pakistan. Records of the Geol. Survey of Pakistan, v. 15, No. 15, pt. 3, 1969, p. 220.
3. Australian Bureau of Mineral Resources, Geology and Geophysics. Australian Mineral Industry, 1973 Review. 1975, p. 15.
4. Barton, W. R., and V. Z. Johnson. Natural Iron Oxide Pigments in New England and New York. New England-New York Inter-Agency Committee, Miner. Res. Study and Rept. Group, 1954, 11 pp.
5. Benjamin, M. Mineral Paints. Ch. in Mineral Resources of the United States, Calendar Year 1885. U.S. Geol. Survey, 1886, pp. 524-533.
6. Berberian, M. Contribution to Seismotectonics of Iran. Geol. Survey of Iran, Rept. 39, pt. 2, 1976, p. 19.
7. Bertraneu, J. Unpublished communication, Dec. 21, 1976. Available upon request from C. T. Collins, Bureau of Mines, Washington, D.C.
8. Blake, G. S. Mineral Resources of Palestine and TransJordan. Hashemite Kingdom of Jordan, Mineral Reports, Jerusalem, 1930, p. 36.
9. Boshier, A., and P. Beaumont. Mining in Southern Africa and the Emergence of Modern Man. Optima, v. 22, No. 1, 1972, pp. 2-12.
10. Brabers, A. J. M. Mineral Pigments. Ch. in Mineral Resources of the Republic of South Africa. South African Geol. Survey, 5th ed., 1977, pp. 391-393.
11. British Steel Quarterly Review (London). Beckermat Mine. Summer 1974, pp. 25-26.
12. Carr, M. S., P. W. Guild, and W. B. Wright. Iron in the United States. U.S. Geol. Survey Miner. Investigations Res. Map MR-51, 1967, p. 4.
13. Ceramic Industry Magazine. V. 104, No. 1, January 1975, p. 23 (advertisement).
14. Chamber of Mines, Republic of South Africa. Mining in South Africa. Min. Survey 76, April 1975, p. 9.
15. Coal, Gold and Base Minerals of Southern Africa (Johannesburg). V. 23, No. 10, December 1975, p. 89 (a statistical table).

16. Collins, C. T. Iron Oxide Pigments. Preprint ch. from the BuMines Minerals Yearbook 1977, 7 pp.
17. Corin, E. R. Minerals Marketing Information. Non-Metallic Mines in South Africa. Dept. of Mines, Minerals Bureau, Liaison Division Prelim. Rept. 2, January 1977, pp. 106-109.
18. Cramer, H. Die Farberdelagerstätten der Nordlichen Oberpfalz (Earth Pigment Deposits of Northern Upper Pfaltz). Ch. in Die Oberpfalz Kallmunz, Hannover, 1933, pp. 134-139.
19. De Chetelat, E. Some Problems in the Mining Industry in Morocco. Unpublished AID Field Report, November 1962, p. 12; available upon request from J. L. W. Jolly, Bureau of Mines, Washington, D.C.
20. Department of Scientific and Industrial Research (London). The Metalliferous Mining Region of Southwest England. Memoirs Geolog. Survey of Great Britain, v. 1, 1956, pp. 31-56.
21. Direccion General de Minas, Spain. Programa Nacional de Investigacion Minera (National Program of Ore Investigation). Ch. in Plan Nacional de la Minera. Ministerio de Industria (Madrid), 1971, pp. 19-36.
22. Du Bois, C. G. B. Minerals of Kenya. Geol. Survey of Kenya Bull. 8, 1966, p. 119.
23. Eckel, E. B. Geology and Mineral Resources of Paraguay-A Reconnaissance. U.S. Geol. Survey Prof. Paper, 1959, 327 pp.
24. Elliott, B. G. Private communication, Sept. 20, 1978. Available upon request from C. T. Collins, Bureau of Mines, Washington, D.C.
25. Engineering and Mining Journal. Meramec Produces 2 Million tpy of High Quality Pellets. V. 175, No. 11, November 1974, p. 147.
26. Federation of Egyptian Industries (Cairo). Mining Industries, 1975. Yearbook 1975, p. 38 (table 8).
27. Gair, J. E. Geology and Mineral Resources of Parts of Minas Gerais, Brazil. U.S. Geol. Survey Prof. Paper 341 A, 1962, 67 pp.
28. German Geological Mission in Jordan 1961-1966. Final Report and Map (unpublished). May 1966, p. 48 (sponsored by Federal Republic of Germany and Geological Survey of Jordan). Available upon request from J. L. W. Jolly, Bureau of Mines, Washington, D.C.
29. Gudden, H. Die Kreide-Eisenerzlagerstätten in Nordost-Bayern (Cretaceous Iron Ore Deposits in Northwest Bavaria). Geologisches Jahrbuch, (Hannover), series D, v. 10, 1975, pp. 201-238.

30. Guild, P. W. Geology and Minerals Resources of the Congonhas District, Minas Gerais, Brazil. U.S. Geol. Survey Prof. Paper 290, 1957, 90 pp.
31. Hancock, K. R. Mineral Pigments. Ch. in Industrial Minerals and Rocks, ed. by S. J. Lefond. American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., New York, 4th ed., 1975, pp. 335-357.
32. Harder, E. C. Iron Ores of the Appalachian Region of Virginia. Contributions to Economic Geology Series. U.S. Geol. Survey Bull. 380, 1908, pp. 215-254.
33. Harness, C. L. Marketing Mineral Pigments. BuMines IC 7217, 1942, 27 pp.
34. Harrer, C. M. Reconnaissance of Iron Resources in Arizona. BuMines IC 8236, 1964, pp. 116-119.
35. Harrer, C. M., and W. J. Tesch, Jr. Reconnaissance of Iron Occurrences in Colorado. BuMines IC 7918, 1959, 82 pp.
36. Harrison, J. V. Of Lime Salt-Plugs in Laristan. Quart. J. Geol. Survey, 1930, v. 86, pp. 463-522.
37. Hartmann, E. Farberden (Earth Pigments). Ch. in Die Nutzbaren Mineralien, Gesteine und Erden Bayerns (The Useful Minerals, Rocks and Earths of Bavaria). Bayern Oberbergamt, Geologische Landesuntersuchung, Munich, v. 2, 1936, pp. 334-344.
38. Hartwell, J. W., and B. A. Brett. Iron Oxide Pigments. BuMines Minerals Yearbook 1959, v. 1, 1960, p. 639.
39. Hill, J. M. Mineral Paints. Ch. in Mineral Resources of the United States, in 1914 (In Two Parts). Part 2, Nonmetals. U.S. Geol. Survey, 1914, pp. 103-122.
40. Hunting Survey Corp. Ltd. (Toronto, Canada). Reconnaissance Geology of Part of West Pakistan. A Colombo Plan Co-Operative Project. 1960, pp. 404, 463.
41. Indian Bureau of Mines, Ministry of Steel and Mines. Ochre. Indian Minerals Yearbook, 1968, p. 486.
42. _____. Ochre. Indian Minerals Yearbook, 1971, p. 582.
43. Industrial Minerals (London). Iron Oxide Pigments. V. 50, November 1971, pp. 9-19.
44. Ingham, F. T. The Geology of the Xeros-Troodos Area. Geol. Survey Dept. (Cyprus), Memoirs 1, 1959, 183 pp.
45. Iran Chamber of Commerce (Tehran). Industries and Mines Directory. 1975, 592 pp.

46. Johnson, S. S. Iron and Titanium Mineral Pigments in Virginia. Va. Miner. (Virginia Division of Mineral Resources), v. 10, No. 3, August 1964, pp. 1-6.
47. Jones, T. S. Iron Oxide Pigments (In Two Parts). Part 1. Fine-Particle Iron Oxides for Pigment, Electronic, and Chemical Use. BuMines IC 8771, 1978, 58 pp.
48. Justus, L. There's More Than Gold in Them Thar Hills. The Atlanta Journal and Constitution Magazine, v. 25, No. 43, February 16, 1975, pp. 12-19.
49. Kesler, T. L. Geology and Mineral Deposits of the Cartersville District, Georgia. U.S. Geol. Survey Prof. Paper 224, 1950, pp. 51-95.
50. Klinger, F. L. Iron Ore. BuMines Mineral Commodity Summaries, 1979, p. 79.
51. Knight, C. L. (ed.). Economic Geology of Australia and Papua New Guinea. 4. Industrial Minerals and Rocks. Australas. Inst. Min. and Met. Monogr. Series 8, 1976, pp. 293-296.
52. Koch, K. E. Private communication, Sept. 14, 1977. Available upon request from C. T. Collins, Bureau of Mines, Washington, D.C.
53. Krehn, F. L. Die Ockergewinnung in der Gegend um Königstein-Neukirchen, b. S. seit dem Weltkrieg (Mining of Ocher in the Area of Königstein-Neukirchen Since the World War). Doctoral Dissertation, Techn. Hochschule, Hannover, 1936, 49 pp.
54. Lees, G. M., and F. D. S. Richardson. The Oil-Field Belt of S.W. Iran and Iraq. Geol. Mag., No. 77, 1940, pp. 227-252.
55. Lehner, L. Die Gliederung der Fränkischen Alb-überdeckenden (Structure of the Cretaceous Cover of the Frankish Hills). Ch. in Neuen Jahrbuch für Centralblatt für Mineralogie, Geologie und Paläontologie. Stuttgart, Germany, 1924, pp. 176-181.
56. _____. Der Neukirchener Ocher (Neukirchen Ocher). Ch. in Neuen Jahrbuch für Centralblatt für Mineralogie, Geologie und Paläontologie. Stuttgart, Germany, 1933, pp. 210-217.
57. Lilljequist, R. The Geology and Mineralization of the Troulli Inlier. Ministry of Commerce and Industry (Nicosia, Cyprus), Bull. 4, 1969, pp. 45-87.
58. Love, C. H. Black Iron Oxides. Ch. in Pigment Handbook, ed. by T. C. Patton. John Wiley & Sons, Inc., New York, v. 1, 1973, pp. 757-758.

59. _____. Colored Iron Oxide Pigments, Natural. Ch. in Pigment Handbook, ed. by T. C. Patton. John Wiley & Sons, Inc., New York, v. 1, 1973, pp. 323-332.
60. _____. Micaceous Iron Oxide. Ch. in Pigment Handbook, ed. by T. C. Patton. John Wiley & Sons, Inc., New York, v. 1, 1973, pp. 759-761.
61. Love, C. H., and J. W. Ayers. The Iron Oxide Pigments. Ch. in Protective and Decorative Coatings, ed. by J. J. Mattiello. John Wiley & Sons, Inc., New York, 1942, pp. 287-328.
62. Maxwell, C. H. Geology and Ore Deposits of the Alegria District, Minas Gerais, Brazil. U.S. Geol. Survey Prof. Paper 341J, 1972, 102 pp.
63. Mayhew, L. D. Paint I: Inorganic Materials in Paint Manufacture. Industrial Minerals (London), No. 99, December 1975, p. 40.
64. McGowan, M. Private communication, July 18, 1978. Available upon request from C. T. Collins, Bureau of Mines, Washington, D.C.
65. Melcher, N. B., and J. M. Forbes. Iron Ore. BuMines Minerals Yearbook 1950, v. 1, p. 613.
66. Ministère du Commerce, de l'Industrie, des Mines et de la Marine Marchande (Rabat, Morocco). Bulletin Mensuel des Statistiques Minières (Monthly Bulletin of Mining Statistics). April 1977, pp. 6, 18.
67. _____. Activité du Secteur Minier 1976 (Mining Sector Activity 1976). 1976, p. 41.
68. Ministerio das Minas e Energia (Brasilia). Anuario Mineral Brasileiro (Minerals Yearbook of Brazil). V. 5, 1976, p. 253.
69. _____. Anuario Mineral Brasileiro (Minerals Yearbook of Brazil). V. 6, 1977, p. 229.
70. Ministerio de Economia Republica Argentina (Buenos Aires). Estadística Minera de la Republica Argentina, Año 1976 (Mineral Statistics of Argentina, 1976). 1977, 300 pp.
71. Ministerio de Industria Servicio de Publicaciones (Madrid). Estadística Minera de España 1975 (Mineral Statistics of Spain 1975). 1976, pp. 72-73.
72. Ministerio de Minería Servicio de Minas del Estado Chile (Santiago). Anuario de la Minería de Chile, Años 1975-1976 (Minerals Yearbook of Chile, 1975-1976). 1977, p. 110.
73. Ministry of Agriculture and Natural Resources, Republic of Cyprus (Nicosia). Annual Report of the Geological Survey Department for the Year 1976. September 1977, 43 pp.

74. Ministry of Finance, Planning and Economic Affairs, Pakistan. Mineral Production of Pakistan and Provinces. Pakistan Statistical Yearbook, 1975, p. 72.
75. Nassberg, B. Micaceous Iron Oxide. Am. Paint. J., v. 54, June 22, 1970, pp. 68-73, 76-77, 80-81.
76. Nasser, T. Z. Construction and Chemical Raw Materials, Salt and Gypsum Deposits in Iran. Ministry of Industry and Mines (Tehran), Nov. 26, 1962, 12 pp.
77. Nicolaidis, A. A. Private communication, May 25, 1977. Available upon request from C. T. Collins, Bureau of Mines, Washington, D.C.
78. Pantazis, T. M. The Geology and Mineral Resources of the Pharmakas-Kalavastos Area. Geol. Survey Dept. Cyprus, Mem. 8, 1967, 190 pp.
79. Pennsylvania Department of Internal Affairs, Pennsylvania State College, School of Mineral Industry. Iron and Ferro-Alloy Metals. Ch. in Pennsylvania's Mineral Heritage. 1944, p. 95.
80. Pratt, J. H. Mineral Paints. Mineral Resources of the United States, Calendar Year 1903. U.S. Geol. Survey, 1904, pp. 1095-1103.
81. Pulfrey, W. The Geology and Mineral Resources of Kenya, Imperial Institute, Mineral Resources Dept. (Nairobi), v. 45, No. 3, 1948, p. 295.
82. Qureshi, N. H. Industrial Minerals and Rocks of West Pakistan, Review of Mining Activities. Pres. at Central Treaty Organization Symp. on Industrial Rocks and Minerals, Lahore, Pakistan, December 1962. The Mineral Resources and Exploration Institute of Turkey, 1963, p. 44.
83. Reyna, J. G. Riqueza Miñera y Yacimientos Minerales de Mexico (Economics of Mining and Mineral Deposits of Mexico). Banco de Mexico, S.A., 1947, p. 372.
84. _____. Riqueza Miñera y Yacimientos Minerales de Mexico (Economics of Mining and Mineral Deposits of Mexico). Banco de Mexico, S.A., 1956, p. 423.
85. Robertson, A. H. F. Origins of Ochres and Umbers: Evidence From Skouriotissa, Troodos Massif, Cyprus. Inst. Mining and Metals Trans., sec. B, v. 85, November 1976, pp. B235-B251.
86. Roch, E. La Géologie du Pays d'Apt (Geology of the Apt Region). Bull. Bur. Rech. Geol. Minières (France), sec. 4, 1971, pp. 48-57.
87. Santmeyers, R. M. Ocher and Ochery Earths. BuMines IC 6132, 1929, 20 pp.
88. Servicio Sindical de Estadística (Madrid). Estadísticas de Producción Industrial 1973 (Industrial Production Statistics 1973). 1974, p. 98.

89. Simpson, T. A., H. H. McCarl, A. F. Hilleke, and H. S. Hanna. Assessment of Iron Ore Availability in Alabama and the Southeastern Appalachian Region. Univ. Ala. NSF Grant AER 77-16114, July 31, 1978, 102 pp.
90. South African Mining and Engineering Journal. Bright Future for Neglected Minerals. November 1975, pp. 28-31.
91. Sullivan, C. J., and A. A. Opik. Ochre Deposits, Rumbalara, Northern Territory. Australia Bureau of Mineral Resources, Geology and Geophysics, Bull. 8, 1951, 21 pp.
92. Termier, H., and G. Termier. Paleontologie Stratigraphique. Pt. 3, Trias, Jurassique, Cretace (Stratigraphic Paleontology, Pt. 3, Triassic, Jurassic and Cretaceous). Masson et c^{ie}, Paris, 1960, p. 6.
93. Treade, M. 316 Micaceous Iron Oxide - For Use as a Barrier Coat in Anti-Corrosive Paint Systems. Am. Paint J., v. 59, Sept. 23, 1974, pp. 52-53, 56, 62.
94. United Nations. Survey of World Iron Ore Resources. 1970, 479 pp.
95. U.S. Embassy, Rome, Italy. State Dept. Airgram A-029, Jan. 26, 1977, 2 pp.
96. U.S. Embassy, Tehran, Iran. State Dept. Airgram A-225, Dec. 29, 1976, 2 pp.
97. Vila, T. Recursos Minerales No-metálicos de Chile (Non-metallic Mineral Reserves of Chile). Editorial Universitaria, S.A. (Chile), 1953, pp. 369-400.
98. Visser, D. J. L., and B. S. Visser. The Ocher Deposits of Riversdale District, Cape Province. Dept. of Mines, Union of South Africa, Johannesburg, 1937, 21 pp.
99. Von Freyberg, B. Geologie der Fränkischen Alb Zwischen Pegnitz und Auerbach (Geology of the Frankish Hills Between Pegnitz and Auerbach). Erlanger Geol. Abh., v. 2, 1952, 28 pp.
100. _____. Erläuterungen zur Geologischen Karte von Bayern (Explanations for the Geological Map of Bavaria). Munich, 1961, plate 6235.
101. Wagner, P. A. The Iron Deposits of the Union of South Africa. Dept. of Mines and Industries Geol. Survey (Johannesburg), Mem. 26, 1928, 268 pp.
102. Watson, T. L. Mineral Resources of Virginia. The Virginia Exposition Commission, Lynchburg, Va., 1907, 618 pp.
103. Wilson, H. Iron Oxide Mineral Pigments of the United States. BuMines Bull. 370, 1933, 198 pp.
104. _____. Ochers and Mineral Pigments of the Pacific Northwest. BuMines Bull. 304, 1929, 74 pp.

APPENDIX A.--GEOLOGIC TIME SCALE

Era	Approximate age in millions of years (radioactivity)	Period System Period refers to a time measure; system refers to the rocks deposited during a period.	
Cenozoic		Recent (Holocene) } Neogene	
		Pleistocene } Neogene	
	7	Pliocene } Neogene	
	26	Miocene } Neogene	
	37-38	Tertiary { Oligocene } Paleogene	
	53-54	Eocene } Paleogene	
Mesozoic	65	Cretaceous	
	136	Jurassic	
	190-195	Triassic	
	225	Permian	
Paleozoic	280	Pennsylvanian } Carboniferous	
	310	Mississippian } Carboniferous	
	345	Devonian	
	395	Silurian	
	430-440	Ordovician	
	500	Cambrian	
	Precambrian	570	
		700	
3,400		Approximate age of oldest rocks discovered.	
4,000			
4,500	Approximate age of meteorites.		

APPENDIX B.--GLOSSARY OF TERMS

Apatite.--A mineral composed of calcium phosphate; also a group of vari-
etal apatite minerals (fluor-apatite, chlor-apatite, etc.).

Argil.--White clay; potter's clay; aluminite.

Bentonite.--A clay derived from decomposed volcanic ash; chief constit-
uent is usually montmorillonite, a magnesium-rich, hydrous aluminum-silicate
clay mineral.

Breccia.--A rock composed of angular fragments larger than 2 millimeters
in diameter.

Calcination.--The heating of ores, concentrates, or precipitates to
decompose carbonates, hydrates, or other compounds.

Chert.--An extremely fine-grained variety of quartz.

Clastic.--Pertaining to rocks or sediments composed of fragments broken
from other preexisting rocks.

Colluvium.--Applied to loose and incoherent deposits, usually at the foot
of a slope or cliff, brought there chiefly by gravity.

Conchoidal fracture.--A break with concave and convex surfaces; shell
shaped.

Concretionary.--Tending to grow together; particles of like chemical com-
position, when free to move, combine and form nodules of various sizes and
shapes, called concretions.

Dike.--A tabular body of rock which lies at an angle to the surrounding
rocks, due to its intrusion in the molten state into fissures in the existing
rock.

Dome.--A symmetrical structural uplift having an approximately circular
outline when projected on a map, and in which the uplifted beds dip outwards,
more or less equally in all directions from the center.

Efflorescent.--Forming a deposit of grains or powder that resembles
lichens or dried leaves; often due to loss of water of crystallization.

Eluviation.--A weathering process that concentrates insoluble and/or
heavy minerals in place by reduction in volume and removal of decomposition
products by solution or wind action. The process usually does not involve any
movement except compaction downward or minor soil creep.

Facies.--The general appearance or nature of one part of a rock body (reflecting conditions and environment of its origin) as contrasted with other parts.

Ferric.--Of, pertaining to, or containing iron in the trivalent state.
Example: Ferric chloride, FeCl_3 .

Ferrite.--A manmade mixed oxide composition of iron and one or more other cationic elements. Bodies produced from the compound are used for their magnetic and electronic properties.

Ferrous.--Of, pertaining to, or containing iron in the bivalent state.
Example: Ferrous chloride, FeCl_2 .

Footwall.--(a) The wall, or rock, that lies below an ore deposit; also (b) the wall below the surface of an inclined fault.

Foraminifera.--A subdivision of protozoa with skeletons known as tests, which are microscopic in size, commonly made of calcium carbonate, more rarely of sand.

Friable.--Easily broken or naturally crumbling.

Glauconite.--A mineral composed of hydrous silicate of iron and potassium, varying in composition.

Gneiss.--Metamorphic, coarse-grained rock characterized by banding of light (quartz and feldspar) and dark (mica and/or hornblende) minerals.

Goethite.--A hydrated oxide of iron; $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$.

Grit.--Very coarse sand or fine gravel.

Hanging wall.--(a) The wall or rock that lies above an ore deposit; also (b) the wall or rock on the upper side of an inclined fault.

Hematite.--A mineral composed of iron oxide; Fe_2O_3 .

Hiding power.--The opacity that pigment imparts to a paint film by its capacity to break up light rays and reflect them back.

Horse.--An irregularity, or waste inclusion, within an ore deposit.

Hydrothermal.--Literally, pertaining to hot water; also commonly applied to a process of ore deposition by hot fluids, high in water content.

Inlier.--A more or less circular or elliptical area of older rocks surrounded by younger strata.

Jasperoid.--Silicified rock; resembling jasper, an impure, opaque, colored quartz.

Kaolin.--A clay, mainly hydrous aluminum silicate.

Karst.--Limestone region with many sinkholes, abrupt ridges, caverns, and underground streams.

Klippe.--An isolated block of rocks separated from the underlying rocks by a fault.

Lake.--A bright, translucent, organic pigment composed of a soluble dye combined with an inorganic carrier.

Laterization.--A residual weathering and oxidation process leading to the conversion of rock to laterite by leaching of silica, carbonates-alkalies, and other rock constituents, leaving an iron- or aluminum-rich residue.

Limonite.--A mineral composed of hydrated oxide of iron; $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$.

Magnetite.--A mineral composed of magnetic iron oxide; Fe_3O_4 .

Marl.--A calcareous clay, or intimate mixture of clay and particles of calcite or dolomite, usually fragments of shells.

Massif.--The dominant central mass (or compact portion) of a mountain range that is more or less defined by longitudinal or transverse valleys or faults.

Martite.--Iron oxide, Fe_2O_3 ; pseudomorphous after magnetite.

Metamorphosed.--Changed while in the solid state, either in texture or in mineral composition, by any of the following: Heat, pressure, stress, shear, or chemically active solutions.

Metasomatic.--Relating to a replacement process of simultaneous substitution by which new minerals are substituted for earlier minerals or rocks.

Meteoric water.--Water derived from rain, watercourses, or other bodies of surface water, part of which circulates through, and becomes stored in, pores and cracks of rocks.

Micronizing.--A jet (steam or air) milling process which yields smaller and more uniform particle size than conventional milling processes.

Monazite.--A phosphate of the cerium metals; a principal ore of the rare earths and thorium.

Ocher.--Earthy pigment material usually consisting of hydrated iron oxide mixed with clay and sand in varying amounts. Native yellow and brown ochers are varieties of limonite, and native reds are varieties of hematite. Reds are also obtained by calcining yellows.

Oolite.--A rock consisting of small, rounded concretions which may be calcareous, siliceous, or hematitic.

Orogenic.--Pertaining to the processes of mountain building, especially folding, faulting, igneous, and metamorphic processes.

Peneplain.--The smooth, rolling surface that developed very late in the erosion cycle.

Phyllite.--A micaceous rock intermediate in texture between slate and schist.

Pillow lavas.--A general term for lavas that exhibit stacks of rounded, pillowlike structures, commonly formed as a result of rapid cooling in water.

Pipe.--An elongated body of mineral; a narrow portion of rich ore extending down the lode.

Porphyry.--Igneous rock with a texture in which some of the crystals are much larger than the matrix.

Pseudomorphous.--Pertaining to a mineral that has replaced another and has retained the form and size of the replaced mineral.

Pyrite.--A mineral composed of iron disulfide, FeS_2 ; often with small amounts of copper, arsenic, nickel, cobalt, gold, selenium; "Fool's Gold."

Pyroclastic.--Pertaining to a clastic rock or texture produced by explosive or aerial ejection of material from a volcanic vent; applied to the deposits, as well as the textures so formed.

Radiolarite.--Siliceous earth composed of fragments of rock containing marine protozoan skeletons.

Residuum.--Material resulting from decomposition of rocks in place and consisting of nearly insoluble material left after all the more readily soluble constituents of the rocks have been removed.

Rhyolite.--Fine-grained igneous rock similar in composition to granite.

Ruddle.--Regional (Germany) term for red iron ore, or coloring earth.

Saddle.--A ridge connecting two higher elevations.

Scarp.--A steep slope; cliff.

Schist.--Foliated metamorphic rock usually containing conspicuous mica.

Shale.--Fine-grained sedimentary rock composed largely of clay and silt, characterized by cleavage parallel to bedding.

Siderite.--A mineral composed of iron carbonate; FeCO_3 .

Sienna.--A brownish orange-yellow clay colored by iron and manganese oxides.

Skarn.--Rock composed of lime-bearing silicates.

Staining power.--The property of certain pigments that allows them to impart color while maintaining a degree of transparency.

Stringer.--A narrow vein of mineral traversing a rock mass of different material.

Talus.--Rock deposit at the bottom of a cliff composed of fragments weathered from the cliff.

Tectonic.--Pertaining to rock structures and topographic features resulting from deformation of the earth's crust.

Tension fracture.--A fracture that is the result of stresses that tend to pull material apart.

Thrust plane.--The plane of a reverse fault that is characterized by a low angle of inclination with reference to the horizontal plane.

Tuff.--Rock formed of compacted volcanic fragments, usually smaller than 4 millimeters.

Ultrabasic.--A term applied to rocks which contain less than 45% silica, virtually no quartz or feldspar, and composed essentially of ferromagnesian silicates. Metallic oxides and sulfides, and native metals are also common. Ultramafic.

Umber.--A naturally occurring brown earth containing iron oxide together with silica, alumina and manganese oxides, and lime.

Unconformity.--A break in the continuity of deposition where one rock is overlain by another that is not the next in geological succession.

Wad.--Dark brown or black impure mixture of manganese and other oxides, soft and containing 10% to 20% water; also called black ocher, earthy manganese, or bog manganese.

Wadi.--Bed or valley of a stream in an arid region, which is dry except during the rainy season.

Wash.--A thin coating, such as watercolor.