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Additional Descriptive Models of Industrial Mineral Deposits

edited by

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INTRODUCTION

This report includes previously written, but unpublished descriptive industrial mineral deposit models not released in earlier reports (Cox and Singer, 1986; Orris, 1992; Orris and Bliss, 1991, 1992). Although some of the models are preliminary, recent and repeated requests for several of the models has led to their release in this compilation. Initial drafts of the clay models were written for individual U.S. deposits or districts by J.W. Hosterman[2] of the U.S. Geological Survey (USGS) in the late 1980's. All of the models in this report have been modified from their original unpublished versions; for most models, the modifications have consisted of additional geologic detail, economic information, and (or) health and environmental considerations related to the deposit type. More extensive alterations have been made to the clay models written by Hosterman, which were put into standard format and extensively revised by G.J. Orris. As much as two-thirds of the information in the current versions of the models post-dates Hosterman's contributions and these models are shown as jointly authored.

Readers not familiar with the industrial minerals industry should be aware that common and industry use of mineral names may not match geologic usage. For instance, "talc" is a mineral name, but many talc ores and products may contain substantial amounts of non-talc minerals. In a commercial sense, talc is a rock composed of magnesium silicates in which the mineral talc may be dominant, abundant, minor, or, in the extreme case, absent

The reader should also be aware that there are ongoing efforts to model more quantitative aspects of the deposits described in this report. Characteristics such as size, grade, contaminant distribution, physical properties, and other measurable characteristics of specific deposit types are being collected, analyzed, and modeled. These quantitative models take much longer to complete than their accompanying descriptive models and are commonly released separately.

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[2] Deceased.

Model 8f

PRELIMINARY DESCRIPTIVE MODEL OF ULTRAMAFIC HOSTED MAGNESITE

by
Norman J Page

BRIEF DESCRIPTION

Magnesite occurs as vein filling material or an alteration product of ultramafic rocks. Deposits occur as massive bodies, lenticular masses, and veins and stockworks.

Deposit synonyms: Cryptocrystalline magnesite, bone magnesite, amorphous magnesite; crystalline magnesite in ultramafic rocks

Principal commodities produced: Magnesite.

By-products: Talc is a coproduct in some deposits.

End uses: High-purity refractories, chemicals, production of Mg metal.

Descriptive/genetic synopsis: Cryptocrystalline magnesite in veins or massive bodies resulting from replacement of serpentine, which replaced the magnesium silicates in dunite and peridotite.

Typical deposits:
Khalkidiki Peninsula, Greece
Kütahya, Turkey
North-central Vermont, USA
Red Mountain District, California, USA
Deloro Deposit, Ontario, Canada

Relative importance of the deposit type: Traditionally, this is the second most important producer of magnesite by deposit type. Deposits are typically small, although there are exceptions.

Associated/related deposit types: Podiform chromite, nickel laterite, serpentine - hosted asbestos.

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting: Ophiolite, accreted terranes.

Age range: Predominantly Paleozoic through Mesozoic.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Serpentinized dunite, peridotite.

Associated rock(s): Pyroxenite, pillow basalt, sheeted dikes.

Ore mineralogy: Magnesite, talc.

Gangue mineralogy: Serpentine minerals, magnetite, olivine, pyroxene, tremolite, actinolite, quartz, dolomite, calcite, chalcedony, chlorite.

Alteration: Carbonatization.

Structural setting: Locally form shells around ultramafic bodies.

Ore control(s): Contacts of ultramafic rocks with country rocks, in faults, fractures, and shear zones.

Typical ore dimensions: Veins range from a few feet to hundreds of feet in length and depth; a few inches to tens of feet in width.

Effect of weathering: Magnesite is relatively more resistant to weathering and may form topographic highs. It is more resistant to weathering than associated dolomite, which has a similar luster and specific gravity. Some magnesite weathers rusty brown.

Other exploration guide(s): Deposits tend to be relatively small and narrow.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: Impurities include lime, silica, boron, iron, and alumina, which may make much of the magnesite from this deposit type unsuitable for refractories.

Compositional/mechanical processing restrictions:

- Deposits run 10-20% magnesite, 3-10% is a recoverable content. Crude magnesite should contain about 43% MgO.
- Beneficiation of cryptocrystalline magnesite commonly is easier than for carbonate-hosted crystalline magnesite because the iron and boron content of the magnesite are typically low.

Distance limitations to transportation, processing, end use: Processing of natural magnesite offers energy advantages over production of magnesia from brine.

Environmental/health concerns related to deposit type:

- Tremolite-actinolite gangue can be a health/environment concern.
- Processing of natural magnesite offers energy advantages over production of magnesia from brine.

OTHER

- Magnesite from this deposit type commonly is cryptocrystalline, but may be fibrous or granular.
- Many of these deposits must be mined by underground methods because of the small size and irregular shape of the deposits.

REFERENCES

Bodenlos and Thayer, 1973
Chidester, 1962
Davis, 1957
Griffis, 1972
Harben and Bates, 1984
Wicken and Duncan, 1975

Model 8g

PRELIMINARY DESCRIPTIVE MODEL OF ULTRAMAFIC-HOSTED TALC

by
Norman J Page

BRIEF DESCRIPTION

The talc is an alteration product of ultramafic rocks and occurs in veins, massive bodies, and lenticular masses.

Deposit synonyms: Soapstone, steatite deposits.

Principal commodities produced: Talc.

By-products: Magnesite is a coproduct in some deposits.

End uses: Paint extender; paper filler and coater; ceramics; cosmetic and pharmaceutical industries; feedstuffs; other.

Descriptive/genetic synopsis: Deposits form from replacement of serpentine minerals, which are the products of replacement of magnesium silicates in dunite and peridotite. Reaction zones between serpentinites and country rock may form concentric shells of talc-bearing rock.

Typical deposits:
Windham, Vermont, USA
Lahnaslampi, Finland
Harford County, Maryland, USA
Altermark, Norway

Relative importance of the deposit type: Most abundant talc resource, but a secondary source of production.

Associated/related deposit types: Ultramafic hosted magnesite, podiform chromite, nickel laterite, serpentine-hosted asbestos.

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting: Ophiolite, accreted terranes.

Age range: Predominantly Precambrian through Mesozoic.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Serpentinite, dunite, peridotite.

Associated rock(s): Gneiss, schist, gabbro, granitic intrusions.

Ore mineralogy: Talc.

Gangue mineralogy: Iron carbonate, tremolite, magnetite, pyrrhotite, pentlandite, chlorite, pyrophyllite, vermiculite, anthophyllite, biotite, serpentine minerals.

Alteration: Carbonatization.

Structural setting: Regional and contact metamorphism in foldbelts.

Ore control(s): Faults, contacts.

Typical ore dimensions: 1 to 100 ft thick; less than 100 ft to 1000's of feet in length.

Geochemical signature(s): Near ore bodies, some minerals and elements may be enriched or depleted in comparison to unaltered host rocks, but element enrichments and depletions vary with each talc district.

Geophysical signature(s): While no geophysical techniques are definitive indicators of talc, a variety of methods can help identify structures and alteration commonly present in talc-bearing regions. VLF-EM can help identify fracture trends (Piniazkiewicz and others, 1994).

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: The color and brightness, fineness, oil absorption, chemical inertness, purity, particle shape, surface area, softness, smoothness, lubricating power, and low thermal and electrical conductivity all determine the specific uses of talc.

- Cosmetic uses require less than 1.0% (frequently < 0.1%) quartz; less than 0.1% tremolite; less than 3 ppm As, and less than 20 ppm Pb (Piniazkiewicz and others, 1994).

Compositional/mechanical processing restrictions: Material specifications related to composition, color, and physical properties are increasingly restrictive.

Distance limitations to transportation, processing, end use: Not a factor for high-end uses.

Environmental/health concerns related to deposit type: Tremolite gangue is considered a health hazard locally if asbestiform. Talc workers exposed to talc dust may exhibit symptoms of talc pneumoconiosis, bronchitis, and emphysema, and may have abnormal chest X-rays and an increased risk of tuberculosis (Ross and others, 1993).

Competition/substitution: Talc filler markets are being rapidly penetrated by carbonate filler products.

OTHER

- Many talc ores and products may contain substantial amounts of non-talc minerals. In a commercial sense, talc is a rock composed of magnesium silicates in which the mineral talc may be dominant, abundant, minor, or, in the extreme case, absent.

REFERENCES

Brown, 1973
Chidester and others, 1964
Harben and Bates, 1984
Merrill, 1963
Piniazkiewicz and others, 1994.
Roe, 1975
Ross and others, 1993

Model 13

PRELIMINARY DESCRIPTIVE MODEL OF PEGMATITES

by
Norman J Page and Lincoln R. Page

BRIEF DESCRIPTION

Deposit synonyms: None.

Principal commodities produced: Feldspar, quartz, sheet and scrap mica, Be, Li, Nb, Ta, Sn, Cs, gems.

By-products: Sb, Ti, U, Th, other radioactive elements, F, Gd.

End uses: Varies by commodity produced.

Descriptive/genetic synopsis: Pegmatites are unevenly textured coarse-grained rocks composed of essentially quartz and feldspars. Pegmatites consist of structural and lithologic units that may make them simple or complex in appearance depending upon the number and variety of mineralogical and textural units. Mineralogical and textural units or zones include a border zone, wall zone, intermediate zones, and a core that may contain fracture fillings or replacement bodies of predominantly quartz and feldspar.

Typical deposits:

Kings Mountain, North Carolina, USA
Greenbushes, Western Australia, Australia
Bikita, Zimbabwe
Spruce Pine, North Carolina, USA
Tanco, Manitoba, Canada

Relative importance of the deposit type: Pegmatites are a major source of feldspar, Cs, Li, mica, Be, Nb, and Ta.

Associated/related deposit types: Alluvial Sn, alluvial Nb-Ta, alluvial gems.

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting: Regional metamorphic terranes, usually above chlorite-grade. Terranes with granitic plutons or batholiths and their associated contact metamorphosed country rocks.

Regional depositional environment: Zoned pegmatites tend to occur in clusters; tend to have accessory mineral compositions related to metamorphic grade with Be, Li, Cs, etc. mineral pegmatites more abundant at lower grades.

Age range: Precambrian through Tertiary.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Mica schist and gneiss, hornblende schist and gneiss, calc-silicate gneiss, silicated marble, quartzite, igneous rocks.

Associated rock(s): Granite, quartz monzonite, granodiorite, quartz diorite.

Ore mineralogy: Plagioclase, quartz, microcline, perthite, muscovite, amblygonite, spodumene, petalite, lepidolite, beryl, tantalite, microlite, columbite, cassiterite, topaz, rutile, samarskite, gadolinite, fluorite, zircon, scheelite, wolframite, stibio-tantalite, pollucite, tourmaline.

Gangue mineralogy: Tourmaline, garnet, apatite, graftonite, triphylite, biotite, vivianite, pyrrhotite, pyrite.

Alteration: Reactions with wall rock produce wall zones and also wall rocks that can be enriched in muscovite, tourmaline, garnet, apatite, beryl, and biotite.

Structural setting: Concordant to discordant bodies controlled by fractures in competent rocks like gneiss or by foliation or bedding in less competent like schist. Plunges of bodies are parallel to lineations (fold axes) or contacts.

Ore control(s): Temperature, pressure, and composition of magmatic fluids and host rocks influence type of mineralization. Faults, fractures, bedding planes.

- Granite pegmatites begin to crystallize at 800° to 700° C; blocky pegmatite crystallizes within the temperature range of 700° to 600°C. Tourmaline, muscovite, beryl, and topaz crystallize in the 600° to 500°C range. Metasomatic replacement of K-feldspar in the blocky zone by albite, muscovite, lithium-micas, spodumene, tin minerals, tungsten, and rare-earth minerals may occur at 500° to 400° C and form complex pegmatites. At lower temperatures, hydrothermal minerals and the quartz core of the pegmatite form.
- Contamination of the magma by basic host rocks may lead to the formation of biotite, cordierite, diopside, or garnet. Low-silica ultrabasic rocks host rocks may cause desilification resulting in the formation of corundum. Contamination by rocks with a high alumina content may result in formation of corundum, sillimanite, andalusite, and chrysoberyl.
- Pegmatites with rare earths tend to form at a depth of 11 km or more. Pegmatites with rare metals (such as beryl, tantalite, spodumene, etc.) and

precious stones probably form between 3.5 and 7 km depth. Rock-crystal bearing pegmatites form at relatively shallow depths of 1.5-3.5 km.

Typical ore dimensions: Deposits range from inches long and wide to more than 1.6 km long and more than 150 m wide. Greenbushes, one of the larger deposits, is 3 km X 150 m X 50 m.

Typical alteration/other halo dimensions: Tabular or thinly lenticular, branching, irregular or teardrop-shaped, pipelike, arcuate, and troughlike forms.

Effect of weathering: Development of kaolinite and other clays (e.g., Greenbushes, Spruce Pine). Release of gems and other insoluble minerals for alluvial deposits.

Effect of metamorphism: Granulization, recrystallization.

Maximum limitation of overburden: Depends on the value of the products.

Geochemical signature(s): ± Li ± P ± Ta ± Nb ± Ti ± F ± W ± REE ± Zr ± U ± Th ± B ± Be± Sn

Geophysical signature(s): Radioactivity; can outline pegmatite bodies with scintillation counter.

Other exploration guide(s): Zonal distribution of minerals is an important concept for individual pegmatite evaluations.

- Cameron and others (1949) reported that zones in pegmatites follow a general sequence from wallrock contact inward as follows: 1) plagioclase-quartz-muscovite; 2) plagioclase-quartz; 3) quartz-perthite-plagioclase, +/- muscovite and (or) biotite; 4) perthite-quartz; 5) perthite-quartz-plagioclase-amblygonite-spodumene; 6) plagioclase-quartz-spodumene; 7) quartz-spodumene; 8) lepidolite-plagioclase-quartz; 9) quartz-microcline; 10) microcline-plagioclase-lithium-mica-quartz; and 11) quartz. Few pegmatites contain all eleven zones, but there is a tendency for zones to occur in this order.
- Not all economic pegmatite deposits are zoned, many show a homogeneous unzoned structure.
- Coarser beryl tends to be in inner zones of pegmatites and large masses of beryl may extend across several zones within a pegmatite. Beryl is evenly distributed in some deposits, but in other pegmatites, it is irregularly distributed.
- Sheet mica tends to occur in pockets randomly scattered throughout pegmatite bodies.

Most readily ascertainable regional attribute: Proximity to granitic batholiths.

Most readily ascertainable local attribute: Identification of thin, fine-grained border zone associated with coarse-grained or pegmatitic rocks.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: Varies with commodity.

Compositional/mechanical processing restrictions: Varies with commodity.

Distance limitations to transportation, processing, end use: Varies with commodity.

Environmental/health concerns related to deposit type: In rare cases, pneumoconiosis can result from the inhalation of large quantities of mica in the absence of other silicates or quartz (Ross and others, 1993).

REFERENCES

Beus, 1966
Cameron and others, 1949
Cameron and others, 1954
Cerny, 1982
Cooper, 1964
Hanley and others, 1950
Harben and Kuzvart, 1996
Hatcher and Elliott, 1986
Jahns, 1946
Jahns and others, 1952
Martin and Cerny, 1992
Norton, 1983
Norton and Page, 1956
Norton and Redden, 1990
Page and others, 1953
Ross and others, 1993

PRELIMINARY DESCRIPTIVE MODEL OF METASOMATIC AND METAMORPHIC REPLACEMENT MAGNESITE

by
Norman J Page

BRIEF DESCRIPTION

Deposit synonyms: Veins; lenticular masses replacing limestone, dolomite, and calc-silicate rocks.

Principal commodities produced: Magnesite and (or) brucite.

End uses: Chemicals, high purity refractories, production of Mg metal.

Descriptive/genetic synopsis: Metamorphic and metasomatic replacement of preexisting lithologies.

Typical deposits:
Gabbs, Nevada, USA
Cedro and Jurema, Ceara, Brazil
Breitenau, Austria
Satka, southern Urals, Russia
Xiafanshen, Liaoning Province, China
Mount Brussiloff, British Columbia, Canada

Relative importance of the deposit type: This traditionally has been the dominant source of natural magnesite supplying as much as two-thirds of the magnesia used commercially.

Associated/related deposit types: Metasomatic and metamorphic replacement talc.

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting: Miogeosynclinal and eugeosynclinal sequences in regions affected by deformation, low-grade metamorphism, and intrusion of plutonic rocks.

Regional depositional environment: Igneous activity, regional metamorphism, contact metamorphism.

Age range: Predominantly Paleozoic through Mesozoic, also Precambrian.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Dolostone, limestone, calc-silicate rocks.

Associated rock(s): Shale, sandstone, quartzite, diabase dikes, granodiorite, granite, rhyolite, amphibolite, pyroxenite, diabase, peridotite.

Ore mineralogy: Magnesite, brucite.

Gangue mineralogy: Dolomite, calcite, serpentine, talc, diopside, magnetite, tremolite-actinolite, chlorite, phlogopite, quartz, garnet, breunnerite, specularite, anthophyllite, enstatite, pyrite, clay minerals.

Alteration: Locally, contacts are gradational from magnesite to dolostone to limestone; silicification; recrystallization.

Ore control(s): Faults, fractures, cleavage planes, original dolomite sediment.

Typical ore dimensions: Bodies typically are lenticular-- hundreds to thousands of meters long and tens to hundreds of meters wide.

Effect of weathering: Magnesite is relatively resistant to weathering and may form topographic highs.

Maximum limitation of overburden: Gabbs deposit has 10 - 15 m of overburden.

Other exploration guide(s): Magnesite is relatively resistant to weathering and may form topographic highs.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use:

- Main impurity is calcium;, more than 4% CaO makes the magnesite unmarketable for high-purity refractories.
- Relatively high iron and silica contents are problems.

Environmental/health concerns related to deposit type: Tremolite-actinolite can be an environmental and health hazard.

OTHER

- Processing of natural Mg offers energy-saving advantages over processing of brines.

REFERENCES

Bodenlos, 1950
Bodenlos and Thayer, 1973
Davis, 1957
Duncan and McCracken, 1994
Harben and Bates, 1990
Schilling, 1968
Wicken and Duncan, 1975

PRELIMINARY DESCRIPTIVE MODEL OF METASOMATIC AND METAMORPHIC REPLACEMENT TALC

by
Norman J Page
(modified by G. Orris, 8/98)

BRIEF DESCRIPTION

Deposit synonyms: Contact metamorphic.

Principal commodities produced: Talc.

End uses: Paint extender; paper filler and coater; ceramics; cosmetic and pharmaceutical industries; filler for animal feed.

Descriptive/genetic synopsis: Hosted in low-grade metasediments, particularly those associated with dolostone.

Typical deposits:
Gouverneur, New York, USA
Yellowstone Mine, Montana, USA
Henderson and Conley Mines, Ontario, Canada
Trimouns, France
Haicheng District, Liaoning Province, China

Relative importance of the deposit type: These deposits are a major source of talc.

Associated/related deposit types: Metasomatic and metamorphic replacement magnesite.

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting: Miogeosynclinal and eugeosynclinal sequences in regions affected by deformation, low-grade metamorphism, and intrusion of plutonic rocks.

Age range: Predominantly Precambrian through Mesozoic.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Dolostone, locally siliceous strata, volcanic rocks, and granitic rocks.

Associated rock(s): Siliceous sedimentary rocks, phyllite, schist, quartzite, granitic plutons, diabase dikes, volcanic rocks.

Ore mineralogy: Talc (see comments under "Other).

Gangue mineralogy: Serpentine minerals, tremolite, fosteritic olivine, diopside, anthophyllite, sphalerite, chlorite, quartz, dolomite, magnesite, graphite.

Ore control(s): Faults, shear zones, igneous-sedimentary rock contacts, local stratigraphy.

Typical ore dimensions: Ore bodies are commonly lensoid. The Treasure Chest Mine in Montana exploited a talc body that extends approximately 360 m along strike, 40 m horizontally, and has been mined over 100 m down dip.

Geophysical signature(s): Various geophysical techniques can identify structures and host rocks associated with talc deposits, but are not definitive indicators of talc deposits.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: The color and brightness, fineness, oil absorption, chemical inertness, purity, particle shape, surface area, softness, smoothness, lubricating ability, and low thermal and electrical conductivity all determine the specific uses of talc.

Compositional/mechanical processing restrictions: Material specifications related to composition, color, and physical properties are increasingly restrictive.

Environmental/health concerns related to deposit type:

- Tremolite is considered a health hazard if asbestiform.
- Talc workers exposed to talc dust may exhibit symptoms of talc pneumoconiosis, bronchitis, and emphysema and may have abnormal chest X-rays and an increased risk of tuberculosis (Ross and others, 1993).

OTHER

- Many talc ores and products may contain substantial amounts of non-talc minerals. In a commercial sense, talc is a rock composed of magnesium silicates in which the mineral talc may be dominant, abundant, minor, or, in the extreme case, absent. At Gouverneur, New York, the talc ores commonly contain more than half tremolite; a typical mineralogical make-up might be 50 to 70% tremolite, 10% anthophyllite, 20-30% talc, and 20-30% antigorite. The typical mineralogy of the commercial products from this area are: 35-60% talc, 30-55% tremolite, 3-10% anthophyllite, 2-5% serpentinite, 1-3% quartz, 0-2% dolomite, 1-2% calcite, and 1-3% magnesite (Harben and Bates, 1990).

REFERENCES

Brown, 1969
Brown, 1973
Chidester and others, 1964
Harben and Bates, 1990
Merrill, 1963,
Roe, 1975
Ross and others, 1993

Model 251.1

PRELIMINARY DESCRIPTIVE MODEL OF HYDROTHERMAL BENTONITE

by John W. Hosterman and G.J. Orris
(modified 2/95)

BRIEF DESCRIPTION

Bentonite is any material composed dominantly of minerals of the smectite clay group and whose properties are dictated by the dominant smectite mineral.

Deposit synonyms: These deposits form through hydrothermal alteration of feldspar-rich rocks; commonly of felsic to intermediate volcanic and associated rocks.

Principal commodities produced: Bentonite, fuller's earth.

By-products: None.

End uses: Decolorizing oils; filler; filtration; pesticide carrier.

Descriptive/genetic synopsis: Bentonite is formed from the hydrothermal alteration of volcanic or other rocks. The formation of bentonite requires the presence of Mg in the host rock or in the leaching solutions.

Typical deposits:

Jupiter Mine, Nevada, USA
S'Aliderru, Sardinia, Italy
Teikoku deposit, Japan
Hei-Shen Mine, Liaoning Province, China

Relative importance of the deposit type: Bentonite production from this type of deposit is relatively insignificant.

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting: Areas that have undergone plutonism and (or) volcanism.

Age range: Most known commercial deposits are Mesozoic and younger

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Extremely variable; but commonly rhyolitic to dacitic volcanic rocks.

Associated rock(s): Felsic to intermediate volcanic rocks and tuffs, including liparite, rhyolite, dacite, trachyte, andesite.

Ore mineralogy: Smectite clays, commonly montmorillonite.

Gangue mineralogy: Kaolinite, feldspar, chlorite, gypsum, quartz, cristobalite, illite, muscovite, pyroxenes, biotite, zeolite, opal, cristobalite

Alteration: The smectite ore is formed by hydrothermal alteration of a variety of host rocks. Leaching of magnesium and iron from bentonite may lead to the formation of kaolinite.

Effects of burial/diagenesis: Burial and diagenesis may convert montmorillonite to illite or chlorite.

Structural setting: Faults and fractures that allow movement of acidic hydrothermal solutions.

Ore control(s): Faults, fractures and reactive host rocks. Calcic and mafic host rocks tend to be most reactive in contact with the acidic hydrothermal solutions that form these deposits.

Typical ore dimensions: At the Jupiter Mine, Nevada, the body of clay is approximately 210 m long, 75 m wide, and more than 12 m thick.

Typical alteration/other halo dimensions:

Effect of weathering: Leaching may remove Mg and Fe from the clay structure leading to formation of kaolinite.

Effect of diagenesis/burial: The abundance of smectite minerals decreases with depth of burial. Burial and diagenesis may convert montmorillonite to illite or chlorite. Montmorillonite and other smectites do not occur in more than small amounts in rocks that have undergone burial to depths greater than about 4 km.

Maximum limitation of overburden: About 20 m.

Other exploration guide(s): Regional exploration relies on the genetic association of this deposit with volcanic rocks. Locally, proximity to differentiated plutonic rocks capable of evolving large quantities of acidic hydrothermal fluids may be favorable. Faults may channel these fluids to where the fluids can intercept reactive country rocks.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: The most important physical and chemical properties of most smectites in determining the properties of bentonite are (O'Driscoll, 1988):

- Extremely small, platelet-shaped flexible crystals with large surface areas;
- A negative excess charge, which results in interstratification of exchangeable cations; and
- An intracrystalline swelling tendency.

Environmental/health concerns related to deposit type: Silicosis may be common in bentonite workers when the deposits contain fine-grained quartz and amorphous silica (Ross and others, 1993).

OTHER

The compositions of the host rock and hydrothermal fluids control many of the physical and chemical properties of the bentonite.

REFERENCES

Harben and Kuzvart, 1996
Papke, 1970
Ross and others, 1993
Taylor and Jenkins, 1986,
Velde, 1985
Weaver, 1959

Model 251.2

PRELIMINARY DESCRIPTIVE MODEL OF HYDROTHERMAL KAOLIN

By John W. Hosterman and G.J. Orris

BRIEF DESCRIPTION

Deposit synonyms: Halloysite, high-alumina clay.

Principal commodities produced: Kaolin, halloysite.

By-products: None.

End uses: Ceramics, including sanitaryware, bone china, floor and wall tiles, and electrical porcelain; filler for paper, plastics, paint, cosmetics, and other products; food additives; filter aids; and a possible source of alumina.

Descriptive/genetic synopsis: Kaolinite and (or) halloysite are formed from alteration of feldspar-rich rocks by reaction with acidic hydrothermal solutions. The hydrothermal solutions leach the alkalies from the host rock; the residual alumina and silica form the kaolin minerals.

Typical deposits:

Little Antelope Valley Deposit, California, USA
Itaya Mine, Japan
Matauri Bay, New Zealand
Cornwall, United Kingdom
(deposit is in part hydrothermal)

Relative importance of the deposit type: This deposit type is a relatively minor source of kaolin.

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting: Areas that have undergone plutonism and (or) volcanism.

Age range: Usually Tertiary or younger.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Granitic rocks, altered tuffaceous beds, rhyolite.

Associated rock(s): Felsic to intermediate volcanic rocks and tuffs.

Ore mineralogy: Kaolinite and (or) halloysite.

Gangue mineralogy: Quartz, opal, cristobalite, sericite, illite, montmorillonite, pyrophyllite, alunite, traces of metallic sulfides, tourmaline, fluorite.

Alteration: Buried clay deposits can be identified where hydrothermal solutions have bleached overlying and surrounding host rocks

Structural setting: Faults and joints that allow hydrothermal solutions to come into contact with reactive feldspathic rocks.

Ore control(s): The deposits are controlled by faulting and fractures, by the composition and reactivity of the host rocks, and by proximity to sources of hydrothermal solutions, such as differentiated igneous rocks..

Typical ore dimensions: One ore body from the Casa Diablo/Little Antelope Valley area of California is 1760 m long, 230 m wide, and 8 m deep.

Typical alteration/other halo dimensions: Deposits may be enclosed by a silica-enriched halo.

Maximum limitation of overburden: Commonly less than 2 m.

Geophysical signature(s): . Alteration of mafic mineral (bleaching) can result in magnetic lows over the deposits.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: Halloysite contains more water than kaolinite and requires additional treatment to remove the extra water. Brightness, color, opacity, and particle size affect end use.

Compositional/mechanical processing restrictions: Presence of quartz and opal restrict end uses of the clay.

Distance limitations to transportation, processing, end use: Strong competition from other more desirable types of kaolin deposits may limit the use and transportation distances of hydrothermal kaolin.

Environmental/health concerns related to deposit type: Kaolinite workers who have been heavily exposed to kaolinite dust may develop kaolinosis, a form of pneumoconiosis similar to that caused by other mineral dusts. If the kaolinite worker also is exposed to silica dust, the lung disease may appear to be typical silicosis (Ross and others, 1993).

REFERENCES

Cleveland, 1962
Patterson and Murray, 1984
Ross and others, 1993

PRELIMINARY DESCRIPTIVE MODEL OF SEDIMENTARY BENTONITE

Deposit subtype: Sodium Bentonite

By John W. Hosterman and G.J. Orris

BRIEF DESCRIPTION

Bentonite is any material composed dominantly of minerals of the smectite clay group and whose properties are dictated by the dominant smectite clay mineral.

Deposit synonyms: Swelling bentonite; western bentonite; Wyoming bentonite; bentonite (UK); sodium montmorillonite.

Principal commodities produced: Sodium bentonite.

By-products: None.

End uses: Drilling mud, foundry sand bond, iron-ore pelletizing, filler, sealant, non-drip paint, putty, adhesives, liquid-fertilizer suspensions, animal feed.

Descriptive/genetic synopsis: Sedimentary bentonite is formed by chemical alteration of andesitic to rhyolitic volcanic ash deposited in an alkaline marine environment. Because calcium is higher in the replacement series than sodium, sodium bentonite only forms where calcium-ion concentrations are low and Na is relatively abundant.

Typical deposits:
Black Hills District, Wyoming-Montana-South Dakota, USA
Hardin District, Montana-Wyoming, USA
Oe, Japan

Relative importance of the deposit type: Almost 90 percent of the sodium bentonite comes from Wyoming and Montana.

Associated/related deposit types:

REGIONAL GEOLOGIC ATTRIBUTES

Regional depositional environment: Felsic to intermediate volcanism producing volcanic ash directly deposited or subsequently washed into an alkaline marine environment.

Age range: Cretaceous.

LOCAL GEOLOGIC ATTRIBUTES

Parent rock(s): Rhyolitic to andesitic volcanic ash.

Associated rock(s): Typically shale.

Ore mineralogy: Sodium montmorillonite (smectite).

Gangue mineralogy: Gypsum, zeolites, cristobalite, kaolinite, illite, muscovite, sericite, quartz, feldspar, pyroxene, biotite, zircon, gypsum, siderite.

Alteration: Leaching of Mg and Fe from the bentonite may lead to formation of kaolinite.

Ore control(s): Proximity of volcanism to alkaline marine basin.

Typical ore dimensions: 10 to 1000 m wide; 1000 to 10,000 m long; typically 1-3 m thick.

Typical alteration/other halo dimensions: None.

Effect of weathering: Weathering usually improves the physical properties of the bentonite.

Effect of diagenesis/burial: The abundance of smectite minerals decreases with depth of burial. Burial and diagenesis may convert montmorillonite to illite or chlorite. Montmorillonite and other smectites do not occur in more than small amounts in rocks that have undergone burial to depths greater than about 4 km.

Maximum limitation of overburden: 20 m.

Other exploration guide(s): Drilling.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: The most important physical and chemical properties of most smectites in determining the properties of bentonite are (O'Driscoll, 1988):

1. extremely small, platelet-shaped flexible crystals with large surface

areas;
2. a negative excess charge, which results in interstratification of exchangeable cations; and
3. an intracrystalline swelling tendency.

• Medium to high surface area of the mineral grains and sorptive properties. Excellent decolorizing, binding, and thickening power.
• Rheological Properties: When added to water, Na-bentonite increases the viscosity, suspending power, and thixotropy of the mixture. The clay particles separate in water and produce a gel (suspension or finely divided plates). Because the plates have negative charges on their surfaces and positive charges on their edges, they orient negative-to-positive and form a structure that gives the suspension a jelly-like (gel) consistency.
• Sorptive Properties: Bentonitic clays have high adsorption and absorption. When calcined, they have a large pore volume and surface area and can take up liquids equivalent to as much as 200% or more of their own weight.

Distance limitations to transportation, processing, end use: There is very little limitation on transport of sodium bentonite because of its desirable physical and chemical properties.

Environmental/health concerns related to deposit type: Some Na-bentonite may be unsuitable for waste linings because of a tendency to shrink when Na is exchanged for divalent and trivalent cations or when salt concentrations are high (Griffin and others, 1976). Silicosis may be common in bentonite workers when the deposits contain fine-grained quartz and amorphous silica (Ross and others, 1993).

REFERENCES

Griffin and others, 1976
Hosterman, 1985
Knechtel and Patterson, 1962
Ross and others, 1993

PRELIMINARY DESCRIPTIVE MODEL OF SEDIMENTARY BENTONITE

Deposit subtype: Calcium Bentonite

By John W. Hosterman and G.J. Orris

BRIEF DESCRIPTION

Bentonite is any material composed dominantly of minerals of the smectite clay group and whose properties are dictated by the dominant smectite clay mineral.

Deposit synonyms: Non-swelling bentonite; southern bentonite; sub-bentonite; Mississippi bentonite (US); Southern bentonite (US); Texas bentonite (US); fuller's earth (UK); calcium montmorillonite.

Principal commodities produced: Ca bentonite.

By-products: None.

End uses: Foundry sand bond, filler, catalyst, absorbent, water treatment, ceramic glazes.

Descriptive/genetic synopsis: Sedimentary bentonite is the result of chemical alteration of andesitic to rhyolitic volcanic ash deposited in an alkaline marine environment. Ca-bentonite formed where Ca-ions were available.

Typical deposits:
Aberdeen-Tipley District, Mississippi, USA
Pembina District, Manitoba, Canada
Cheto, Arizona, USA
Marnia District, Argentina
Combe Hay Mine, United Kingdom

Relative importance of the deposit type: About 45 percent of calcium bentonite comes from Mississippi.

REGIONAL GEOLOGIC ATTRIBUTES

Age range: Late Cretaceous through mid-Tertiary.

LOCAL GEOLOGIC ATTRIBUTES

Parent rock(s): Felsic to intermediate volcanic ash/tuff.

Associated rock(s): Commonly glauconitic sands.

Ore mineralogy: Calcium montmorillonite (smectite).

Gangue mineralogy: Gypsum, zeolites, cristobalite, kaolinite, and illite; minor sulfates, apatite, sphene, sphalerite, feldspar, limonite; rare quartz.

Alteration: None.

Ore control(s): Proximity of volcanism to alkaline marine basin.

Typical ore dimensions: 10 to 1000 m wide; 1000 to 10,000 m long; 1-2 m thick.

Typical alteration/other halo dimensions: None.

Effect of weathering: Weathering usually improves the physical properties of the bentonite. Often weathering leads to an "alligator skin" texture. Leaching of Mg and Fe from the bentonite may lead to formation of kaolinite.

Effect of diagenesis/burial: The abundance of smectite minerals decreases with depth of burial. Burial and diagenesis may convert montmorillonite to illite or chlorite. Montmorillonite and other smectites do not occur in more than small amounts in rocks that have undergone burial to depths greater than about 4 km.

Maximum limitation of overburden: 20 m.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: These are low-swelling bentonites. The most important physical and chemical properties of most smectites in determining the properties of bentonite are (O'Driscoll, 1988):

- Extremely small, platelet-shaped flexible crystals with large surface areas;
- A negative excess charge, which results in interstratification of exchangeable cations; and
- An intracrystalline swelling tendency.

Compositional/mechanical processing restrictions: Ca-bentonite cannot compete with Na-bentonite for some uses.

Distance limitations to transportation, processing, end use:

Environmental/health concerns related to deposit type: This clay is gaining market in pet litter because it commonly does not require a health hazard label for harmful forms of silica, especially cristobalite. Ca-bentonite may make better waste liners than some Na-bentonites because they do not shrink during cation exchange or in the presence of salt. Silicosis may be common in bentonite workers when the deposits contain fine-grained quartz and amorphous silica (Ross and others, 1993).

REFERENCES

Hosterman, 1984a
Hosterman, 1985
Knechtel and Patterson, 1962
Ross and others, 1993

PRELIMINARY DESCRIPTIVE MODEL OF SEDIMENTARY KAOLIN

Deposit Subtype: Ball Clay

By J.W. Hosterman and G.J. Orris

BRIEF DESCRIPTION

Ball clay is composed largely of kaolinite and related clays that can be fired to white or nearly white. Ball clays contain organic matter, have a high plasticity, high dry strength, and have a long vitrification range.

By-products: Lignite, sand

End uses: China, sanitaryware, electrical insulators, floor and wall tile, art ware, dump linings, rubber, pipe, brick.

Descriptive/genetic synopsis: Some ball clays are fluvial in origin and probably were deposited in swampy environments such as temperate shallow lakes formed on flood plains.

Typical deposits:

Paris, Tennessee, USA
Skalna area, Czechoslovakia
Westerwald area, Germany
Bovey Basin, Devon, United Kingdom

Relative importance of the deposit type: This deposit type is the only recognized source of ball clay in the literature; Tennessee produces about 75 percent of the ball clay in the U.S.

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting: Tertiary basins.

Age range: Tertiary.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Lignitic shale, silty clay, sand, lignite.

Ore mineralogy: Ball clay is largely composed of poorly crystalline kaolinite (about 70%) and small amount of illite and (or) montmorillonite, chlorite.

Gangue mineralogy: Quartz, carbonaceous material, chlorite, cristobalite, feldspar, dolomite, calcite; minor anatase, siderite, marcasite, feldspar, zircon; rare imenite, tourmaline, rutile.

Alteration: None.

Typical ore dimensions: Lengths range from 100 to 800 m, width from 50 to 300 m, and thickness' commonly range from 1 to 5 m.

Effect of diagenesis/burial: Deeper, longer burial lithifies plastic ball clay into non-plastic fireclay.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: Plasticity, color, brightness, and refractoriness affect end use. Ball clay requires between 40 and 65 percent water of plasticity to become workable. It's natural characteristics are high plasticity, high dry-green strength, excellent adhesion, and toughness. When fired, it is almost white in color, dense, vitreous, and the deformation (melting) temperature is between 1670° and 1765°.

Compositional/mechanical processing restrictions: Iron and carbonate minerals may make the material unusable.

Distance limitations to transportation, processing, end use: Of little importance.

Environmental/health concerns related to deposit type:

- Increasing use as liner material for toxic and domestic waste dumps.
- Kaolinite workers who have been heavily exposed to kaolinite dust may develop kaolinosis, which is a pneumoconiosis similar to that caused by other mineral dusts. If the kaolinite worker also is exposed to silica dust, the lung disease may appear to be typical silicosis (Ross and others, 1993).

OTHER

- The term "ball clay" originated from an early English mining practice of rolling chunks of highly plastic clay weighing 10-20 kg from the area where it was dug to wheelbarrows.

REFERENCES

Hosterman, 1973
Hosterman, 1984a
Olive and Finch, 1969
Patterson and Murray, 1984
Phelps, 1972
Ross and others, 1993
Whitlatch, 1940

PRELIMINARY DESCRIPTIVE MODEL OF SEDIMENTARY KAOLIN

Deposit Subtype: Fire Clay

By J.W. Hosterman and G.J. Orris

BRIEF DESCRIPTION

Kaolinitic clay with a pyrometric cone equivalent (PCE) of 19 or above.

Deposit synonyms: Underclay; refractory clay; flint clay.

Principal commodities produced: Refractory brick.

By-products: None.

End uses: Furnace (kiln) and flue linings.

Descriptive/genetic synopsis: Flint clay is a hard, resistant, nonplastic, refractory clay possessing the flintlike characteristics of homogeneity and conchoidal fracture. The stratigraphic, paleontological, mineralogical, and chemical evidence indicate that the flint clay beds were formed by severe leaching of potassium and silica from fine-grained, largely illitic sediments in acid swamps. In some areas, the leaching was severe enough to remove enough silica to form diaspore and boehmite.

Typical deposits:
Clearfield District, Pennsylvania, USA
Oak Hill District, Ohio, USA
Wingen area, New South Wales, Australia
Ramon Valley, Israel

Relative importance of the deposit type: Deposits of this type in Missouri and Pennsylvania produce about 54 percent of the fire clay in the United States.

Associated/related deposit types: Commonly associated with coal beds.

REGIONAL GEOLOGIC ATTRIBUTES

Regional depositional environment: Fine-grained sediment accumulated in marshes and swamps located in coastal lowland areas that experienced periodic advances and withdrawals of brackish or marine water.

Age range: Pennsylvanian through Tertiary

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Shale, sandstone, claystone, coal, conglomerate.

Ore mineralogy: Crystalline kaolinite with small amounts of diaspore and boehmite.

Gangue mineralogy: Quartz, sericite, siderite, pyrite, anatase, carbonaceous material.

Alteration: Alteration by leaching during and shortly after deposition produced crystalline kaolinite. Where the leaching of silica was severe, diaspore and boehmite were formed. Recrystallization of kaolinite.

Typical ore dimensions: Deposits tend to be lenticular. Deposits in the US are commonly less than 240 m long, less than 150 m wide, and less than 8 m thick.

Effect of weathering: Short-term weathering has no detrimental effect.

Maximum limitation of overburden: Approximately 15 m. Clay of this type has been mined by underground methods.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: Changes in technology by the steel industry now require an ultra-high temperature refractory brick. Because most clay refractory brick cannot meet this standard, production of fire clay declined from almost 12 million metric tons in the 1950's to less than 600,000 metric tons were produced in 1986.

Distance limitations to transportation, processing, end use: End product is very heavy, which limits transport distances to market.

Environmental/health concerns related to deposit type: Kaolinite workers heavily exposed to kaolinite dust may develop kaolinosis, which is a pneumoconiosis similar to that caused by other mineral dusts. If the kaolinite worker also is exposed to silica dust, the lung disease may appear to be typical silicosis (Ross and others, 1993).

OTHER

- Sedimentary clay deposits tend to be higher grade than hydrothermal clay deposits.

REFERENCES

Hosterman, 1972
Keller and others, 1954
Patterson and Hosterman, 1962
Patterson and Murray, 1984
Ross and others, 1993

PRELIMINARY DESCRIPTIVE MODEL OF SEDIMENTARY KAOLIN
Deposit Subtype: Kaolin

By J.W. Hosterman and G.J. Orris

BRIEF DESCRIPTION

Kaolin consists chiefly of kaolinite that is white naturally or through beneficiation or firing, and can be used as a filler or extender in many different products.

Deposit synonyms: High alumina clay; china clay (archaic)

Principal commodities produced: Filler-grade clay, air-floated clay

By-products: Silica sand.

End uses: Paper coating; fine china and dinnerware; refractories; ceramics; filler in adhesives, paint, paper, plastics, and rubber; mineral wool; petroleum-cracking catalysts; inks; fiberglass; and pharmaceuticals.

Descriptive/genetic synopsis: These deposits formed in a temperate climate when meteoric water containing carbonic, organic, or other acids percolated down through feldspathic rocks converting the feldspar to kaolinite or halloysite. These clays were eroded and deposited in tidal flat, and (or) estuarine environments. Some deposits, or parts of deposits, may have formed from in-place weathering of older argillaceous sediments.

Typical deposits:
South Carolina -Georgia-Alabama kaolin belt, USA
Jari District, Brazil
Weipa, Queensland, Australia
Hirshau area, Bavaria, Germany
Mesa Alta District, New Mexico, USA
Cornwall??

Relative importance of the deposit type: Georgia produces more than 80 percent of the kaolin in the United States from this deposit type.

REGIONAL GEOLOGIC ATTRIBUTES

Age range: Largely Mesozoic, Tertiary.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): White to cream-colored clay, sand.

Associated rock(s): Lignite, pisolitic clay.

Ore mineralogy: Crystalline kaolinite.

Gangue mineralogy: Quartz, ilmenite, and muscovite. Some gibbsite in the younger deposits.

Alteration: None.

Typical ore dimensions: Lenticular deposits. Cretaceous deposits of U.S. Coastal Plain are less than 12 m thick, less than 2 km long, and less than 500 m wide; Tertiary deposits of that area are less than 25 m thick, less than 18 km long, and less than 2 km wide.

Typical alteration/other halo dimensions: None.

Effect of weathering: Katamorphic alteration after deposition may cause recrystallization of the kaolinite and leaching of silica to produce gibbsite (bauxite).

Maximum limitation of overburden: 20 m.

Geophysical signature(s): None.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: Very small quantities of iron oxide minerals and (or) ilmenite effect the color of the kaolin and limit its usage. Brightness, color, opacity, and particle size also affect end use.

Compositional/mechanical processing restrictions: Large quantities of quartz and muscovite may lead to excessive processing cost..

Distance limitations to transportation, processing, end use: None.

Environmental/health concerns related to deposit type: Kaolinite workers heavily exposed to kaolinite dust may develop kaolinosis, which is a pneumoconiosis similar to that caused by other mineral dusts. If the kaolinite worker also is exposed to silica dust, the lung disease may appear to be typical silicosis (Ross and others, 1993).

OTHER

Sedimentary clay deposits tend to be higher grade than hydrothermal clay deposits.

REFERENCES

Mark, 1963
Patterson and Murray, 1984
Ross and others, 1993

Model 34e

PRELIMINARY DESCRIPTIVE MODEL FOR PALYGORSKITE

By John W. Hosterman
(modified by G.J. Orris, 8/98)

BRIEF DESCRIPTION

Palygorskite (attapulgite) is a complex magnesium silicate that has a fibrous crystal habit and contains about 50 percent free and combined water.

Deposit synonyms: Attapulgite, fuller's earth.

Principal commodities produced: Fuller's earth.

By-products: None.

End uses: Absorbent (cat litter), drilling mud (where salt water is encountered), filter (clarifier), carrier for insecticides and fungicides.

Descriptive/genetic synopsis: Palygorskite largely formed through diagenetic alteration of smectite clays in a marine environment and partly as a primary precipitate through a reaction between sea water and magnesium-rich seawater in that same environment.

Typical deposits: Meigs-Attapulgus-Quincy District, Georgia-Florida, USA
Mbour, Senegal

Relative importance of the deposit type: The Meigs-Attapulgus-Quincy District is the only US producer of palygorskite, which supplies almost 40 percent of the fuller's earth produced in the United States.

REGIONAL GEOLOGIC ATTRIBUTES

Age range: Know deposits are Tertiary.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Clay beds and lenses, marl.

Associated rock(s): Fine- to medium-grained sand, limestone and dolostone.

Ore mineralogy: Palygorskite (70-80%), montmorillonite (20-30%).

Gangue mineralogy: Kaolinite, sepiolite, montmorillonite, quartz, some feldspar, calcite, dolomite, opal, clinoptilolite, biogenic material.

Typical ore dimensions: Deposits are commonly less than 1000 m long, less than 300 m wide, and 2 to 20 m thick.

Effect of weathering: Palygorskite can be altered to kaolinite by weathering.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: Relatively high surface area and surface charge make palygorskite an excellent sorbent for oil and water. Its elongate shape prevents flocculation. The mineral structure contains small open channels that will readily absorb polar organic or inorganic molecules after dehydration.

Distance limitations to transportation, processing, end use: Transportation costs may be a limiting factor.

Environmental/health concerns related to deposit type: Palygorskite may make more effective clay liners than other clays for those applications where sorptive capacity and stability against flocculation are important. Health concerns have been raised about the dusts associated with mining this commodity and about the fibrous nature of these minerals. Health effects for miners and processors include potential for pneumoconiosis and long term exposure may lead to a higher incidence of lung cancer than amongst the general population (Ross and others, 1993).

REFERENCES

Bowles and others, 1971
Heivilin and Murray, 1994
Patterson, 1974
Ross and others, 1993.

Model 38h

PRELIMINARY DESCRIPTIVE MODEL FOR RESIDUAL KAOLIN

By John W. Hosterman

BRIEF DESCRIPTION

Deposit synonyms: Saprolite, high-alumina clay.

Principal commodities produced: Kaolin.

By-products: Muscovite, sericite.

End uses: Ceramics, electrical insulators, specialty brick, white cement, and a possible source of alumina.

Descriptive/genetic synopsis: Residual kaolin (saprolite) forms from chemical weathering of feldspathic rocks. A feldspathic rock with a high mica content yields kaolinite; one with a low mica content yields halloysite. In the weathering process, meteoric water containing carbonic, organic, or other acid percolates downward through the rocks converting feldspar to kaolinite or halloysite.

Typical deposits:

Spruce Pine, North Carolina, USA
Kikino Mine, Japan
Alberhill District, California, USA
Cornwall, United Kingdom
(deposit is in part hydrothermal)

Relative importance of the deposit type: Residual kaolin deposits account for a very small percentage of total kaolin production.

REGIONAL GEOLOGIC ATTRIBUTES

Age range: Katamorphic alteration-- Cretaceous (?) to Tertiary.

LOCAL GEOLOGIC ATTRIBUTES

Host rock(s): Felsic rocks ranging in age from Precambrian to Tertiary, including granite, gneiss and other crystalline metamorphic rocks, basalt, nepheline syenite, andesite, slate, volcanic breccia.

Ore mineralogy: Kaolinite, halloysite.

Gangue mineralogy: Quartz, muscovite, and ilmenite and other heavy minerals.

Alteration: Katamorphic-- formation of kaolinite or halloysite from feldspar.

Structural setting: N/A.

Ore control(s): Zones of groundwater movement protected from subsequent erosion.

Typical ore dimensions: Deposits are irregularly shaped.

Typical alteration/other halo dimensions:

Effect of weathering: Once formed these deposits must be protected from subsequent weathering and erosion.

Most readily ascertainable local attribute: Residual boulders of parent rock enclosed by concentric layers of partly weathered rock are common in the least weathered parts of many deposits of this type.

ECONOMIC LIMITATIONS

Physical/chemical properties affecting end use: Halloysite contains more water than kaolinite and requires additional treatment for its removal. Brightness, color, opacity, and particle size affect end use.

Compositional/mechanical processing restrictions: Recovery of kaolin from saprolite requires beneficiation. Byproducts may help to make operations profitable.

Distance limitations to transportation, processing, end use: Strong competition from other types of kaolin deposits may limit use and transportation distances.

Environmental/health concerns related to deposit type: Kaolinite workers heavily exposed to kaolinite dust may develop kaolinosis, which is a pneumoconiosis similar to that caused by other mineral dusts. If the kaolinite worker also is exposed to silica dust, the lung disease may appear to be typical silicosis (Ross and others, 1993).

REFERENCES

Hosterman, 1984b
Hosterman and others, 1960
Parker, 1946
Patterson and Murray, 1984
Ross and others, 1993

REFERENCES CITED

Beus, A.A., 1966, Geochemistry of beryllium: San Franciso, W.H. Freeman and Co., 401 p.

Bodenlos, A.J., 1950, Magnesite deposits of Central Ceará, Brazil: U.S. Geological Survey Bulletin 962-C, p. 121-154.

Bodenlos, A.J., and Thayer, T.P., 1973, Magnesian refractories, *in* Brobst, D.A., and Pratt, W.P., eds., United States Mineral Resources: U.S. Geological Survey Professional Paper 820, p. 379-384.

Bowles, F.A., Angino, E.A., Hosterman, J.H., and Galle, O.K., 1971, Precipitation of deep-sea palygorskite and sepiolite: Earth and Planetary Science Letters, v. 11, no. 4, p. 324-332.

Brown, C.E., 1969, New talc deposit in St. Lawrence County, New York: U.S. Geological Survey Bulletin 1272-D, 13 p.

Brown, C.E., 1973, Talc, *in* Brobst, D.A., and Pratt, W.P., eds., United States mineral resources: U.S. Geological Survey Professional paper 820, p. 619-626.

Cameron, E.N., Jahns, R.H., McNair, A.H., and Page, L.R., 1949, Internal structure of granitic pegmatites: Economic Geologic Monograph 2, 115 p.

Cameron, E.N., Larrabee, D.M., McNair, A.H., Page, J.J., Stewart, G.W., and Shainin V.E., , 1954, Pegmatite investigations 1942-45, New England: U.S. Geological Survey Professional Paper 255, 352 p.

Cerny, Petr, ed., 1982, Granitic pegmatites in science and industry: Mineralogical Association of Canada Short Course Handbook 8, at least 461 p.

Chidester, A.H., 1962, Petrology and geochemistry of selected talc-bearing ultramafic rocks and adjacent country rocks in north-central Vermont: U.S. Geological Survey Professional Paper 345, 207 p.

Chidester, A.H., Engel, A.E.J., and Wright, L.A., 1964, Talc resources of the United States: U.S. Geological Survey Bulletin 1167, 61 p.

Cleveland, G.B., 1962, Geology of the Little Antelope Valley clay deposit, Mono County, California: California Division of Mines and Geology Special Report 72, 28 p.

Cooper, D.G., 1964, The geology of the Bikita pegmatite, in The geology of some ore deposits in southern Africa, v. 2: Geological Society of South Africa, p. 441-461.

Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p

Davis, R.E., 1957, Magnesium resources of the United States-- a geologic summary and annotated bibliography to 1953: U.S. Geological Survey Bulletin 1019-E, p. 373-515.

Duncan, L.R., and McCracken, W.H., 1994, Magnesite and magnesia, *in* Carr, D.D., ed., Industrial minerals and rocks, 6th edition: Society for Mining, Metallurgy, and Exploration, Inc., p. 643-654.

Griffin, R.A., Cartwright, Keros, Shimp, N.F., Steele, J.D., Ruch, R.R., White, W.A., Hughes, G.M., and Gilkeson, R.H., 1976, Attenuation of pollutants in municipal landfill leachate by clay minerals: Part 1- Column leaching and field verification, *with contributions by* W.J. Armon, L.R., Camp, D.R.

Dickerson, G.B. Dreher, J.K. Frost, D.B. Heck, L.R. Henderson, J.K. Kuhn, J.A. Schleicher, R.H. Shiley, and R.M. Trandel: Illinois State Geological Survey Environmental Geology Notes, no. 78, 34 p.

Griffis, Robert, 1972, Genesis of a magnesite deposit, Deloro Twp., Ontario: Economic Geology, v. 67, p. 63-71.

Hanley, J.B., Heinrich, E.W., and Page, L.R., 1950, Pegmatite investigations in Colorado, Wyoming and Utah, 1942-1944: U.S. Geological Survey Professional Paper 227, 125 p.

Harben, P.W., and Bates, R.L., 1984, Geology of the nonmetallics: New York, Metal Bulletin Inc., 392 p.

Harben, P.W., and Bates, R.L., 1990, Industrial minerals--geology and world deposits: London, Metal Bulletin Plc., 312 p.

Harben, P.W., and Kuzvart, Milos, 1996, Industrial minerals-- a global geology: London, Industrial Minerals Information Ltd., 462 p.

Hatcher, M.I., and Elliott, A., 1986, Greenbushes--a new world source of lithium: 7th "Industrial Minerals" International Congress, p. 217-232.

Heivilin, F.G., and Murray, H.H., 1994, Hormites: Palygorskite (attapulgite) and sepiolite, *in* Carr, D.D., ed., Industrial minerals and rocks, 6th edition: Society for Mining, Metallurgy, and Exploration, Inc., p. 249-254.

Hosterman, J.W., 1972, Underclay deposits of Somerset and eastern Fayette Counties, Pennsylvania: U.S. Geological Survey Bulletin 1363, 17 p.

Hosterman, J.W., 1973, Clays: U.S. Geological Survey Professional Paper 820, p. 123-131.

Hosterman, J.W., 1984a, Ball clay and bentonite deposits of Central and Western gulf of Mexico Coastal Plain, United States: U.S. Geological Survey Bulletin 1558-C, 22 p.

Hosterman, J.W., 1984b, White clays of Pennsylvania: U.S. Geological Survey Bulletin 1558-D, 38 p.

Hosterman, J.W., 1985, Bentonite and fuller's earth resources of the United States: U.S. Geological Survey Mineral Investigations Resource Map MR-82.

Hosterman, J.W., Scheid, V.E., Allen, V.T., and Sohn, I.G., 1960, Investigations of some clay deposits in Washington and Idaho: U.S. Geological Survey Bulletin 1091, 147 p.

Jahns, R.H., 1946, Mica deposits of the Petaca district, Rio Arriba County, N. Mex. with brief description of the Ojo Caliente district, Rio Arriba County and Elk Mountain district, San Miguel County: New Mexico Bureau of Mines and Mineral Resources Bulletin 25, 289 p.

Jahns, R.H., and others, 1952, Mica deposits of the Southeastern Piedmont, Part 1: U.S. Geological Survey Professional Paper 248A, p. 1-101.

Keller, W.D., Westcott, J.F., and Bledsoe, A.O., 1954, The origin of Missouri fire clays, *in* Swindeforth, Ada, ed., Clays and clay minerals: National Academy of Sciences National Research Council Publication 327, p. 7-46.

Knechtel, M.M., and Patterson, S.H., 1962, Bentonite deposits, Northern Black Hills District, *in* Contributions to Economic Geology: U.S. Geological Survey Bulletin 1082, p. 893-1030.

Mark, Helen, 1963, High-alumina kaolinitic clay in the United States: U.S. Geological Survey Mineral Investigations Resource Map MR-37.
Martin, R.F., and Cerny, P., eds., 1992, Granitic Pegmatites: The Canadian Mineralogist, v. 30, pt. 3, p. 497-954.
Merrill, C.W., 1963, Selected bibliography of talc in the United States: U.S. Geological Survey Bulletin 1182-C, 26 p.
Norton, J.J., 1983, Sequence of mineral assemblages in differentiated granitic pegmatites: Economic Geology, v. 78, p. 854-874.
Norton, J.J., and Page, L.R., 1956, Methods used to determine grade and reserves of pegmatites: Mining Engineering, v. 8, no. 4, p. 401-414.
Norton, J.J., and Redden, J.A., 1990, Relations of zoned pegmatites to other pegmatites: granite and metamorphic rocks in the southern Black Hills, South Dakota: American Mineralogist, v. 75, p. 631-655.
Olive, W.W., and Finch, W.I., 1969, Stratigraphic and mineralogic relations and ceramic properties of clay deposits of Eocene age in the Jackson Purchase region, Kentucky and in adjacent parts of Tennessee: U.S. Geological Survey Bulletin 1282, 35 p.
Orris, G.J., 1992, Industrial mineral deposit models-- descriptive models for three lacustrine deposit types: U.S. Geological Survey Open-File Report 92-593, 14 p.
Orris, G.J., and Bliss, J.D., eds., 1991, Industrial mineral deposit models-- descriptive deposit models: U.S. Geological Survey Open-File Report 90-11A, 73 p.
Orris, G.J., and Bliss, J.D., eds., 1992, Industrial mineral deposit models: grade and tonnage models: U.S. Geological Survey Open-File Report 92-437, 84 p.
Page, L.R., and others, 1953, Pegmatite investigations 1942-1945, Black Hills, South Dakota: U.S. Geological Survey Professional Paper 247, 228 p.
Papke, K.G., 1970, Montmorillonite, bentonite, and fuller's earth deposits in Nevada: Nevada Bureau of Mines and Geology Bulletin 76, 47 p.
Parker, J.M., 1946, Residual kaolin deposits of the Spruce Pine District, North Carolina: North Carolina Division of Mineral Resources Bulletin 48, 45 p.
Patterson, S.H., 1974, Fuller's earth and other industrial mineral resources of the Meigs-Attapulgus-Quincy district, Georgia and Florida: U.S. Geological Survey Professional Paper 828, 45 p.
Patterson, S.H., and Murray, H.H., 1984, Kaolin, refractory clay, ball clay, and halloysite in North America, Hawaii, and the Caribbean region: U.S. Geological Survey Professional Paper 1306, 56 p.
Phelps, G.W., 1972, The ball clays of Tennessee and Kentucky: Society of Mining Engineers of AIME Preprint 72-H-305, 11 p.
Piniazkiewicz, R.J., McCarthy, E.F., and Genco, N.A., 1994, Talc, *in* Carr, D.D., ed., Industrial minerals and rocks, 6th edition: Society for Mining, Metallurgy, and Exploration, Inc., p. 1049-1069.
Roe, L.A., 1975, Talc and pyrophyllite, in Lefond, S.J., ed., Industrial minerals and rocks (nonmetallics other than fuels): New York, American Institute of Mining, Metallurgical, and Petroleum Engineers Inc., p. 1127-1147.
Ross, Malcolm, Nolan, R.P., Langer, A.M., and Cooper, W.C., 1993, Health effects of mineral dusts other than asbestos, in Guthrie, G.D., Jr., and Mossman, B.T.,

eds., Health effects of mineral dusts: Mineralogical Society of America Reviews in Mineralogy, v. 28, p. 361-407.
Schilling, J.H., 1968, The Gabbs magnesite-brucite deposit, Nye County, Nevada, in Ridge, J.D., ed., Ore deposits of the United States 1933-1967m The Graton-Sales volume: The American Institute of Mining, Metallurgical, and Petroleum Engineers, v. II, p. 1607-1622.
Taylor, D.R., and Jenkins, D.B., 1986, Acid-activated clays: Society of Mining Engineers of AIME Preprint 86-365, 11 p.
Velde, B., 1985, Clay minerals--a physico-chemical explanation of their occurrence: New York, Elsevier, Developments in Sedimentology 40, 427 p.
Weaver, C.E., 1959, The clay petrology of sediments: Clays and Clay Minerals, v. 6, p. 154-187.
Whitlatch, G.I., 1940, The clays of west Tennessee: Tennessee Division of Geology Bulletin 49, 368 p.
Wicken, O.M., and Duncan, L.R., 1975, Magnesite and related minerals, in Lefond, S.J., ed., Industrial minerals and rocks (nonmetallics other than fuels): New York, American Institute of Mining, Metallurgical, and Petroleum Engineers Inc., p. 805-820.