UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

U.S. GEOLOGICAL SURVEY-INGEOMINAS

MINERAL RESOURCE ASSESSMENT OF COLOMBIA: ORE DEPOSIT MODELS

By Dennis P. Cox, Editor

Open-File Report
83-423

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards.

Menlo Park, California
1983
This compendium of ore deposits models was assembled for the Colombia Mineral Resource Assessment Project. The objectives of the compendium are: (1) to define mineral deposit types so that all project members have a common vocabulary or deposit classification scheme to which mineral occurrences, favorable geologic environments, favorable geochemical anomalies, and tonnage-grade models may be related; (2) to provide data on the environments of ore deposition so that favorable rocks, structures, and tectonic settings can be easily recognized by project geologists; and (3) to relate possibly the associations of elements within geochemical anomalies to specific deposit types so that geochemical data may be more easily interpreted. A key-word index and an element association index are included to help in achieving the second and third objectives.

The compendium is not complete at this stage and many models useful in the Colombia assessment still need to be added. Appropriate models for the Proterozoic shield environments of eastern Colombia are needed.

The editor is pleased to acknowledge the cooperation of the authors of the models included in this report. Blank forms and instructions for their use are included in the following pages to encourage other authors to join in this effort. Send your models to Dennis P. Cox, Mail Stop 41, U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025.
EXPLANATION OF DEPOSIT MODEL FORM

Deposit type: Fill in your preferred name for the deposit type.

Subtype: Optional. Use if it is convenient for your classification scheme.

Author: Author of model.

Date: When you filled out the form.

Approximate synonym: Optional. A different, but well-known name used by another author.

Of (reference): The author that used the synonym.

Description: A short description so that the casual user will not have to read the whole form.

General reference: Optional. May be a volume of papers on one deposit type, or a single comprehensive article.

Rock types: Rocks typical of the geologic terrane in which the deposits are found. (For igneous rock, use terminology of Williams and Turner, and Gilbert, 1954.)

Textures: Special textures associated with the rocks.

Age range: Ages of known deposits and ages in which such deposits might have formed.

Depositional environment: Plutonic, volcanic, or sedimentary environments related to ore-forming process.

Tectonic setting(s): Regional tectonic features important in the genesis of the deposit type.

Associated deposits: Example, copper skarns associated with copper porphyries.

Metal concentrations: Regional geochemical anomalies that might be indicative of the deposit or related to associated deposits.

Ore minerals: List ore and gangue minerals in assemblages. Show zonal or temporal relation between assemblages. List essential minerals with (+) signs, and varietal minerals with (+) signs. Group trace minerals separately. List biproduct metals i.e., Au, Ag, that may not form minerals. Do not include secondary minerals except for deposits formed by weathering.

Texture/structure: Describe appearance of ore.
Alteration: Minerals produced by reaction of ore-forming fluids with rocks. List in assemblages. Show zonal or temporal relation between assemblages. Use terms such as potassic (potassium-feldspar+biotite), phyllic (white mica+pyrite), argillic (clay+white mica), advanced argillic (clay+pyrophyllite+alunite+Al₂O₃ minerals) as they apply. Include skarn mineral assemblages where appropriate.

Ore controls: List special stratigraphic, structural, or geochemical features that are believed to have influenced ore-mineral deposition.

Weathering: Optional. List any special weathering characteristics or secondary minerals that might serve as prospecting guides.

Geochemical signature: Elements expected to be anomalous (enriched or depleted) in and near the deposit. List element assemblages and show zonal arrangement where possible.

Examples: A Colombian or Andean example should be included where possible.

References: One reference for each example. Give name and year. Include complete reference on a separate sheet.

Additional information needed

Sketch: Where possible, include a well-labeled map or section of a deposit, or a cartoon of an ideal deposit, showing ore controls, zoning, and approximate dimensions.

Key words: Underline in red those words or word combinations that should appear in an index. Pillow basalt is a key word for Cyprus-type massive sulfides, for example.
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Deposits Model Form
DEPOSIT TYPE Podiform chromite

AUTHOR John P. Albers

DATE December 6, 1982

APPROXIMATE SYNONYM Alpine type chromite

OF (REFERENCE) Thayer, 1964

DESCRIPTION Podlike masses of chromitite in ultramafic parts of ophiolite complexes.

GENERAL REFERENCE Dickey, 1975.

GEOLOGICAL ENVIRONMENT

Rock Types Highly deformed dunite and harzburgite of ophiolite complexes; commonly serpentinized.

Textures Nodular, orbicular, gneissic, cumulate, pull-apart; most relict textures are modified or destroyed by flowage at magmatic temperatures.

Age Range Phanerozoic.

Depositional Environment Lower part of oceanic lithosphere.

Tectonic Setting(s) Magmatic cumulates in elongate magma pockets along accreting plate boundaries.

Associated Deposit Types "Disseminated" chromite.

Metal Concentrations Platinum-group metals are common accessories.

DEPOSIT DESCRIPTION

Ore Minerals: Chromite, olivine, serpentine minerals.

Texture/Structure As above.

Alteration No

Ore Controls Restricted to dunite bodies in tectonized harzburgite.

Weathering Highly resistant to weathering and oxidation but locally forms secondary minerals such as uvarovite.

Geochemical Signature: None recognized.

Examples High Plateau, Del Norte Cty, CA References Wells, F. G. et al 1946 Santa Helena, Antioquia, Colombia Coto Mine, Luzan, P.I.
Marine sediments
Pillow lavas
Diabase dikes
Massive diorite
and gabbro
Cumulates
Transition zone
Podiform chromite deposits
Tectonite peridotite

From Dickey, 1975

Sea level
5 km
Magma pockets
10-
15-
Podiform chromite deposits
20-
25-
30-
35-

Lavas
Dikes
Cumulates
Residual tectonite peridotite
Zone of magma segregation

Minimum depth of residual (melt-depleted) peridotite

Directions of plate motion

From Dickey, 1975
DEPOSIT TYPE  Zoned ultramafic Cr Pt

AUTHOR  N. J Page

APPROXIMATE SYNONYM  Alaskan, Uralan

DESCRIPTION  Crosscutting ultramafic to felsic intrusives with approximately concentric zoning of rock types containing chromite, platinum and Ti-V magnetite.

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types  Dunite, wehrlite, harzburgite, pyroxenite, magnetite-hornblende pyroxenite, 2 pyroxene gabbros, hornblende gabbro, hornblende clinopyroxenite hornblende magnetite clinopyroxenite, olivine gabbro, norite, tonalite, diorite.

Textures  Cumulus textures poikilitic, mush flow textures, lineated fabrics, layered.

Age Range  Precambrian to late Mesozoic, most Paleozoic and Mesozoic.

Depositional Environment  Deposits occur in the layered ultramafic and mafic rocks that intrude into granodiorite terranes, island arc, or ophiolite terrains.

Tectonic Setting(s)  Unstable tectonic areas.

Associated Deposit Types  Platinum group elements (PGE) plus Au placer deposits.

Metal Concentrations  Cr, Ni, PGE.

DEPOSIT DESCRIPTION


Alteration  serpentinitization—not as a result of the mineralization

Ore Controls  Appear to be restricted to specific rock types by magmatic processes.

Weathering  Mechanical weathering produces placers, chemical weathering could produce laterites.

Geochemical Signature:  Cr, PGE, Cu, Ni, S, As, probably chondrite normalized PGE patterns from placer deposits are diagnostic.
Examples

- Urals, USSR
- Duke Island, Alaska
- Choco River placer, Columbia

References

- Duparc and Tikonovitch, 1920
- Irvine, 1974
- Wokitel, 1961, Taylor, 1967
DEPOSIT TYPE Porphyry, Cu

SUBTYPE Mo rich

AUTHOR D. P. Cox

DATE December 1, 1982

DESCRIPTION Stockwork veinlets of quartz, chalcopyrite and molybdenite in or near a porphyritic intrusion.


GEOLOGICAL ENVIRONMENT

Rock Types Quartz monzonite to tonalite intrusives and breccia pipes into older batholithic, volcanic or sedimentary rocks.

Textures Intrusions contemporaneous with ore are porphyries with fine to medium grained aplitic groundmass.

Age Range Mainly Mesozoic—Tertiary but can be any age.

Depositional Environment In intrusive porphyry or in country rock rich in mafic minerals or carbonate minerals.

Tectonic Setting(s) Numerous faults.

Associated Deposit Types Cu, Zn, or magnetite skarns may be rich in gold, gold+base metal sulfosalts in veins, gold placers

Metal Concentrations Cu, Mo, Pb, Zn, W, Au, Ag

DEPOSIT DESCRIPTION

Ore Minerals: Chalcopyrite+pyrite+molybdenite. Peripheral vein/replacement deposits with chalcopyrite+sphalerite+galena+gold. Outermost zone may have veins of Cu, Ag, Sb, sulfides and gold.

Texture/Structure Veinlets and disseminations or massive replacement of favorable country rocks.

Alteration Quartz+K-feldspar+biotite (chlorite)+ anhydrite grading outward to propylitic. Late white mica+clay alteration may form capping or outer zone or may affect the entire deposit.

Ore Controls Veinlets and mineralized fractures are closely spaced. Favorable country rocks are calcareous sediments; diabase tonalite or diorite.

Weathering Intense leaching of surface wide areas of iron oxide stain.

Geochemical Signature: Cu+Mo+W center; Pb, Zn, au, Ag, As, Sb, Te, Mn, and Rb in outer zone.

Examples El Salvador, Chile
Silver Bell, Arizona
Highland Valley, B.C. Canada

References Gustafson and Hunt, 1975
Graybeal, 1982
McMillan, 1976
Porphyry copper molybdenum 2.1

Surface

Water table

Phyllic, argillic, alteration

Quartz monzonite to granodiorite porphyry

Breccia pipe with tourmaline

Leached zone

Chalcocite zone

AuAg veins with CuSb sulfides

Replacement galena sphalerite

Skarn with chalcopyrite

Chalcopyrite + molybdenite in quartz stockwork

Propylitic alteration

Potassic alteration

Scale

1 to 4 km
DEPOSIT TYPE Porphyry Cu
SUBTYPE Au rich

AUTHOR Dennis P. Cox
DATE December 1, 1982

DESCRIPTION Stockwork veinlets of chalcopyrite, bornite and magnetite in porphyritic intrusions and coeval volcanic rocks.

GENERAL REFERENCE Sillitoe, 1979

GEOLOGICAL ENVIRONMENT

Rock Types Tonalite, quartz monzonite; dacite, andesite flows and tuffs coeval with intrusives. Also syenite, monzonite, and shoshonitic volcanics.

Textures Intrusive rocks are porphyritic with fine to medium grained aplitic groundmass.

Age Range Cretaceous to Quaternary.

Depositional Environment In intrusive porphyry, coeval volcanic rocks and intrusion breccia. Porphyry bodies may be as dikes.

Tectonic Setting(s) Numerous faults, large scale breccias. Evidence of volcanic center, 1 to 2 km depth of emplacement.

Associated Deposit Types Porphyry copper molybdenum; gold placers.

Metal Concentrations Cu, Au, Zn, Mo, Pb, Ag.

DEPOSIT DESCRIPTION

Ore Minerals: Chalcopyrite+bornite, gold and silver do not form minerals.

Texture/Structure Veinlets and disseminations.

Alteration Quartz+magnetite+biotite (chlorite)+ K-feldspar+actinolite, center. Outer propylitic zone. Late quartz+pyrite+white mica+clay may be present.

Ore Controls Veinlets and fractures of quartz, sulfides, K-feldspar magnetite, biotite, or chlorite are closely spaced.

Weathering Surface iron staining may be weak or absent if pyrite content is low in protore. Copper silicates and carbonates.

Geochemical Signature: Central Cu, Au, Ag; peripheral Mo, Pb, Zn, Mn

Examples Tanama, Puerto Rico
Dos Pobres, Arizona
Copper Mountain, B.C., Canada

References Cox, unpublished data
Langton and Williams, 1982
Fahrni, McCauley and Preto, 1976
DEPOSIT TYPE  Molybdenum Porphyry

SUBTYPE  Climax

AUTHOR  Steve Luddington

DATE  December 6, 1982

APPROXIMATE SYNONYM  Granite molybdenite

OF (REFERENCE) Mutschler and others, 1981

DESCRIPTION  Stockwork of quartz and molybdenite associated with fluorite in granite porphyry.

GENERAL REFERENCE  White and others, 1981.

GEOLOGICAL ENVIRONMENT

Rock Types  Granite-rhyolite with >75 percent SiO₂ content. Rhyolite dikes with spessartine garnets on periphery of system.

Textures  Porphyry with fine to medium-grained aplitic groundmass.

Age Range  Mesozoic, Tertiary.

Depositional Environment  Hypabyssal intrusions. Mainly continental interior, thick continental crust.

Tectonic Setting(s)  Mainly rift zones in cratons. Less commonly in continental margin mobile belts.

Associated Deposit Types  Ag-base-metal Gold veins, fluorspar deposits.

Metal Concentrations  Mo, F, W, Sn, U, Be, Li and rare earths.

DEPOSIT DESCRIPTION

Ore Minerals:  Molybdenite+fluorite+pyrite+wolframite+cassiterite+topaz.

Texture/Structure  Disseminated and in veinlets and fractures.


Ore Controls  Stockwork ore zone draped over small <1 km² cupolas.

Weathering  Yellow ferrimolybdite stains.

Geochemical Signature:  Outer Cu zone, peripheral Pb, U, and RE anomalies. Rb and Cs in K-feldspar altered host rocks.

Examples  Climax Colorado

References  White and others, 1981
DEPOSIT TYPE  Molybdenum porphyry           SUBTYPE  Low fluorine

AUTHOR  Ted G. Theodore                  DATE  December 6, 1982

APPROXIMATE SYNONYM  Calc-alkaline Mo Stockwork  OF (REFERENCE)  Westra
and Keith, 1981

DESCRIPTION  Stockwork of quartz-molybdenite veinlets in felsic porphyry

GENERAL REFERENCE  Westra and Keith, 1981

GEOLOGICAL ENVIRONMENT

Rock Types  Tonalite granodiorite-quartz monzonite

Textures  Porphyry, fine aplitic groundmass

Age Range  Mesozoic-Tertiary

Depositional Environment  Continental margin

Tectonic Setting(s)  Numerous faults

Associated Deposit Types  Vein deposits of chalcopyrite-enargite-bornite-
                             molybdenite; or pyrite-gold; or sphalerite-galena-gold-silver

Metal Concentrations  Mo, Cu, W, Ag, Au, Pb, Zn

DEPOSIT DESCRIPTION

Ore Minerals:  Molybdenite+pyrite±scheelite±chalcopyrite

Texture/Structure  Disseminated and in veinlets and fractures

Alteration  Potassic outward to propylitic. Phyllic and argillic overprint

Ore Controls  Stockwork

Weathering  Yellow ferrimolybdite after molybdenite

Geochemical Signature:  Zoning outward and upward from Mo+Cu to Cu, Au to Zn,
Pb, Au, Ag

Examples  Buckingham, Nevada

USSR deposits  References  Blake and others, 1979

Pavlova and Rundquist, 1980
DEPOSIT TYPE  Iron skarn

AUTHOR  Dennis Cox

DATE  December 8, 1982

DESCRIPTION  Magnetite in calc silicate contact metasomatic rocks.

GENERAL REFERENCE  Einaudi and Burt, 1982; Einaudi and others, 1981.

GEOLOGICAL ENVIRONMENT

Rock Types  Gabbro, diorite, diabase syenite and coeval volcanic rocks.

Textures  Granitic texture in intrusive rocks; granoblastic to hornfelsic.

Age Range  Mainly Mesozoic and Tertiary, may be any age.

Depositional Environment  Contacts of intrusion and carbonate rocks or calcareous clastic rocks.

Tectonic Setting(s)  Oceanic island arc and rifted continental margin.

Associated Deposit Types  Metal Concentrations  Fe, Cu, Co, Au

DEPOSIT DESCRIPTION

Ore Minerals:  Magnetite±chalcopyrite±cobaltite±pyrite±pyrrhotite.  Rarely cassiterite.

Texture/Structure  Granoblastic with interstitial ore minerals.

Alteration  Diopside-hedenbergite+grossular-andradite+epidote.  Late stage amphibole+chlorite+ilvaite.

Ore Controls  Carbonate rocks, calcareous rocks, igneous contacts and fracture zones near contacts.

Weathering  Magnetite generally crops out or forms abundant float.

Geochemical Signature:  Fe, Cu, Co, Au, possibly Sn

Examples  Daiquiri, Cuba  References  Lindgren and Ross, 1916
Shinyana, Japan  Uchida and Iiyama, 1982
<table>
<thead>
<tr>
<th>DEPOSIT TYPE</th>
<th>Copper skarn</th>
<th>SUBTYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUTHOR</td>
<td>Dennis P. Cox</td>
<td>DATE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>December 9, 1982</td>
</tr>
<tr>
<td>APPROXIMATE SYNONYM</td>
<td></td>
<td>OF (REFERENCE)</td>
</tr>
<tr>
<td>DESCRIPTION</td>
<td>Chalcopyrite in calc-silicate contact metasomatic rocks.</td>
<td></td>
</tr>
<tr>
<td>GENERAL REFERENCE</td>
<td>Einaudi and Burt, 1982; Einaudi and others, 1981</td>
<td></td>
</tr>
<tr>
<td>GEOLOGICAL ENVIRONMENT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock Types</td>
<td>Granodiorite to quartz monzonite intruding carbonate rocks or calcareous clastic rocks.</td>
<td></td>
</tr>
<tr>
<td>Textures</td>
<td>Granitic texture, porphyry, granoblastic to hornfelsic.</td>
<td></td>
</tr>
<tr>
<td>Age Range</td>
<td>Mainly Mesozoic but may be any age.</td>
<td></td>
</tr>
<tr>
<td>Depositional Environment</td>
<td>Miogeoclinal sequences intruded by felsic plutons.</td>
<td></td>
</tr>
<tr>
<td>Tectonic Setting(s)</td>
<td>Continental margin late orogenic magmatism.</td>
<td></td>
</tr>
<tr>
<td>Associated Deposit Types</td>
<td>Porphyry Cu, zinc skarn, replacement Pb Zn</td>
<td></td>
</tr>
<tr>
<td>Metal Concentrations</td>
<td>Cu, Pb, Zn, Au, Ag, Mo</td>
<td></td>
</tr>
<tr>
<td>DEPOSIT DESCRIPTION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ore Minerals:</td>
<td>Chalcopyrite+pyrite+hematite+magnetite+bornite+pyrrhotite+molybdenite+tennantite+gold and silver.</td>
<td></td>
</tr>
<tr>
<td>Texture/Structure</td>
<td>Granoblastic with interstitial sulfides.</td>
<td></td>
</tr>
<tr>
<td>Alteration</td>
<td>Diopside+andradite center; wollastonite outer zone; marble peripheral zone. Late stage actinolite+chlorite+montmorillonite. Igneous rocks may be altered to epidote pyroxene garnet or to potassic and phyllic assemblages.</td>
<td></td>
</tr>
<tr>
<td>Ore Controls</td>
<td>Carbonate rocks, calcareous rocks, igneous contacts and fracture zones near contacts.</td>
<td></td>
</tr>
<tr>
<td>Weathering</td>
<td>Cu carbonates, gossan.</td>
<td></td>
</tr>
<tr>
<td>Geochemical Signature:</td>
<td>Cu, Pb, Zn, Au, Ag, Mo possibly Bi.</td>
<td></td>
</tr>
<tr>
<td>Examples</td>
<td>Carr Fork, Utah</td>
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<tr>
<td></td>
<td>Morococha, Peru</td>
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</tr>
<tr>
<td></td>
<td>Mina Vieja, Colombia</td>
<td></td>
</tr>
<tr>
<td>References</td>
<td>Atkinson and Einaudi, 1978</td>
<td></td>
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<tr>
<td></td>
<td>Petersen, 1965</td>
<td></td>
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<tr>
<td></td>
<td>Alberto Nunez, oral commun., 1982</td>
<td></td>
</tr>
</tbody>
</table>
Copper skarn 2.6

Approximate scale
100 to 500 m

Showing minerals developed in calcareous rocks

Pyroxene + epidote alteration (endoskarn) or potassic/phylllic alteration and quartz-sulfide stockwork
DEPOSIT TYPE     Zinc-lead skarn

SUBTYPE

AUTHOR    Dennis P. Cox      DATE December 9, 1982

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Sphalerite and galena in calc silicate rocks.

GENERAL REFERENCE Einaudi and Burt, 1982; Einaudi and others, 1981

GEOLOGICAL ENVIRONMENT

Rock Types Granodiorite to granite, diorite to syenite. Carbonate rocks, calcareous clastic rocks.

Textures Granitic to porphyritic; granoblastic to hornfelsic.

Age Range Mainly Mesozoic but may be any age.

Depositional Environment Miogeoclinal sequences intruded by generally small bodies of igneous rock.

Tectonic Setting(s) Continental margin, late orogenic magmatism.

Associated Deposit Types Copper skarn.

Metal Concentrations Zn, Pb, Ag, Cu, W.

DEPOSIT DESCRIPTION

Ore Minerals: Sphalerite+galena±pyrrhotite±pyrite±magnetite±chalcopyrite±
bornite±arsenopyrite±scheelite±bismuthinite±stannite±fluorite. Gold and silver do not form minerals.

Texture/Structure Granoblastic, sulfides massive to interstital.

Alteration Mn-hedenbergite±andradite±grossular±spessartine±bustamite±
rhodonite. Late stage Mn-actinolite±ilvaite±chlorite±dannemorite
±rhodochrosite.

Ore Controls Carbonate rocks. Deposit may be 100's of meters from intrusive contact. Shale-limestone contacts.

Weathering Gossan.

Geochemical Signature: Zn, Pb, Cu, Co, Au, Ag, As, W, Sn, F, Mn possibly Be.

Examples Ban Ban, Australia
El Sapo, Colombia

References Ashley, 1980
Alberto Nunez, oral commun., 1982
DEPOSIT TYPE  Tungsten skarn  
SUBTYPE  

AUTHOR  Dennis P. Cox  
DATE  December 9, 1982  

APPROXIMATE SYNONYM  
OF (REFERENCE)  

DESCRIPTION  Scheelite in calc silicate contact metasomatic rocks.  

GENERAL REFERENCE  Einaudi and Burt, 1982; Einaudi and others, 1981  

GEOLOGICAL ENVIRONMENT  

Rock Types  Tonalite, granodiorite, quartz monzonite; limestone.  

Textures  Granitic, granoblastic.  

Age Range  Mainly Mesozoic, may be any age.  

Depositional Environment  Contacts and roof pendants of large batholith and thermal aureoles of apical zones of stocks.  

Tectonic Setting(s)  Continental margin. syn-late orogenic.  

Associated Deposit Types  Tin tungsten skarns, zinc skarns.  

Metal Concentrations  W, Mo, Zu, Cu.  

DEPOSIT DESCRIPTION  

Ore Minerals: Scheelite±molybdenite±pyrrhotite±sphalerite±chalcopyrite±bornite±arsenopyrite±pyrite±magnetite±traces of wolframite fluorite, cassiterite, and native bismuth.  

Texture/Structure  

Alteration  Diopside-hedenbergite±gроссular--andradite. Late stage spessartine±almandine. Outer barren wollastonite zone. Inner zone of massive quartz may be present.  

Ore Controls  Carbonate rocks in thermal aureoles of intrusions.  

Weathering  

Geochemical Signature:  W, Mo, Zn, Cu, Sn, Bi, Be, As.  

Examples  Pine Creek, California  
MacTung British Columbia  
Strawberry, California  

References  Newberry, 1982  
Dick and Hodgson, 1982  
Nokleberg, 1981
DEPOSIT TYPE Sn-W skarn

AUTHOR Dennis P. Cox

DATE December 10, 1982

DESCRIPTION Tin, tungsten, beryllium minerals in skarns, veins, stockworks and greissen near granite-limestone contacts.

GENERAL REFERENCE Einaudi and Burt, 1982; Einaudi and others, 1981

GEOLOGICAL ENVIRONMENT

Rock Types Granite-rhyolite, carbonate rocks.

Textures Granitic, fine grained granitic, porphyritic aphanitic granoblastic to hornfelsic.

Age Range Mainly Mesozoic, may be any age.

Depositional Environment Late or anorogenic granites in carbonate terrain.

Tectonic Setting(s) Stable(?) continental interior.

Associated Deposit Types W skarn, Sn greissen deposits, Sn veins.

Metal Concentrations Sn, W, F, Be, Zn, Pb, Cu, Ag.

DEPOSIT DESCRIPTION

Ore Minerals: Cassiterite±scheelite±sphalerite±pyrrhotite±magnetite±pyrite±arsenopyrite±fluorite in skarn.

Texture/Structure Granoblastic skarn, stockwork veins, breccia.

Alteration Topaz tourmaline greissen. Idocrase+Mn-grossular-andradite±Sn-andradite±malayaite in skarn. Late stage amphibole+mica+chlorite and mica+tourmaline+fluorite.

Ore Controls Intrusive contact with carbonate rocks. Crosscutting veins and rhyolite dikes.

Weathering

Geochemical Signature: Sn, W, F, Be, Zn, Pb, Cu, Ag, Li, Rb, Cs, Re, B.

Examples Lost River, Alaska

References Dobson, 1982
DEPOSIT TYPE  Cyprus massive sulfide

AUTHOR  Donald Singer

DATE  December, 1982

APPROXIMATE SYNONYM  Cupreous pyrite

OF (REFERENCE)  Franklin, and others, 1981

DESCRIPTION  Massive pyrite, chalcopyrite, and sphalerite in pillow basalts.

GEOLOGICAL ENVIRONMENT

Rock Types  Ophiolite assemblage: Tectonized dunite and harzburgite, gabbro, sheeted diabase dikes, pillow basalts, and fine-grained massive rocks such as chert and phyllite.

Textures  Diabase dikes, pillow basalts, and in some cases brecciated basalt.

Age Range  Archean(?) to Tertiary-majority are Ordovician or Cretaceous.

Depositional Environment  Marine-believed to be ocean ridge.

Tectonic Setting(s)  Local fault-controlled basins. May be adjacent to steep normal faults.

Associated Deposit Types

Metal Concentrations  Mn and Fe-rich cherts regionally. Some deposits overlain by ochre (Mn-poor, Fe-rich bedded sediment containing goethite, maghemite, and quartz).

DEPOSIT DESCRIPTION


Stringer (stockwork): pyrite+pyrrhotite, minor chalcopyrite and sphalerite, (cobalt gold and silver present in minor amounts).

Texture/Structure  Massive sulfides (>60 percent sulfides) with underlying sulfides stockwork or stringer zone.

Alteration  Stringer zone--feldspar destruction, abundant quartz and chalcedony, abundant chlorite, some illite and calcite.

Ore Controls  Pillow basalts or mafic volcanic breccias, diabase dikes below; in some cases in sediments above pillows. May be local faulting.

Weathering  Many deposits overlain by orange-yellow to brown ochre.

Geochemical Signature: General loss of Ca and Na and introduction and redistribution of Mn and Fe in the stringer zone.
Examples
Oxec (Guatemala)
Limni (Cyprus), York Harbor, (Canada)
Turner-Albright, (USA)

References
Petersen and Zantop, 1980

Cyprus type massive sulfide 3.1

Shale or phyllite and interbedded Fe-Mn-rich chert

Massive pyrite + chalcopyrite
Siliceous sulfide zone

Pillow basalt

Diabase dikes

Stringer or stockwork zone
DEPOSIT TYPE  Massive sulfide in felsic to intermediate volcanics

AUTHOR  Donald Singer

DATE  December, 1982

APPROXIMATE SYNONYM  Kuroko, Noranda, Volcanogenic massive sulfide

DESCRIPTION  Copper and zinc-bearing massive sulfide deposits in marine volcanic rocks of intermediate to felsic composition.

GENERAL REFERENCE  Franklin and others, 1981.

GEOLOGICAL ENVIRONMENT

Rock Types  Felsic to intermediate marine volcanic rocks and associated sediments.

Textures  Flows, tuffs, pyroclastics, breccias, beds, and in some cases felsic domes.

Age Range  Archean through Cenozoic.

Depositional Environment  Marine.

Tectonic Setting(s)  Local extensional tectonic activity, faults or fractures.

Associated Deposit Types  Gold-bearing quartz veins; bedded barite.

Metal Concentrations  Ba, Au

DEPOSIT DESCRIPTION

Ore Minerals:  Upper stratiform massive zone—pyrite+sphalerite+chalcopyrite+pyrrhotite+galena+barite; lower stratiform massive zone—pyrite+chalcopyrite+sphalerite+pyrrhotite+magnetite; Stringer (stockwork) zone—pyrite+chalcopyrite (gold and silver).

Texture/Structure  Massive (>60 percent sulfides); in some cases, an underlying stringer or disseminated sulfide zone.

Alteration  Adjacent to and blanketing massive sulfide in some deposits—zeolites, montmorillonite (and chlorite?); stringer (stockwork) zone—silica, chlorite, and sericite; below stringer—chlorite and albite.

Ore Controls  Towards the more felsic top of volcanic or volcanic-sedimentary rocks. Near center of felsic volcanism. May be locally brecciated and/or have felsic dome nearby.

Weathering  Yellow, red, and brown gossans.

Geochemical Signature:  Gossan may be high in Pb and typically Au is present. Adjacent to deposit—enriched in Mg and Zn, depleted in Na. Within deposits—Cu, Zn, Pb, Ba, As, Ag, Au, Se, Sn, Bi, Fe.
Examples  Bailadores (Venezuela)  References  Carlson, 1977  
Kidd Creek (Canada)  Stoll, 1962  
Hanaoka (Japan)  
Macuchi, Equador  

Massive sulfide in felsic to intermediate volcanics 3.2
DEPOSIT TYPE  Volcanogenic Gold    SUBTYPE

AUTHOR  Byron R. Berger    DATE  December 1982

APPROXIMATE SYNONYM  Massive sulfide gold    OF (REFERENCE)

DESCRIPTION  Stratabound to stratiform gold deposits in siliceous- or carbonate-iron formation in metavolcanic terrane

GENERAL REFERENCE  Hutchinson and Burlington, unpublished report

GEOLOGICAL ENVIRONMENT

Rock Types  Mafic or felsic metavolcanic rocks, volcaniclastic sediments, quartz porphyries, felsic plutonic rocks, banded iron formation (silica, carbonate)

Textures

Age Range  Precambrian to Tertiary

Depositional Environment  Active oceanic ridge spreading centers; submarine volcanic intruded by granitic stocks

Tectonic Setting(s)

Associated Deposit Types  Base-metal massive sulfide deposits, iron formation, low sulfide gold quartz veins

Metal Concentrations  Cu+Pb  Cu+Zn  Pb+Zn  Cu+Pb+Zn

DEPOSIT DESCRIPTION

Ore Minerals:  Native gold+pyrite+arsenopyrite+sphalerite+chalcopyrite.  May get minor tetrahedrite+scheelite+wolframite+molybdenite+fluorite

Texture/Structure  Narrow veins or lenses, stringers (stockworks)

Alteration  Quartz+siderite and (or) ankerite+tourmaline+chlorite+magnetite in mafic volcanic terranes:  chromian mica.  Chlorite particularly around veins and stockworks

Ore Controls  Bedded ores in chemical sediments with vein and stockworks in feeder zones to these sediments, often interlayered with flow rocks

Weathering  Gossans from magnetite lateral from carbonate iron formation

Geochemical Signature:  Au+As+B+Sb (+platinum-group metals in mafic volcanic terranes)

Examples  Homestake, South Dakota  References  Rye and Rye, 1974
Passagem, Brazil  Fleisher and Routhier, 1973
Kirkland Lake, Canada  Ridler, 1970
DEPOSIT TYPE  Red-bed--Green-bed Cu

AUTHOR D. P. Cox

DATE December 14, 1982

APPROXIMATE SYNONYM

DESCRIPTION  Stratabound, disseminated copper sulfides in reduced beds of red-bed sequences

GENERAL REFERENCE  Tourtelot and Vine, 1976

GEOLOGICAL ENVIRONMENT

Rock Types  Red-bed sequence containing green or gray shale, siltstone, and sandstone. Thin carbonate and evaporite beds. Local channel conglomerate.

Textures  Algal mat structures, mudcrackes, deltaic cross bedding. Fossil wood in channels.


Tectonic Setting(s)  Intracontinental rift. Aulacogen. Failed arm of triple junction of plate spreading. Major growth faults.

Associated Deposit Types  Halite, sylvite, gypsum, anhydrite. Sandstone uranium. Native copper in basaltic rocks

Metal Concentrations  Cu, Ag, Mo, Pb, Zn, V, U

DEPOSIT DESCRIPTION

Ore Minerals:  Chalcocite and other Cu$_2$S minerals+pyrite+bornite+native silver. Cu$_2$S replacement of early fine-grained pyrite is common. Deposits may be zoned with centers of chalcocite+bornite, rims of chalcopyrite, and peripheral galena+sphalerite.

Texture/Structure  Fine disseminated, stratabound, locally stratiform

Alteration  Green, white or gray (reduced) color in red beds. Regionally matmorphosed red beds may have purple color.

Ore Controls  Reducing low pH environment such as fossil wood, algal mat. Abundant biogenic sulfur. Pyritic sediments. Petroleum in paleoaquifers.

Weathering  Surface exposures may be completely leached. Secondary chalcocite enrichment down dip is common.

Geochemical Signature:  Cu, Ag, Pb, Zn (Mo, V, U)

Examples  Kupferschiefer, Germany  References  Wedepohl, 1971
           White Pine, Michigan  Brown, 1971
           Western Montana (Belt)  Harrison, 1972
DEPOSIT TYPE  Volcanic native Cu  SUBTYPE  

AUTHOR  D. P. Cox  

APPROXIMATE SYNONYM  Volcanic Red Bed Cu  OF (REFERENCE)  Kirkham, 1982

DESCRIPTION  Disseminated native copper and copper sulfides in subaerial basalt flows and copper sulfides overlying sedimentary beds

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types  Subaerial basalt flows and breccias, red bed sandstone and conglomerate. Younger limestone and black shale

Textures  Amygdules. Flow-top breccias

Age Range  Proterozoic, Triassic-Jurassic, any Phanerozoic age

Depositional Environment  Copper-rich (100-200 ppm) subaerial basaltic volcanism followed by shallow marine peralic basin, Near paleo equator

Tectonic Setting(s)  Intracontinental rift, continental margin rift. Regional low-grade metamorphism may mobilize copper

Associated Deposit Types  Copper shale, red-bed copper

Metal Concentrations  Cu, Ag

DEPOSIT DESCRIPTION

Ore Minerals:  Native copper, native silver+chalcosite and other Cu₂S minerals. Chalcopyrite in some deposits.

Texture/Structure  Disseminated open-space filling. Stratabound and veins

Alteration  Calcite-zeolite. Red coloration due to fine hematite

Ore Controls  Flow top breccias, amygdules, fractures in basalt organic shale, limestone, in overlying sequence. Limestone is tidal, algal, with stromatolite fossils

Weathering  Widely dispersed copper nuggets in streams

Geochemical Signature:  Cu Ag

Examples  Keweenaw, Michigan (White)  References  Maze, W. B., 1982
Wrangellia Terrane, Alaska (Bateman)  Champetier de Ribes and others, 1963  
Sierra de Perija  


DEPOSIT TYPE: Dolomitic copper cobalt

AUTHOR: D. P. Cox

DESCRIPTION: Cu, Co, U in stratiform deposits in carbonates and shale

GENERAL REFERENCE: Bartholome, 1974

GEOLOGICAL ENVIRONMENT

Rock Types: Dolomite, limestone, shale, siliceous dolomite, carbonaceous shale

Textures: Finely laminated dolomite, stromatolites, solution breccias

Age Range: Proterozoic-Zaire; Devonian-Alaska


Tectonic Setting(s): Intracontinental rift. Passive margin rift.

Associated Deposit Types: None

Metal Concentrations: Cu, Co, U, V, Ge, Zn, Pb, Ga, Bi, Pt, Pd

DEPOSIT DESCRIPTION

Ore Minerals: Bornite + chalcopyrite + pyrite + carrollite + linnaeite + chalcocite + cobaltiferous pyrite. Traces of germanite, pitchblende. At Ruby Creek, assemblage includes sphalerite plus traces of galena and late tetrahedrite

Texture/Structure: Finely laminated fine grained. At Ruby Creek, breccia filling

Alteration: Dolomite-magnesite, relation to mineralization is not clear. Dolomite breccia with fine pyrite matrix

Ore Controls: Paleoaquifers, paleo redox boundaries. At Ruby Creek, dolomite breccia with fine pyrite matrix.

Weathering: Malachite, azurite, black Co oxide or pink arsenate

Geochemical Signature: Cu, Co, U, V, Ge, Ga, Pt, Pd. At Ruby Creek also Zn, Pb, As, Sb

Examples: Zaire Copper Belt

References:
Ruby Creek, Alaska
Kona Dolomite, Michigan
DEPOSIT TYPE Sandstone Uranium SUBTYPE Roll front, epigenetic carbonaceous

AUTHOR C. A. Hodges DATE December 15, 1982

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Concentrations of uranium oxides in localized reduced environments within medium- to coarse-grained sedimentary beds

GENERAL REFERENCE Nash and others, 1981

GEOLOGICAL ENVIRONMENT

Rock Types Feldspathic or tuffaceous sandstone, arkose, mudstone, conglomerate

Textures Permeable—medium to coarse grained; highly permeable during mineralization, subsequently restricted by cementation and alteration

Age Range Post-Silurian (<0.4 b.y.); roll-front deposits mainly Tertiary

Depositional Environment Continental—basin margins, fluvial channels, fluvial fans (especially mid-fan facies), stable coastal plain; nearby felsic plutons or felsic volcanics

Tectonic Setting(s) Stable platform or foreland-interior basin, shelf margin; adjacent major uplifts provide favorable topographic conditions

Associated Deposit Types Hydrocarbon source rocks; "red-bed Cu" deposits may be in similar host rocks and may contain U

Metal Concentrations FeS₂, Se, Mo, V

DEPOSIT DESCRIPTION

Ore Minerals: Pitchblende, coffinite, carnitote—almost invariably associated with pyrite; Se, Mo, V commonly in zonal arrangement, caused by geochemical gradient—Se generally richer in oxidized facies

Texture/Structure Stratabound deposits—tabular or roll front; disseminated mineralization

Alteration Host rocks typically contain both diagenetically reduced and oxidized facies; V ores in reduced facies (typically gray-green-white) or concentrated at interface (see diagram)

Ore Controls Permeability; adsorptive agents (humic materials, Ti oxides); reducing agents—C matter, reduced S species, "sour" gas, FeS₂; bedded sequences with low dips; felsic plutons or tuffaceous seds adjacent to or above host rock are favorable source rocks

Weathering Oxidation of primary pitchblende, coffinite, carnitite; little effect on ore grade or localization

Geochemical Signature: Anomalous radioactivity (5 to 10 x normal background); low redox potential; carbonaceous material, FeS₂, other reducing agents required; Se, Mo, V, Cu commonly associated
Examples: Colorado Plateau
Grants, New Mexico
Texas Gulf Coast (ross frong)

References: Isachsen and Evernsen, 1956; Hilpert, 1969; Eargle and others, 1975

Roll type uranium deposit 4.4

Plan:

Surface leaching

Groundwater migration

Oxidation

Reduced

Tongue

Host

Ore concentrations

(After Nash et al., 1981)

Cross-section:

Red-pink

Gray-green

Reduced facies:

Pyrite-marcasite

Magnetite

Carbonaceous debris

Ore concentration

Tuffs

Permeable ss

GW

Oxidized facies:

TiO₂

Se

Fe₂O₃

26
DEPOSIT TYPE Sediment-hosted, submarine exhalative Zn-Pb

AUTHOR Joseph A. Briskey

APPROXIMATE SYNONYM Shale-hosted Zn-Pb

DESCRIPTION Stratiform basinal accumulations of sulfide and sulfate minerals interbedded with euxinic marine sediments

GENERAL REFERENCE Large (1980)

GEOLOGICAL ENVIRONMENT

Rock Types Euxinitic sedimentary rocks including: black shale, siltstone, sandstone, chert, dolostone, and micritic limestone

Textures Contrasting sedimentary thicknesses and facies changes across hinge zones. Slump breccias and conglomerates near synsedimentary faults

Age Range Middle Proterozoic (1,700-1,400 Ma); Ordovician to Mississippian (530-300 Ma)

Depositional Environment Epicratonic marine basins or embayments, with smaller local restricted basins

Tectonic Setting(s) Epicratonic basins or embayments associated with hinge zones controlled by synsedimentary faults

Associated Deposit Types Strataform barite deposits

Metal Concentrations Highest expected background in black shales: Pb = 500 ppm; Zn = 1,300 ppm; Cu = 750 ppm; Ba = 1,300 ppm

DEPOSIT DESCRIPTION

Ore Minerals: Pyrite, pyrrhotite, sphalerite, galena, sporadic barite, and chalcopyrite, and minor to trace amounts of marcasite, arsenopyrite, bismuthinite, molybdenite, enargite, millerite, freibergite, cobaltite, cassiterite, valleriite, and melnicovite

Texture/Structure Finely crystalline and disseminated. Metamorphosed examples are coarsely crystalline and massive

Alteration Stockwork and disseminated sulfide and alteration (silicification, tourmalization, carbonate depletion, albitization, chloritization, dolomitization) minerals representing the feeder zone of these deposits commonly present beneath or adjacent to stratiform deposits

Ore Controls Within larger fault-controlled basins, small local basins form the morphological traps that contain the stratiform sulfide and sulfate minerals. The faults are synsedimentary and serve as feeders for the stratiform deposits

Weathering Surface oxidation may form large gossans containing abundant carbonates, sulfates, and silicates of lead, zinc, and copper
Geochemical Signature: Metal zoning includes lateral Cu-Pb-Zn-Ba sequence extending outward from feeder zone; or a vertical Cu-Zn-Pb-Ba sequence extending inward. Exhalative chert interbedded with stratiform sulfide and sulfate minerals. Regional Mn halos

Examples: Sullivan mine, Canada

References: Hamilton and others (1981)

Sediment hosted submarine exhalative zinc-lead deposit

4.5

Major synsedimentary fault

Stratiform facies

Crosscutting facies

Veinlets grading upward to breccia containing chalcopyrite ± pyrrhotite

Alteration: Silicification tourmaline-albite-chlorite-dolomite

Modified from Large (1980)

EXPLANATION

Tuffaceous layers

Black shale, siltstone, sandstone, chert, dolomite, micritic limestone

Intraformational slumping
DEPOSIT TYPE  Stratabound Carbonate-hosted Pb-Zn  
SUBTYPE  Southeast Missouri type

AUTHOR  Joseph A. Briskey  
DATE  1/5/83

DESCRIPTION  Stratabound carbonate-hosted deposits of galena, sphalerite, and chalcopyrite in rocks having primary and secondary porosity, commonly related to reefs on paleotopographic highs

GENERAL REFERENCE  Snyder and Gerdemann (1968)

GEOLOGICAL ENVIRONMENT

Rock Types  Dolomite; locally ore bodies also occur in sandstone, conglomerate, and calcareous shales

Textures  Calcarenites are most common lithology. Tidalites, stromatolite finger reefs, reef breccias, slump breccias; oolites, cross bedding, slump breccias, micrites

Age Range  Cambrian to Lower Ordovician

Depositional Environment  Shallow-water marine carbonate sedimentation, with prominent facies control by reefs growing on flanks of paleotopographic basement highs

Tectonic Setting(s)  Stable cratonic platform

Associated Deposit Types  Precambrian deposits of magnetite-hematite, and magnetite-copper (+Co, Ni, Ba); Ba-Pb deposits occur higher in the Cambrian section

Metal Concentrations  Background for carbonates:  Pb = 9 ppm; Zn = 20; Cu = 4

DEPOSIT DESCRIPTION

Ore Minerals:  Galena, sphalerite, chalcopyrite, pyrite, marcasite, siegenite, bornite, tennantite, barite, bravoite, digenite, covellite, arsenopyrite, fletcherite, adularia, pyrrhotite, magnetite, millerite, polydymite, vaesite, djurleite, chalcocite, anilite, and enargite in order of abundance

Texture/Structure  Early fine-grained replacement; main stage coarse grained; some colloform; dissolution

Alteration  Regional dolomitization; latter brown, ferroan and bitumin-rich dolomite; extensive dissolution and development of residual shales; mixed-layer illite-chlorite altered to 2M muscovite; dickite and kaolinite in vugs; very minor adularia

Ore Controls  Numerous! Open-space filling and replacement, most commonly at the interface between gray and tan dolomite, but also in traps at any interface between permeable and impermeable units. Any porous units may host ore: sandstone pinchouts; dissolution collapse breccias; faults; permeable reefs; slump, reef, and fault breccias; coarsely crystalline dolostone; etc.
Geochemical Signature: Regional anomalous amounts of Pb, Zn, Cu, Mo, Ag, Co, and Ni in insoluble residues. Zoning is roughly Cu (+Ni+Co)-Pb-Zn-iron sulfide going up section; inconsistent lateral separation of metal zones.

Examples Viburnum subdistrict

References Heyl (1982)

Carbonate hosted lead-zinc 4.6

EXPLANATION

Preferred locations of ore bodies

Dolomite

Shale

Conglomerate

Coarse crystalline white dolomite

Sandstone

Reef and reef breccia

Crystalline basement

Generalized cross section of the Viburnum trend, S.E. Missouri. Modified from Evans, 1977

Scale
DEPOSIT TYPE        Stratabound carbonate-hosted zinc-lead   SUBTYPE
Appalachian deposits

AUTHOR         Joseph A. Briskey       DATE       January 5, 1983

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Stratabound deposits of sphalerite and minor galena in primary
and secondary voids in favorable beds or horizons in thick platform dolostone
and limestone

GENERAL REFERENCE Hoagland (1976)

GEOLOGICAL ENVIRONMENT

Rock Types Dolostone and limestone

Textures Subtidal, intratidal, and supratidal textures are common, especially
in the dolostones; limestones are commonly micritic, some with birdseye
textures

Age Range Deposits occur in rocks of cambrian to middle Ordovician age.

Depositional Environment Shallow-water, tidal and subtidal marine
environments

Tectonic Setting(s) Stable continental shelf

Associated Deposit Types Stratabound carbonate-hosted deposits of barite-
fluorite-sphalerite, and of limonite-siderite-(+sphalerite)

Metal Concentrations Background in carbonate rocks: Zn = 20 ppm; Pb = 9 ppm

DEPOSIT DESCRIPTION

Ore Minerals: Sphalerite, with variable but subordinate pyrite and minor
marcasite, and with minor barite, fluorite, gypsum, and anhydrite. Galena is
usually absent or rare, but may be locally the third most abundant mineral
behind sphalerite and pyrite

Texture/Structure Coarse to medium crystalline, with concentric growth
banding

Alteration Extensive dolomitization occurs regionally and in close proximity
to ore bodies. Silicification is typically closely associated with ore
bodies. Extensive limestone dissolution and development of residual shales

Ore Controls Ore occurs within dissolution collapse breccias that occupy (1)
readily soluble limestone beds, or (2) paleo-aquifer solution channels
controlled by fractures or folds in limestone

Weathering Zinc silicate and carbonate ores form in the zone of weathering
and oxidation
Geochemical Signature: Oxidized sphalerite at the surface caused readily detectable zinc anomalies in residual soils and in stream sediments. Primary zinc haloes in carbonate rocks near ore are not large enough to assist in exploration.

Examples East Tennessee zinc district References Crawford and Hoagland (1968)


DEPOSIT TYPE  Sandstone-hosted Pb-Zn  SUBTYPE

AUTHOR  Joseph A. Briskey  DATE  December 28, 1982

APPROXIMATE SYNONYM  OF (REFERENCE)

DESCRIPTION  Stratabound to stratiform galena and sphalerite in multiple, thin, sheetlike ore bodies in arenaceous sedimentary rocks

GENERAL REFERENCE  Briskey (1982)

GEOLOGICAL ENVIRONMENT

Rock Types  Continental, terrigenous, and marine arenaceous quartzitic and arkosic sandstones, conglomerates, grits, and siltstones

Textures  Bedding, crossbedding, paleochannels, liquification structures, and intraformational slump breccias. Quartz and calcite cement

Age Range  Proterozoic to Cretaceous host rocks

Depositional Environment  Host rocks deposited in piedmont, lagoonal-lacustrine, lagoonal-deltaic, lagoonal-beach, and tidal channel-sand bar environments

Tectonic Setting(s)  Marine platform or piedmont sedimentation associated with at least some orogenic uplift

Associated Deposit Types  Sandstone-hosted copper deposits

Metal Concentrations  Background in sandstone: Pb = 7 ppm; Zn = 16 ppm

DEPOSIT DESCRIPTION

Ore Minerals  Fine- to medium-crystalline galena with sporadic smaller amounts of sphalerite, pyrite, barite, and fluorite. Minor chalcopyrite, tetrahedrite-tennantite, chalcocite, freibergite, bournonite, bornite. Quartz and calcite are usual gangue minerals

Texture/Structure  Clots 0.5 to several centimeters in diameter; disseminations 0.1-1 mm dia; locally massive

Alteration  "Sericite" (white mica?) reported in some deposits; but may only be recrystallized sedimentary illite?

Ore Controls  Intergranular porosity. Ore may be massive where localized by sedimentary structures (above), impermeable barriers, faults, joints, and fractures. Within or immediately above paleochannels or paleoridges. With organic matter.

Weathering  Surface oxidation of galena to cerussite, chalcopyrite to malachite, and probably of sphalerite to smithsonite, hemimorphite, etc.

Geochemical Signature  Anomalous amounts of Pb and Zn in host rocks and derivative soils; Ba, Fl, and Ag are enriched in lowermost parts of some deposits
| Examples | Laisvall mine, Sweden | References | Rickard and others (1979) |
DEPOSIT TYPE  Replacement

SUBTYPE  Limestone Replacement

AUTHOR  Hal T. Morris

DATE  December 15, 1982

APPROXIMATE SYNONYM  Manto deposits

OF (REFERENCE)  Many authors

DESCRIPTION  A hydrothermal, epigenetic, sulfide mineral deposit, commonly later oxidized, that replaces limestone, dolomite, or other soluble rock.


GEOLOGICAL ENVIRONMENT

Rock Types:  Sedimentary rocks, chiefly including limestone, dolomite, and shale, commonly overlain by volcanics and intruded by porphyritic, calc-alkaline plutons.

Textures:  The textures of the replaced sedimentary rocks are not important; associated plutons typically are porphyritic.

Age Range:  Not important, but many are Late Mesozoic to Early Cenozoic.

Depositional Environment:  Carbonate host rocks that commonly occur in broad sedimentary basins, such as epicratonic miogeosynclines.

Tectonic Setting(s):  Most deposits occur in mobile belts that have undergone moderate deformation and have been intruded by small plutons.

Associated Deposit Types:  Veins that cut the more massive igneous or sedimentary rocks, skarns, and porphyry-type disseminated copper deposits.

Metal Concentrations  Over a broad area associated metals include lead, zinc, silver, copper, gold, arsenic, antimony and bismuth.

DEPOSIT DESCRIPTION

Ore Minerals:  Galena, sphalerite, argentite, tetrahedrite, pyrite, enargite chalcopyrite, proustite, pyrargyrite, jamesonite, bouronite, tennantite, jordanite, stephanite, polybasite, sylvanite, calaverite, native gold, bismuthinite, marcasite, barite, quartz, rhodochrosite, calcite, and dolomite.

Texture/Structure:  Ranges from massive to highly vuggy and porous.

Alteration:  Typical limestone wallrocks are dolomitized and silicified; shales and igneous rocks are chloritized and commonly are argillized; where syngenetic iron oxide minerals are present, rocks are pyritized.

Ore Controls:  Tabular, podlike and pipelike ore bodies are localized by faults or vertical beds; ribbonlike or blanketlike ore bodies are localized by bedding-plane faults or by susceptible beds.

Weathering:  Near the surface, these ore bodies commonly are oxidized to ochreous masses containing cerrusite, anglesite, hemimorphite, and cerargyrite.
5.1 (continued)

**Geochemical Signature:** On a district-wide basis ore deposits commonly are zoned outward from a copper-rich central area through a wide lead-silver zone, to a zinc- and manganese-rich fringe.

5.2

**DEPOSIT TYPE** Carbonate-hosted gold  
**SUBTYPE** Disseminated gold

**AUTHOR** Byron R. Berger  
**DATE** December 1982

**APPROXIMATE SYNONYM** Carlin-type or invisible gold  
**OF** (REFERENCE)

**DESCRIPTION** Very fine grained gold and sulfides disseminated carbonaceous calcareous rocks

**GENERAL REFERENCE**

**GEOLOGICAL ENVIRONMENT**

**Rock Types** Host rocks: thin-bedded silty or argillaceous carbonaceous limestone or dolomite often with carbonaceous shales. Intrusive rocks: felsic dikes, often porphyritic

**Textures**

**Age Range** Mainly Tertiary, but can be any age

**Depositional Environment** Association with intrusive. Best host rocks formed as carbonate turbidites in somewhat anoxic environments. Deposits formed where these are intruded by igneous rocks under nonmarine conditions.

**Tectonic Setting(s)** High-angle normal fault zones

**Associated Deposit Types** Tungsten-moly skarn, porphyry molybdenum, placer gold, stibnite-barite veins

**Metal Concentrations** Hg, Sb, As, Mo, W

**DEPOSIT DESCRIPTION**

**Ore Minerals:** Native gold (very fine grained)+pyrite+realgar+orpiment+arsenopyrite+cinnabar+fluorite+barite

**Texture/Structure** Silica replacement of carbonate, generally less than 1 percent fine-grained sulfides

**Alteration** Unoxidized ore: "jasperoid"+quartz+illite+kaolinite+calcite. Hypogene oxidized ore: kaolinite+montmorillonite+illite+jarosite+alunite

**Ore Controls** Selective replacement of carbonaceous carbonate rocks adjacent to and along high-angle faults or regional thrust faults

**Weathering** Light red gray and (or) tan oxides, light brown to reddish brown iron-oxide stained jasperoid

**Geochemical Signature:** Au+As+Hg+W+Mo  
As+Hg+Sb+Tl+F (this stage superimposed on preceding)

**Examples** Carlin, Nevada
Getchell, Nevada
Mercur, Utah

**References** Radtke, Rye and Dickson, 1980
Joralemon, 1951
Gilluly, 1932
DEPOSIT TYPE Low-sulfide quartz veins

AUTHOR Byron R. Berger

DATE December 1982

APPROXIMATE SYNONYM Mesothermal quartz veins

DESCRIPTION Gold in massive persistent quartz veins mainly in regionally metamorphosed volcanics and volcanic sediments

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Greenstone belts; oceanic sediments: graywacke, shale, quartzite, batholithic terranes

Textures

Age Range Precambrian to Tertiary

Depositional Environment Continental margin mobile belts, accreted margins

Tectonic Setting(s) Fault and joint systems

Associated Deposit Types Massive sulfide, iron formation, volcanogenic gold, skarn

Metal Concentrations Ag+Pb+Zn, Cu+Pb+Zn

DEPOSIT DESCRIPTION

Ore Minerals: Native gold+pyrite+galena+sphalerite+arsenopyrite+pyrrhotite. May get tellurides+scheelite+bismuth+molybdenite+fluorite. Productive quartz is grayish or bluish in many instances because fine-grained sulfides

Texture/Structure Saddle reefs, ribbon quartz, absence of open-space filling

Alteration Quartz+siderite and (or) ankerite+albite in veins with selvage of quartz+chlorite+biotite. Wallrock alteration is minimal, chromium mica in areas of mafic volcanism

Ore Controls Veins are persistent along regional high-angle faults, joint sets. Best deposits overall in areas with greenstones

Weathering

Geochemical Signature: Arsenic best pathfinder in general

Examples Yellowknife, Canada

References Boyle, 1970

Mother Lode, Grass Valley areas, Calif.

Lindgren 1896, and

Knopf Appalachian slate belt, U.S.A. 1929
DEPOSIT TYPE  Epithermal Gold, Silver  SUBTYPE  Quartz-Adularia

AUTHOR  Byron R. Berger  DATE  December, 1982

APPROXIMATE SYNONYM  Precious- and base-metal veins  OF (REFERENCE)

DESCRIPTION  Gold in vuggy quartz veins with abundant pyrite, arsenopyrite, sphalerite and galena.
GENERAL REFERENCE  Buchanon, 1980

GEOLOGICAL ENVIRONMENT

Rock Types  Areas of volcanism: andesite, dacite, quartz latite, rhyodacite, rhyolite
Textures  Porphyritic
Age Range  Mainly Tertiary for bonanza deposits, but may be any age
Depositional Environment  Centers of volcanism and associated intrusive activity for bonanza deposits; batholiths
Tectonic Setting(s)  Through-going fractures systems; major normal faults, fractures related to doming, ring fracture zones, joints
Associated Deposit Types  Placer gold

Metal Concentrations  Ag+Pb+Zn, Ag+W+Bi+Pb+Zn

DEPOSIT DESCRIPTION

Ore Minerals: Native gold+electrum+pyrite+arsenopyrite+galena+sphalerite in high Au: Ag deposits. Native gold+electrum+tetrahedrite+pyrite+galena+sphalerite+barite+rhodochrosite in high Ag: Au deposits in hypogene oxidized areas of supergene zones gold+ruby silver+native silver
Texture/Structure  Banded veins, open space filling, lamellar quartz, stockworks

Alteration  Top to bottom of system: quartz+kaolinite+montmorillonite+zeolite+barite+calcite; quartz+illite; quartz+adularia+illite; quartz+chlorite presence of adularia is variable

Ore Controls  Through-going, anastomosing fracture systems

Weathering  Bleached country rock, goethite, jarosite, alunite—supergene processes often important factor in increasing grade of deposit

Geochemical Signature: Higher in system Au+As+Sb+Hg; Au+Ag+Pb+Zn+Cu; Ag+Pb+Zn, Cu+Pb+Zn, Base metals generally higher in deposits with silver.

Examples  Jarbridge, Nevada  References  Schrader, 1923
Comstock, Nevada  Becker, 1882
Guanajuato, Mexico  Buchanan, 1980, and Wandke and Martinez, 1928
Creede Colorado  Steven and Ratte, 1965
Epithermal Gold
quartz adularia type

Barren qtz + calcite ± fluorite ± barite
Qtz + kaolinite + alunite + zeolites

Silicification
Qtz + illite + pyrite + native metals + sulfosalts
Qtz + illite + native metals + sulfarsenides + sulfantimonides + Ag-sulfides + base-metal sulfides

Bonanza and/or stockwork ores
Qtz + adularia + illite + Ag sulfides + base-metal sulfides

Possible barren zone
Pre- "higher level" qtz + illite ± kaolinite + sulfide capping

Early qtz + Ag-sulfides + base-metal sulfides + adularia
Vein structure
DEPOSIT TYPE Epithermal gold

SUBTYPE Quartz-alunite

AUTHOR Byron R. Berger

DATE December 1982

APPROXIMATE SYNONYM Acid-sulfate or enargite gold OF (REFERENCE)

DESCRIPTION Gold, pyrite and enargite in vuggy veins and breccias in zones of advanced argillic alteration related to felsic volcanism

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Volcanic: dacite, quartz latite, rhyodacite, rhyolite. Hypabyssal intrusions or domes

Textures Porphyritic

Age Range Generally Tertiary, but can be any age

Depositional Environment Within the volcanic edifice, ring fracture zones of calderas, or areas of igneous activity with sedimentary evaporites in basement

Tectonic Setting(s) Throughgoing fracture systems: keystone graben structures, ring fracture zones, normal faults, fractures related to doming, joint sets

Associated Deposit Types Porphyry copper, active or fossil acid-sulfate hot springs, pyrophyllite, hydrothermal clay

Metal Concentrations Copper, arsenic, antimony

DEPOSIT DESCRIPTION

Ore Minerals: Native gold+enargite+pyrite+silver-bearing sulfosalts+ chalcopyrite+bornite+precious-metal tellurides+galena+sphalerite+huebnerite. May have hypogene oxidation phase with chalcocite+covellite+luzonite with late-stage native sulfur

Texture/Structure Veins; breccia pipes, pods, dikes; replacement veins often porous, vuggy

Alteration Highest temperature assemblage: quartz+alunite+pyrophyllite; may be early stage of quartz+alunite with pervasive alteration of host rock and veins of these minerals; zoned around quartz+alunite is quartz+alunite+kaolinite+montmorillonite; pervasive propylitic alteration depends on extent of early alunitization:chlorite+calcite

Ore Controls Through-going fractures, centers of intrusive activity

Weathering Abundant yellow limonites, jarosite, goethite, white argillization with kaolinite, fine-grained white alunite veins, hematite

Geochemical Signature: Higher in system Au+As+Cu with increasing base metals at depth. Also Te, and at El Indio, W

Examples Goldfield, Nevada

Kasuga mine, Japan

References Ransome, 1909

Taneda and Mukaiyama, 1970
5.5 (continued)

El Indio, Chile

Walthier and others, 1982
unpublished report
DEPOSIT TYPE  Hot Springs Gold Silver

AUTHOR  Byron R. Berger

DATE  December 1982

DESCRIPTION  Fine-grained silica and quartz in silicified breccia with gold, pyrite and Sb and As sulfides

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types  Areas of volcanic activity: rhyolite
Textures  Porphyritic

Age Range  Mainly Tertiary and Quaternary

Depositional Environment  Rhyolitic volcanic centers, rhyolite domes

Tectonic Setting(s)  Through-going fracture systems

Associated Deposit Types  Quartz veins, breccia pipes

Metal Concentrations:  Mo, W, Ag-sulfosalts, placer gold

DEPOSIT DESCRIPTION

Ore Minerals:  Native gold+pyrite+stibnite+realgar or arsenopyrite+sphalerite+chalcopyrite+fluorite or native gold+Ag-selenide or tellurides+pyrite

Texture/Structure:  Structure banded veins, stockworks, breccias (cemented or uncemented w/silica)

Alteration:  Top of bottom of system: Chalcedonic sinter, massive silicification, stockworks and veins of quartz+adularia and breccias cemented w/quartz, quartz+chlorite - Veins generally chalcedonic, some opal

Ore Controls:  Through-going fracture systems, brecciated cores of intrusive domes; cemented breccias important carrier of ore

Weathering:  Bleached country rock, yellow limonites w/jarosite and fine grained alunite, hematite, goethite

Geochemical Signature:  Au+As+Sb+Hg+Tl higher in system, increasing Ag w/depth, decreasing As+Sb+Tl+Hg with depth

Examples  McLaughlin, California

Round Mtn., Nevada

Delamar, Idaho

References  Averitt 1945 and Becker, 1888

Ferguson, 1921

Lindgren, 1900
Hot Springs Gold-Silver 5.6

Hydrothermal explosion breccia
  Bedded fallout material
  Silica sinter
  Sb, As, Au, Ag, Hg in seams
  Opalized rock or porous, vuggy silica
  Native S, cinnabar
  Pervasive silicification
  Dispersed As, Sb, Au, Ag, Tl
  Stockwork veins
    Au, Ag, As, Tl, Sb in qtz, chalcedony
  Acid leaching
    Kaolinite, alunite, silica, jarosite
  Base of silicification
  Breccia dikes
  Hydrothermal brecciation
    (low-angle veins)
    Au, Ag, As, Sb, Tl sulfides and qtz
  Qtz-sulfide veins
    Au, Ag, As, (Cu, Pb, Zn) in sulfides with adularia
  Qtz-sulfide veins
    Cu, Pb, Zn, (Au, Ag) in sulfides with chlorite
DEPOSIT TYPE Disseminated Hg  SUBTYPE Aranzazu type

AUTHOR D. Cox  DATE 12/1/82

APPROXIMATE SYNONYM Almaden type  OF (REFERENCE)

DESCRIPTION Stratabound disseminated native mercury in volcaniclastic sedimentary rocks

GENERAL REFERENCE Saupe, 1973

GEOLOGICAL ENVIRONMENT

Rock Types Shale, graywacke, calcareous graywacke, andesitic lava and tuff, andesite dikes. Volcanic vent breccia

Textures

Age Range Cretaceous

Depositional Environment Permeable sedimentary rocks, andesite dikes possibly near volcanic center

Tectonic Setting(s) Volcanic centers along major deep-seated fault zone

Associated Deposit Types Stibnite veins

Metal Concentrations Hg As Sb

DEPOSIT DESCRIPTION

Ore Minerals: Native mercury+cinnabar+pyrite+calcite+quartz

Texture/Structure Disseminated

Alteration

Ore Controls Mineralized zone follows major fault, highest grade ore in calcareous graywacke

Weathering

Geochemical Signature: Hg As Sb

Examples Nueva Esperanza, Caldas, Colombia  References Lozano and others (1977)

Almaden, Spain  Saupe (1973)

Santa Barbara, Peru
DEPOSIT DESCRIPTION

Ore Minerals: Cinnabar, native Hg, other minor sulfides: pyrite, stibnite, chalcopyrite, sphalerite, galena, and bornite

Texture/Structure Replacement and minor veins

Alteration Replacement of serpentine by quartz and dolomite and minor hydrocarbons to form "silica-carbonate" rock

Ore Controls Contact of serpentine with siltstone especially where contact forms antiform ore primarily in silica-carbonate rock

Weathering

Geochemical Signature: Unknown, probably Hg Sb Cu Zn

Examples New Almaden, Calif. References Bailey (1964)
DEPOSIT TYPE  Hot spring Hg    SUBTYPE

AUTHOR  J. Rytuba    DATE  January 11, 1983

APPROXIMATE SYNONYM  Sulphur Bank    OF (REFERENCE)  White, 1981

DESCRIPTION  Cinnabar and pyrite disseminated in graywacke, shale, andesite, and basalt flows and diabase dikes

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types  Andesite-basalt flows, diabase dikes, andesitic tuffs, and tuff breccia

Textures

Age Range  Tertiary

Depositional Environment  Near paleo groundwater table in areas of fossil hot spring system

Tectonic Setting(s)  Extensional faulting with associated small volume mafic to intermediate volcanism

Associated Deposit Types  Hot Springs gold

Metal Concentrations

DEPOSIT DESCRIPTION

Ore Minerals:  Cinnabar - native Hg

Texture/Structure  Disseminated and coatings on fractures

Alteration  Above paleo groundwater table, kaolinite-alunite-Fe oxides; below paleo groundwater table, pyrite, zeolites, potassium feldspar, chlorite, and quartz. Opal deposited at the paleo water table.

Ore Controls  Paleo groundwater table within hot spring systems developed along high-angle faults

Weathering

Geochemical Signature:  Hg  As  Sb  +Au

Examples  Sulfur bank, California    References  White and Roberson (1962)
DEPOSIT TYPE  Emerald veins  

SUBTYPE

AUTHOR  D. Cox  

DATE  2/24/83

APPROXIMATE SYNONYM  

OF (REFERENCE)

DESCRIPTION  Emerald in plagioclase-dolomite veins in black shale

GENERAL REFERENCE  Escovar, 1979

GEOLOGICAL ENVIRONMENT

Rock Types  Black shale, claystone, siltstone. Minor sandstone, limestone and conglomerate. Locally coarse dolomite breccia filled by carbonates and oligoclase.

Textures  Diabasic diorite dikes present but not prominent.

Age Range  Cretaceous–Tertiary

Depositional Environment  Thick epicontinental marine shale. Evaporites may have provided saline solutions.

Tectonic Setting(s)  Major faults. Minor intrusions may have provided heat sources for fluid circulation.

Associated Deposit Types  May be associated with Pb–Zn deposits

Metal Concentrations  Be+Pb–Zn

DEPOSIT DESCRIPTION

Ore Minerals:  Emerald+greenish berly+oligoclase+dolomite+calcite+pyrite+fluorite+rutile+quartz

Texture/Structure  Crustified banding, vuggy, coarsely crystalline

Alteration  Shales altered to black hornfels, fossils replaced by oligoclase. Dolomitization

Ore Controls  Major fault at intersections of minor cross faults sharp–walled veins and tabular breccia bodies

Weathering  Plagioclase weathers to pockets of kaolinite

Geochemical Signature:  In veins:  high Be, Na, Mg; low Li, Ba, K, Mo, Pb relative to shales outside of mineralized areas

Examples  Gachala District Colombia  

References  Escobar, 1979
DEPOSIT TYPE  Tin-tungsten veins
SUBTYPE

AUTHOR  William C. Bagby
DATE  February 1983

APPROXIMATE SYNONYM  Dike-vein systems
OF (REFERENCE)

DESCRIPTION  Wolframite, cassiterite, quartz, siderite, arsenopyrite veins in metamorphic rocks above large granitic batholiths


GEOLOGICAL ENVIRONMENT

Rock Types  Hornfels comprised of quartzites and shales; schists with volumetrically minor granitic intrusions

Textures  Fine-grained sediments metamorphosed to schists and hornfels.

Age Range  Mesozoic and younger

Depositional Environment  Open fracture filling in country rocks above massive granitic intrusions

Tectonic Setting(s)  Andean arc farthest from trench

Associated Deposit Types  Sn-W placer deposits. Veins may grade into porphyry tin deposits with depth.

Metal Concentrations  As, Sn, Be, Sb, Pb, Zn, Cu

DEPOSIT DESCRIPTION

Ore Minerals:  Wolframite (ferberite, hubnerite) and cassiterite are major ore minerals accompanied by quartz, siderite, arsenopyrite, tourmaline, apatite, pyrrhotite, pyrite, vivianite, chalcopyrite, and sphalerite. See cartoon for zoning

Texture/Structure  Veins are massive quartz siderite with Sn/W ore minerals

Alteration  Quartz+tourmaline is intense at deposit center. This grades outward through sericite+pyrite to propylitic (calcite+pyrite)

Ore Controls  Open fractures in shear zones and breccia pipes above differentiating granitic batholiths. Temperatures are high (390°C for Chicote Grande)

Weathering  Weathering of arsenopyrite results in jarosite-rich deposits which are easily eroded creating placer deposits of wolfranite and cassiterite

Geochemical Signature:  As and Sb are anomalously high

Examples  Isla de Pinos, Cuba
McAllister,
Chicote Grande Bolivia
Huanuni, Bolivia

References  Page L. R., and J. F., 1944
Personal Visit
Zoning Patterns

Metals:

Pb-Zn-Sb
Sn
W

Alteration:

sericite-pyrite
propylitic
quartz
tourmaline

Depositional Environment

Sn-W Veins
metasedimentary rocks

From Grant, J.N. and others. 1980
DEPOSIT TYPE Volcanogenic Uranium

AUTHOR William C. Bagby

DATE February 14, 1983

DESCRIPTION Uranium mineralization in epithermal veins comprised of quartz fluorite, and iron, arsenic, and molybdenum sulfides

GENERAL REFERENCE Nash, J. T., 1981

GEOLOGICAL ENVIRONMENT

Rock Types High silica alkali rhyolite and potash trachytes. Both peralkaline and peraluminous rhyolite, host ore

Textures Porphyritic to aphyric vesicular flows and shallow intrusives

Age Range Pre-Cambrian to Tertiary

Depositional Environment Subaerial to subaqueous volcanic complexes. Near-surface environment, association with shallow intrusives is important

Tectonic Setting(s) Continental rifts and associated calderas

Associated Deposit Types Roll front uranium in volcaniclastic sediments

Metal Concentrations Hg, Li, Be, Mo, +B, +REE

DEPOSIT DESCRIPTION

Ore Minerals: Coffinite, uraninite, brannerite are most common uranium minerals. Other minerals include pyrite, realgar/orpiment, jordisite, leucoxene, fluorite, quartz, adularia, and barite. Gold is present in some deposits. Deposits associated with alkaline complexes may contain bastnaesite.

Texture/Structure Open-space filling in breccias. Uraninite commonly encapsulated in silica.

Alteration Kaolinite, montmorillonite, and alunite are common.

Silicification, accompanied by adularia, affects wall rocks spatially most closely associated with ore.

Ore Controls Through-going fractures and breccias formed along the margins of shallow intrusives. Vugs in surface flows are of minor importance

Weathering Near surface oxidation produces a variety of secondary uranium minerals. Supergene uranium enrichment is generally not important.

Geochemical Signature: Li and Hg are zoned away from the ore. High anomalous As, Sb, F, Mo, +W occur near and with the ore. Mo is deep. Hg is shallow. REE maybe highly anomalous.

Examples Marysvale, Utah
Autota prospect, Oregon
Rexspar British Columbia

References Kerr, P. F., et al 1957
Joubin, F. R., and James, D. G., 1957
DEPOSIT TYPE  Cauca Valley Bauxite  
SUBTYPE

AUTHOR  Dennis P. Cox  
DATE  December 6, 1982

DESCRIPTION  Bauxite in weathered fluvio lacustrine deposits.

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types  Andesitic tuffs, flows and agglomerate overlain by fine grained fluvio lacustrine sediments.

Textures

Age Range  Plio-Pleistocene.

Depositional Environment  Lake beds weathered in humid tropical environment.

Tectonic Setting(s)  Horizontal beds.

Associated Deposit Types

Metal Concentrations

DEPOSIT DESCRIPTION

Ore Minerals:  Cliachite, gibbsite, clay.

Texture/Structure  Coarse gibbsite aggregates in clay matrix.

Alteration

Ore Controls  Uppermost lake beds.

Weathering

Geochemical Signature:

Examples  Upper Cauca Valley, Colombia

References  Rosas, 1978; oral commun., 1982
REFERENCES


Atkinson, W. W., Jr., and Einaudi, M. T., 1978, Skarn formation and mineralization in the contact aureole at Carr Fork, Bingham, Utah: Economic Geology, v. 73, p. 1326-1365.


Hutchinson, R. W., and Burlington, J. L., 198, Some broad characteristics of greenstone belt gold lodes:


Thayer, T. P., 1964, Principal features and origin of podiform chromite deposits and some observations on the Guliman-Sordag district, Turkey: Economic Geology, v. 59, p. 1497-1524.


Wokittel, R., 1961, Geologia economico del Choco, Colombia: Bol. Geol., v. 7, p. 119-162.
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INDEX TO GEOCHEMICAL ASSOCIATIONS
[M, Major element or recoverable metal; H, Anomalously high in ore zone; P, anomalously high in zones peripheral to ore; L, Anomalously low, depleted, below background]

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